Development and Implementation of Evidence-Based Guidelines for IV Insulin: A Statewide Collaborative Approach

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ABSTRACT

Purpose: Recent studies have shown that the outcomes of hospitalized patients are greatly enhanced when steps are taken to improve control of their blood glucose levels. The Georgia Hospital Association Research and Education Foundation's Partnership for Health Accountability established a Diabetes Special Interest Group (D-SIG) in February 2003. Goals of the D-SIG were to enlighten health care professionals in Georgia hospitals about the benefits of controlling hyperglycemia in hospitalized patients and to develop processes to assist hospitals in the adoption of an IV insulin dosing algorithm, development of an IV insulin standing order set, and implementation of a hyperglycemia management plan.

Methods: The D-SIG created an assessment tool titled "Key Elements of IV Insulin Guidelines" and evaluated numerous published IV insulin administration algorithms and protocols. After an extensive literature review, including international protocols and guidelines, user-friendly guidelines for subcutaneous and IV insulin were developed by a multidisciplinary work group, with members representing hospitals and other stakeholders from throughout the state. The group chose a well-researched method that was available in both computerized and hand-calculated formats and developed a Columnar Insulin Dosing Chart to assist with IV insulin infusions. This insulin-infusion table stems from mathematical formulas published by multiple investigators since the 1980s. The D-SIG guidelines and dosing chart were evaluated for ease of use, effectiveness, and safety in 3 settings: a small, rural critical-access hospital (CAH); an intensive care unit (ICU) in the trauma center of a large Georgia teaching hospital; and a surgical ICU in a midsize metropolitan hospital.

Results: After implementation of the guidelines, the incidence of hypoglycemia (blood glucose level <60 mg/dL) was 0.9% in the trauma center ICU and 0.6% in the surgical ICU. All hypoglycemic patients in these 2 settings were asymptomatic, remained hypoglycemic only for a short time, and experienced no complications attributable to hypoglycemia. Using a moderate insulin sensitivity level for dosing initiations resulted in a time to target blood glucose level (80–110 mg/dL) of 6.4 hours, whereas using the most conservative approach required 12.8 hours to attain target range. At the CAH, time to reach the target blood glucose level (90–140 mg/dL) was 5.8 hours, and no episodes of hypoglycemia

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were reported. Although not part of the pilot initiative, the surgical ICU also reported a 5-fold reduction in surgical infection rates. The success of the dosing chart and standing order set paralleled that of the computerized formula when similar initiation doses were used.

Conclusions: The Columnar Insulin Dosing Chart and sample clinical guidelines were piloted at 3 different settings and found to be safe and effective. Furthermore, by including the treatment for hypoglycemia in the guidelines, nurses in all patient care areas were able to manage blood glucose levels below the target range in a safe and timely manner. Use of the dosing chart and guidelines reduced blood glucose levels to the target range with no clinically significant hypoglycemia. (*Insulin*. 2008;3:67–77) © 2008 Excerpta Medica Inc.

Key words: insulin, guidelines, evidence-based, intravenous, dosing chart, Georgia, hospital.

INTRODUCTION

The Georgia Hospital Association Research and Education Foundation (GHAREF) took a positive, proactive, collaborative approach regarding the application of best practices to promote patient safety and enhance the quality of patient care through the establishment of the Partnership for Health and Accountability (PHA). Over the past 7 years, the PHA has become the driving force and facilitator in GHAREF's effort to identify proven, effective methods of patient care and promote best-practice implementation.

In early 2002, the PHA identified hospitalized patients with diabetes and/or hyperglycemia as a high-risk group. It was determined that application of best practices may have a dramatic impact on inpatient morbidity and mortality rates. Multiple studies revealed striking decreases in morbidity and mortality rates when hyperglycemia was controlled in hospitalized patients:

- Maintaining blood glucose levels between 80 and 110 mg/dL in patients in intensive care units (ICUs) resulted in reductions in mortality rate (34%), the incidence of sepsis (46%), the need for acute dialysis (41%), the need for blood transfusions (50%), and the incidence of critical-care polyneuropathy (44%).[1]
- Uncontrolled hyperglycemia resulted in a 6-fold increase in nosocomial and wound infections.[2]
- Mortality risk for stroke doubled when blood glucose levels remained >140 mg/dL.[3]
- Sternal wound infections following cardiac surgery were reduced by 60% when IV insulin was used perioperatively.[4]
- For patients with acute myocardial infarction, mortality at 1 year was reduced by 30% when IV insulin was administered for blood glucose levels >198 mg/dL and followed with subcutaneous insulin.[5]

These studies represent a small sample of the research being conducted on the effects of tight glycemic control in patients in cardiac, surgical, and ICUs.

In February 2003, the PHA formed a Diabetes Special Interest Group (D-SIG), a multidisciplinary team of clinical experts (endocrinologists, internal medicine specialists, hospital physicians, nurses, diabetes educators, dietitians, pharmacists) and representatives from the governmental, health insurance, and pharmaceutical sectors, who volunteer their time to participate in an effort to improve patient care outcomes and to help control health care costs. Early meetings and input from members of the D-SIG identified the need to develop evidence-based guidelines for IV insulin that could be used by nurses in all areas of patient care. Although many IV insulin protocols have been recognized and accepted by the medical community, most were developed for use in the ICU and contained multiple pages of orders requiring mathematical calculations. The protocols required the skills of an experienced, dedicated workforce with an intensive background in the use of the protocols. Despite this expertise, nurses still had to contend with the errors inherent in the use of mathematical calculations.

The benefits of tight glycemic control for cardiac, surgical, and other ICU patients are well documented. New studies are examining the benefits of tight glycemic control in patients with other acute illnesses such as community-acquired pneumonia and chronic obstructive pulmonary disease.[6,7] Little doubt remains that controlling hyperglycemia will soon become a best-practice standard for all acute illnesses.

METHODS

To properly evaluate existing methods of hyperglycemia management, the D-SIG spent months developing the "Key Elements of IV Insulin Guidelines," a comprehensive list of considerations formatted into an audit tool to assist with the development and/or evaluation of IV insulin infusion guidelines (**Table I**). Additional questions that should be addressed when evaluating IV insulin protocols for hospital-wide use are presented in **Table II.**[8]

Selection of an IV Insulin Dosing Protocol

More than 30 nationally and internationally originated protocols were evaluated to find those that were most compliant with the key elements. The protocols and dosing algorithms selected for evaluation were obtained from individual members of the D-SIG, published protocols, and Internet search engines using terms such as *IV insulin protocol*, *IV insu-*

Table I. Key elements for developing insulin standing order sets.

I. Should be evidence based and user-friendly
   a. Meet or exceed the standards of the American Academy of Endocrinologists and/or The American Diabetes Association
   b. Keep as short and concise as possible
   c. Eliminate or minimize mathematical calculations
   d. Eliminate all problematic abbreviations as defined by the Institute for Safe Medication Practices
   e. Evaluate at least annually with continuous quality improvement initiative to ensure compliance

II. Identify patients who need initiation or modification of insulin therapy
   a. Indicate blood glucose (BG) levels that trigger contact with the physician to initiate insulin therapy
   b. Evaluate and reconcile all previous medication orders relating to diabetes
   c. Indicate BG trigger levels to adjust, maintain, or hold the insulin dose in order to reach or maintain euglycemic levels
   d. Provide conversion factors for switching from IV to subcutaneous dosing and vice versa
   e. Address too-rapid normalization of BG levels in patients with excessively high BG levels at initiation of therapy
   f. Address individual variations in insulin sensitivity as they relate to dosing
   g. Ensure that basal insulin requirements are determined and met, with allowances for causes of hyperglycemia such as infection, surgery, medications, and stress
   h. Include BG levels that trigger corrective measures for hypoglycemic and hyperglycemic episodes and the time frames for those corrective measures, as well as trigger levels for contacting the physician
   i. Address the time frame, frequency, and method of BG testing

III. Address the unique dietary requirements of patients from one area of care to another area
   a. Include separate dosing conversions for patients who are eating and patients who are not eating
   b. Address the addition/deletion of insulin to/from total parenteral nutrition when the patient is receiving IV insulin
   c. Ensure that the timing of meals and administration of insulin are coordinated with the type of insulin prescribed
   d. Address unique departmental care requirements (eg, perioperative, intensive care, ambulatory acute care)
   e. Consider dietary requirements such as carbohydrate supplementation, source of supplementation, and rate of supplementation (bolus vs continuous)
   f. Include required laboratory test values for potassium and instructions for initiating supplementation when the predetermined trigger value is reached

IV. Address the administration requirements for insulin infusion
   a. Use only one standard solution for all insulin infusions
   b. Address the adsorption of insulin with some IV bags and tubing
   c. Consider the acceptable fluids and flow rate needed to keep the vein open
   d. Address the use of IV infusion pumps and their dosing limitations
   e. Include time considerations for maintaining IV insulin infusion after subcutaneous administration is initiated

V. Provide consultation/education for patients
   a. Because fluid appropriateness, insulin dosages, and electrolyte requirements may differ in children and adolescents, provide a trigger to refer these patients to a pediatric endocrinologist and/or a comprehensive diabetes specialty team
   b. Provide a trigger to refer all patients presenting with hypoglycemia or hyperglycemia to diabetes education and nutritional services
   c. Provide a trigger to refer all admitted patients with continuous subcutaneous insulin infusion pumps to diabetes education and nutritional services

lin algorithm, *inpatient hyperglycemia*, and *insulin drip*. The hyperglycemia management algorithm that was selected met the criteria of the evaluation/audit tools developed by the D-SIG (**Tables I** and **II**). The algorithm had been widely used in numerous hospitals, both as a manually calculated insulin-infusion formula and later as part of a computer-assisted dosing system. The algorithm, which was based on a study by White et al,[9] showed that the IV insulin-infusion requirement in a pediatric clinical research center was the product of any blood glucose level >60 mg/dL times a calculated slope (also known as a sliding scale factor or multiplier), or ~0.02.

Davidson[10] (a member of the D-SIG) expanded White's study in the 1980s, making the multiplier or insulin sensitivity factor of the patient an integral part of the desired glyce-

Table II. Questions to ask when evaluating or selecting an IV insulin protocol.

1. Do the guidelines assume that all patients can be placed into one of a few subgroups for dosing adjustments?

   Many guidelines contain a few algorithms with directions to move to a higher algorithm if the blood glucose (BG) level is not dropping. Other guidelines may have a few dosing schedules based on how far or fast the BG level is rising or falling; others may group patients in a few weight-based categories. All of these scenarios make the assumption that the insulin sensitivity of all hyperglycemic patients can be combined into one of just a few categories rather than addressing the uniqueness of the individual patient.

2. Have the guidelines been clinically proved to be effective, safe, and meet current best-practice requirements?

   Various methods may be used to lower BG levels, but guidelines that comply with current best practices will do so in a process that has proved to be safe and clinically sound. The guidelines should prevent the occurrence of a peak-and-valley effect (continuous increases and decreases in BG levels), maintain patients in the target range for extended periods, and have an acceptable published rate of hypoglycemia.

3. Can nurses in all areas of patient care use the guidelines safely and successfully?

   All patients should be able to receive the benefits of tight glycemic control, not just those limited to the intensive care unit (ICU). Dr. Bruce Bode, a member of the Diabetes Special Interest Group, stated, "One key, which I feel is extremely important, is that you have to be able to use it anywhere in the hospital. You can't fill up your ICUs with people needing a drip; that's crazy. You just use it wherever you need it. If they need it in rehabilitation, put it on the rehab floor; it should be that easy."[8]

4. Does the insulin-drip guideline take into consideration the patient's insulin sensitivity level when titrating toward the target BG level?

   If the insulin sensitivity level of the patient is not considered, fine-tuning of the insulin infusion to safely reach the target BG levels and maintain the patient in the target range over an extended period of time becomes all but impossible. All hyperglycemic patients do not have the same response to the same dose of insulin. The "Correction Factor" (CF) (mg/dL decrease in BG level expected from administration of 1 unit of insulin) varies from patient to patient. If one patient has a CF of 80 and another has a CF of 10, a dosage adjustment of just 1 unit of insulin per hour might ideally lower one patient (CF = 10) into the target range but result in a severe hypoglycemic episode for the other patient (CF = 80).

5. Do the guidelines make small incremental changes in the infusion rate after the target BG level has been reached?

   A standard, fixed insulin dose that reduces the BG level to the target level may also result in a decrease in BG level to below target or hypoglycemic levels. After the BG level reaches the target range, the guidelines should continue to make small, continuous incremental changes to maintain the patient safely in the target range over an extended period of time.

6. Can the guidelines adjust the insulin drip by one tenth of a unit per hour?

   If the guidelines' lowest adjustment to the insulin infusion is 0.5 to 1.0 unit per hour, the hourly adjustments may result in the patient receiving an extra 12 to 24 units of insulin per day. This can be detrimental to all patients, especially those with high CF values (often frail elderly or chronically debilitated patients). It can also result in the peak-and-valley effect and make transitioning to subcutaneous insulin a guesswork process because total daily insulin requirements cannot be determined precisely.

mic target range. Multiple glycemic target ranges have been published for different types of patients in different areas of care. The formula developed by Davidson enables the lowering of blood glucose to target in a safe and timely manner and has the ability to maintain the target range for all patients, regardless of their insulin sensitivity level.[10,11] Using Davidson's formula,

$$\text{units of insulin/h} = \text{multiplier} \times (\text{blood glucose level} - 60) \quad (1)$$

the initial multiplier is set at 0.02; a blood glucose value is obtained every hour and used to help calculate the units of IV insulin required for the next hour. If the patient's blood glucose level reaches the target range, no change to the multiplier is needed, but hourly calculations continue to maintain the level within the target range. If the blood glucose level is higher than the target range and has not decreased by at least 15% over the past hour, the multiplier is increased by 0.01 when calculating the dose for the next hour; if the blood glucose is lower than the target range, the multiplier is decreased by 0.01. The blood glucose level is determined hourly until stable results are achieved; then it is measured every 2 hours until the patient is ready to transition to subcutaneous insulin.[10]

Studies by Hawkins et al[12] and Biggs[11] proved the efficacy and safety of Davidson's process, even when using

0.03 as the initial multiplier to reach the target blood glucose level at a faster rate. Osburne et al[13] reported that the starting multiplier for each patient can be individualized based on the patient's known insulin requirement and sensitivity.

In 1984, Davidson et al[14] computerized the "Multiplier Algorithm" and developed the Glucommander (GlucoTec, Greenville, South Carolina), a technology that automatically calculates the units of insulin required per hour based on the current blood glucose level, the desired target range, and the insulin sensitivity of the specific patient. Since then, more than 120,000 hours of testing to determine the efficacy and safety of the multiplier algorithm have been documented with the Glucommander.[14]

In 2004, Biggs et al[11] evaluated the Portland Guidelines, Diabetes Mellitus Insulin-Glucose Infusion in Acute Myocardial Infarction Guidelines, Leuven Guidelines, Multiplier Guidelines, and Texas Diabetes Council Guidelines. (The Texas guidelines were incomplete at the time of testing and thus were reviewed retrospectively.) Biggs noted that "The multiplier protocol was found to be unique, advantageous, and preferred over the other protocols."[11] The multiplier protocol:

- "Makes changes based on a Multiplier, a surrogate for insulin sensitivity. It then changes the insulin rate hourly based on the difference between the measured BG [blood glucose] and target BG."[11] "For excessively high BG at initiation, it provides enough insulin for rapid normalization of glucose, but also rapidly reduces the insulin infusion rate when BG levels normalize."[11]
- "Makes small, incremental changes to the infusion rate even while the BG is in the target range. The insulin infusion typically settles into the center of the target range and then stays very close to the center. None of the other protocols had this feature."[11]
- "The insulin drip goes to very low levels and if the BG gets below target, the D50W [50% dextrose] administered is titrated to the degree of hypoglycemia rather than a preset, arbitrary, amount."[11] The amount of glucose needed to correct below-target BG episodes is dependent on both the BG level at that time and the patient's weight. In a normal-weight patient, 25 g of glucose (half a bristojet of D50W) will raise the BG level by ~125 mg/dL. The following formula is used in all of the D-SIG's guidelines:

$$(100 - \text{BG}) \times (0.4) = \text{mL of D50W to be administered} \quad (2)$$

Such precise treatment with D50W is effective without overcorrection of blood glucose to a target value of 100 mg/dL.[10]

Development and Initiation of a Tight Glycemic Control Program

The D-SIG determined that the multiplier method was not only evidence based but also the most user-friendly of all the protocols studied. The complete collection of D-SIG guidelines addresses the preparation, administration, and directions for use of both IV and subcutaneous insulin. All patients who receive IV insulin infusions are evaluated for ongoing subcutaneous insulin therapy after the insulin infusion. The guidelines also contain critical aspects of hyperglycemia management, including nutritional and educational considerations.

> The D-SIG guidelines contain critical aspects of hyperglycemia management, including nutritional and educational considerations.

Members of the D-SIG agreed that the most challenging aspect of tight glycemic control was the method of IV insulin administration used to manage hyperglycemia. IV insulin infusion is viewed by nurses as highly labor intensive. Depending on the number of hyperglycemic patients being managed in a facility, the initial financial investment needed for appropriate implementation of tight glycemic control can pose challenges to leadership if measurable outcomes are not realized. Hundreds of hours were invested in determining how best to infuse insulin in an easy, cost-effective manner usable by nurses in all hospital practice settings.

> Intravenous insulin infusion is viewed by nurses as highly labor intensive.

RESULTS

The recommendations for all methods of insulin administration are presented in a user-friendly, step-by-step process (**Table III**). To make the IV insulin guidelines easier to use by all nurses, a Columnar Insulin Dosing Chart (insulin-infusion table) was developed by one of the authors (L.S.) (**Table IV**). The rows of the chart are color coded, with white representing blood glucose levels above the target range, yellow representing blood glucose levels within the target range, and blue representing blood glucose levels below the target range. The dosing chart eliminates all mathematical calculations. Three separate dosing charts have been developed, based on the ranges of blood glucose levels that are appropriate for patients in different clinical areas: 80 to 110 mg/dL for the ICU, 90 to 140 mg/dL for the Medical/Surgical unit, and 70 to 100 mg/dL for Labor and Delivery. The chart developed for the ICU (80–110 mg/dL) is shown in **Table IV**.

Each dosing chart is designed with multiple blood glucose tiers, or ranges (presented in rows) instead of single

Table III. IV insulin infusion guidelines for a target blood glucose level of 80 to 110 mg/dL: Columnar Insulin Dosing Chart.

I. Starting orders
  a. Discontinue all previous diabetes medication orders
  b. Obtain basic metabolic profile now, again in six (6) hours, then daily
  c. IV fluid: ( ) Normal saline, ( ) D51/2 Normal saline, ( ) D51/2 Normal saline/20 mEq/L K^+, ( ) Other ____.
  If the patient is NPO and not receiving TPN or continuous enteral feedings and the BG level is <250 mg/dL, the IV fluid selected and the rate of infusion should reflect a glucose source of ≥5 g/h
  d. Rate of fluid infusion:______ mL/h (minimum rate to keep vein open: ______ mL/h)
  e. ______ mEq/L KCl (If K^+ level is <4 mEq/L, order the above-listed IV fluid with 20 mEq/L K^+)
  f. Diet: ( ) NPO, ( ) Continuous enteral feeding, ( ) TPN mixed without insulin, ( ) Other ____.
  Do not feed calorie-containing foods unless additional mealtime insulin is ordered

II. IV insulin administration
  a. Mix 250 units of Human R insulin in 250 mL normal saline (1 unit/mL)
  b. Flush ~30 mL through the line before administration
  c. Do not use a filter or filtered set with insulin
  d. Piggyback insulin drip into IV fluid using an IV infusion pump with capability of 0.1 mL/h

III. Initiate IV insulin flow sheet

IV. BG testing
  a. Check BG level now and every hour by finger stick using a hospital-certified glucose meter
  b. Do not alternate test sites without physician approval
  c. After hourly BG levels have remained in the desired range for 4 consecutive hours, begin BG testing every 2 hours
  d. Have the laboratory verify "stat" all BG levels <40 mg/dL or >500 mg/dL

V. Determine the IV insulin infusion rate: units of insulin/h = (BG – 60) × multiplier
  a. Initiate infusion using the drip rate (mL/h) shown in column 2 of the chart for the current BG tier
  b. To determine the drip rate (mL/h) for each hourly BG measurement, compare the current BG tier with the previous tier
    1. If the current BG tier has dropped, stay in the same column to determine the new drip rate
    2. If the current BG tier has not changed or is higher, move 1 column to the right to determine the new drip rate
  c. When the hourly BG level is 80 to 110 mg/dL, remain in the current column and adjust the rate accordingly
  d. When the hourly BG level is <80 mg/dL, move 1 column to the left to calculate the new drip rate and refer to the Action section in the lower-left corner of the chart

VI. Determine the treatment for below-target BG levels (<80 mg/dL)
  a. Move 1 column to the left and give D50W by IV push according to instructions in the Action section in the lower-left corner of the chart
  b. Recheck the BG level in 15 minutes (repeat the previous step [VI.a above] if the BG level is still <80 mg/dL)
  c. Resume hourly BG monitoring and insulin drip adjustments

VII. Notify the physician if:
  a. BG level is <60 mg/dL for 2 consecutive measurements
  b. BG level reverts to >200 mg/dL for 2 consecutive measurements
  c. Insulin requirement exceeding 24 units/h does not lower the BG level
  d. K^+ level drops to <4 mEq/L
  e. Continuous enteral feeding, TPN, or IV insulin infusion is stopped or interrupted

VIII. Transition to subcutaneous insulin
  a. BG levels should be within the target range for at least four (4) hours before discontinuing administration of IV insulin
  b. Calculate the TDI: units of insulin for the past 4 hours of IV drip × (6) for patients receiving D5W
  c. Begin insulin glargine = 50% of TDI (for pregnant patients, use NPH twice daily)
  d. Begin rapid-acting insulin analogue = 50% of TDI divided by 3 (give 3 times a day, immediately before meals)
  e. Continue IV insulin infusion for two (2) hours after initiation of subcutaneous therapy
  f. Refer to the subcutaneous insulin guideline for administration times and dosage adjustments
  g. Refer the patient for diabetes education, nutritional services, and discharge planning to ensure that the patient can afford medications/supplies and has follow-up disease-state management after discharge

K^+ = potassium; NPO = nothing by mouth; TPN = total parenteral nutrition; BG = blood glucose; KCl = potassium chloride; D50W = 50% dextrose; TDI = total daily insulin; D5W = 5% dextrose; NPH = neutral protamine Hagedorn.

Table IV. Columnar Insulin Dosing Chart: Target blood glucose level 80 to 110 mg/dL (1 mL = 1 unit).

Directions	BG Tier (mg/dL)	Drip Rate (mL/h)															
Start infusion using the drip rate (mL/h) in **COLUMN 2** for the current BG tier		Col 1	**Col 2**	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13	Col 14	Col 15	Col 16
To determine the new drip rate, compare the current BG tier with the previous BG tier If the current BG tier is lower than the previous BG tier, **STAY IN THE SAME COLUMN** If the current BG tier has not dropped (is the same or higher), **MOVE 1 COLUMN TO THE RIGHT** (*If >16 columns are needed, see back of page for columns 17–32*)	>450	4.4	8.8	13.2	17.6	22.0	**26.4**	**30.8**	**35.2**	**39.6**	**44.0**	**48.4**	**52.8**	**57.2**	**61.6**	**66.0**	**70.4**
	385–450	3.6	7.2	10.8	14.4	18.0	21.6	**25.2**	**28.8**	**32.4**	**36.0**	**39.6**	**43.2**	**46.8**	**50.4**	**54.0**	**57.6**
	334–384	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0	**27.0**	**30.0**	**33.0**	**36.0**	**39.0**	**42.0**	**45.0**	**48.0**
	290–333	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	**25.0**	**27.5**	**30.0**	**32.5**	**35.0**	**37.5**	**40.0**
	251–289	2.1	4.2	6.3	8.4	10.5	12.6	14.7	16.8	18.9	21.0	23.1	**25.2**	**27.3**	**29.4**	**31.5**	**33.6**
	217–250	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3	17.0	18.7	20.4	22.1	23.8	**25.5**	**27.2**
	188–216	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.0	15.4	16.8	18.2	19.6	21.0	22.4
	163–187	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	15.6	16.8	18.0	19.2
	141–162	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
	121–140	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	11.2	12.0	12.8
	111–120	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6
When the hourly BG level is 80–110 mg/dL, stay in the same column to determine the new drip rate. **DO NOT CHANGE COLUMNS**	106–110	**0.5**	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
	101–105	**0.4**	0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.5	5.0	5.4	5.8	6.3	6.7	7.2
	96–100	**0.4**	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.4
	91–95	**0.3**	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.2	3.5	3.8	4.2	4.6	4.9	5.3	5.6
	86–90	**0.3**	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8
	80–85	**0.2**	**0.5**	0.7	1.0	1.2	1.5	1.7	2.0	2.3	2.5	2.7	3.0	3.2	3.5	3.7	4.0
When the new BG level is <80 mg/dL, **MOVE 1 COLUMN TO THE LEFT** and refer to the ACTION section (lower-left corner of the chart) for D50W treatment	75–79	**0.2**	**0.4**	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
	71–74	**0.1**	**0.3**	**0.4**	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.7	1.8	1.9	2.1	2.2	2.4
	60–70	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
	<60	**0**	**0**	**0**	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0

BG (mg/dL)	D50W	ACTION
70–79	10 mL IV push	If you have not moved 1 column to the left as directed above, do so now.
60–69	15 mL IV push	Recheck BG in 15 minutes. Repeat as necessary.
50–59	20 mL IV push	If you have not moved 1 column to the left as directed above, do so now.
30–49	25 mL IV push	Recheck BG in 15 minutes. Repeat as necessary.
<30	30 mL IV push	Contact physician if BG is <60 mg/dL for 2 consecutive measurements.

NOTIFY PHYSICIAN IF:
BG is <60 mg/dL for 2 consecutive measurements
BG reverts to >200 mg/dL for 2 consecutive measurements
An insulin requirement >24 units/h does not result in a lower BG level or if the drip rate (mL/h) drops to <0.5 unit/h
The K^+ level drops to <4 mEq/L
Continuous enteral feeding, TPN, or IV insulin infusion is stopped or interrupted

BG = blood glucose; D50W = 50% dextrose; K^+ = potassium; TPN = total parenteral nutrition. ☐ BG above target range, ☐ BG within target range, ☐ BG below target range.
Numbers in **red** indicate **when to notify the physician** that the drip rate is either very high (evaluate all causes of insulin resistance) or very low (ready for transition to subcutaneous insulin).

blood glucose values. Each column in the chart corresponds to the multiplier used in the algorithm and determines the number of units of insulin required per hour using Davidson's base formula (Equation 1).

The blood glucose tiers (rows) in the dosing chart were designed to reflect a 15%-per-hour decrease in blood glucose level, which indicates that the patient is safely moving toward the target range in a timely manner. As the target range is approached, the 15% hourly decrease is reduced to help ensure that the blood glucose level does not drop prematurely to the bottom of the target range. Tiers close to or within the target range are only a small percentage apart to provide a way to maintain the target range effectively when the patient is initially stabilized. Small dose changes help to ensure that the blood glucose level does not decrease too rapidly or drop below the target range.

The insulin doses in the chart were calculated using the midrange (average) blood glucose value of each tier, minus 60, times the multiplier reflected at the top of the column. The result of the mathematical calculation using a multiplier of 0.02 corresponds to the mathematical values found in column 2.

All hyperglycemic patients are started in column 2, reflecting appropriate doses for patients with an insulin sensitivity (multiplier) of 0.02. If the blood glucose level does not decrease to a lower tier (row) within the next hour, the starting insulin sensitivity factor was too low; the user then moves one column to the right (to column 3) on the tier (row) that includes the new blood glucose level. That insulin dose is run for the next hour.

Example: Starting Insulin Infusion

First Hour

The patient's starting blood glucose level is 311 mg/dL. We begin in column 2 of the dosing chart (see notes in green).

We find blood glucose tier 290–333 mg/dL, which includes 311 mg/dL.

We find the insulin dose in the box where column 2 and the patient's blood glucose tier intersect (in this case, 5 mL per hour).

We run that insulin dose for the next hour.

Second Hour

The patient's blood glucose level is now 275 mg/dL. We are in column 2.

We find blood glucose tier 251–289 mg/dL, which includes 275 mg/dL. The patient's blood glucose level has dropped into the tier (row) below the one used for the last reading. The insulin sensitivity factor of 0.02 in column 2 was effective in lowering the blood glucose level at least 15% during the past hour, so we stay in column 2.

We find the insulin dose in the box where column 2 and the patient's blood glucose tier intersect (in this case, 4.2 mL per hour).

We run that dose for the next hour.

Mathematics Underlying the Chart

To calculate the dose for the first hour, we used our base formula: (blood glucose level – 60) × 0.02.

The averaging of 290 + 333 mg/dL (the upper and lower limits of the tier) determined the midrange number (311.5 mg/dL) used for the blood glucose level.

Using the formula, 60 was subtracted from 311.5 to yield 251.5 mg/dL, which was multiplied by 0.02.

The result was a starting drip rate (5.03 units per hour) shown in column 2 for initiation of therapy (in this case, the units of insulin to administer per hour equals 5). (Note: Because IV pumps are calibrated for 10ths of an mL/hour instead of 100ths, the calculation is rounded to accommodate the pump.)

All rules for adjusting the rate of insulin infusion are explained clearly on the chart. Once the target range (yellow section of chart) is reached, the user remains in the same column. For below-target blood glucose levels (blue section of chart), the user moves 1 column to the left and refers to the Action section in the lower-left corner of the chart, which indicates whether other corrective measures are needed. Instructions for notifying the patient's physician are provided in the lower-right corner of the chart.

To validate the dosing chart and standing order set, these tools were used for various types of patients in different types of hospitals. Some of the patients had dietary restrictions (nothing by mouth), had diabetic ketoacidosis or hyperosmolar coma, were unstable, or needed determination of their total daily insulin requirement. A critical-access hospital (<25 beds) piloted the 90 to 140 mg/dL dosing chart and reported a time to target blood glucose level of 5.8 hours; no episodes of hypoglycemia were reported. The pilot was an overwhelming success. The facility continues to use the dosing chart, and no hypoglycemic events have occurred. The dosing chart was also piloted in the ICUs of 2 metropolitan hospitals (1 large, 1 midsize). The rate of hypoglycemic episodes (blood glucose level <60 mg/dL) for target levels of 80 to 110 mg/dL was 0.9% in the trauma center ICU and 0.6% in the surgical ICU. All hypoglycemic patients in these 2 settings were asymptomatic, remained hypoglycemic only for a short time, and experienced no complications attributable to hypoglycemia. Using a moderate insulin sensitivity level for dosing initiations resulted in a time to target blood glucose level (80–110 mg/dL) of 6.4 hours, whereas using the most conservative approach required 12.8 hours to attain target range.

Numerous educational programs were initiated by the D-SIG's multidisciplinary core team and held throughout the state of Georgia to share the rationale for tight glycemic control, the key elements evaluation tool, the sample clinical guidelines, and the process of implementation (**Figure**). The methodology for implementation of a tight glycemic control program was based on the experience of the diverse members of D-SIG, who had not only implemented hyperglycemia programs in their hospitals, but also had networked with physicians, nurses, and pharmacists across the

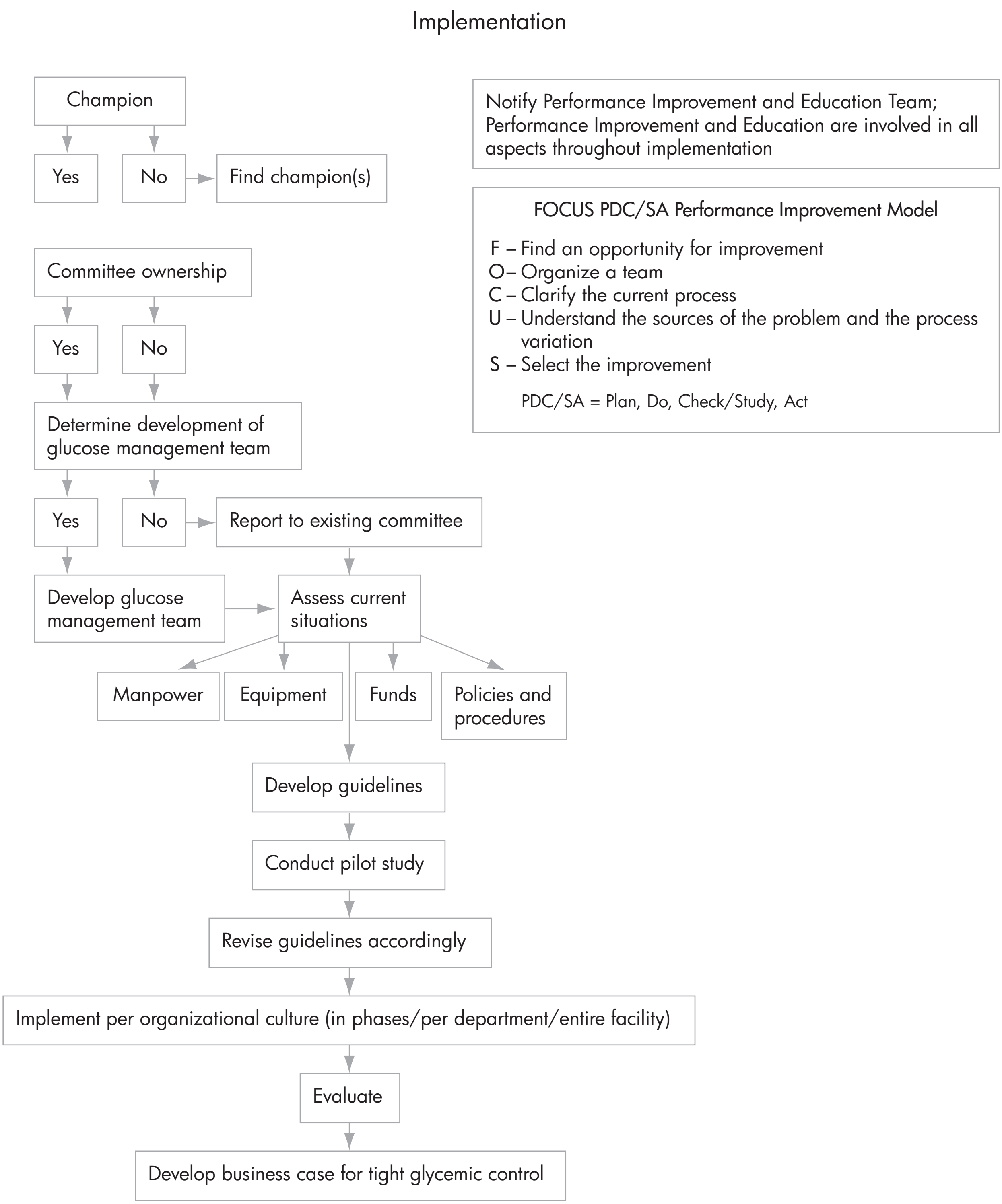

Figure. Algorithm for implementation of a tight glycemic control program.

nation to discuss the challenges associated with program implementation.

All educational programs were well received. Use of the dosing chart eliminated errors in insulin dosing that stem from flawed mathematical calculations and revealed no sustained hypoglycemia or persistent symptoms of hypoglycemia.

DISCUSSION

Comparing results on time to target blood glucose levels is difficult and can be misleading because the process is affected by multiple variables. Patient acuity, insulin sensitivity, medications, dosing requirements, the beginning blood glucose value, and the desired target range must all be evaluated. It is difficult to isolate the significance of each individual variable as it relates to time to target range.

An unexpected benefit reported in the surgical ICU pilot was a dramatic 5-fold decrease in the rate of superficial, deep-leg, and chest-incision infections after surgery. Although the pilot of this dosing chart was not extensive, other researchers using either the manual calculation approach or a computerized device had already performed extensive testing of this formula.

> An unexpected benefit reported in the surgical ICU pilot was a dramatic 5-fold decrease in the rate of superficial, deep-leg, and chest-incision infections after surgery.

"At first glance and without any explanation, the Columnar Insulin Dosing Chart can be intimidating with its page full of numbers and colored sections that correspond to directions for use. However, after the novice reads the instructions and is given a brief overview showing the chart's use and the mathematical alternatives, the simplicity of the chart is realized."[13] Implementation of any new procedure can result in initial fears and resistance by the workforce. The D-SIG's dosing chart and guidelines are no exception.

The mathematical algorithm for IV insulin infusion developed by Davidson and adopted by the D-SIG is now available for use in 3 forms: (1) the Glucommander (a computer-directed IV insulin system that enables licensed health care professionals to titrate dosing of insulin, glucose, saline, and other medications for patients receiving IV and subcutaneous therapy, and to reach target blood glucose levels more quickly and with fewer complications than with other treatment methods); (2) the Columnar Insulin Dosing Chart (a visual, graphic calculator that requires nurses to compare the patient's current blood glucose level with the previous level and then enter the drip rate for the next hour [shown on the chart] in the IV pump); and (3) the Nurse Calculated Guidelines (a manual calculation approach that requires nurses to be responsible and accountable for all mathematical processes).

Manual methods cannot replace the accuracy or ease of use that technology affords us, but the dosing chart provides a viable alternative. We also recommend the dosing chart for facilities that already have technology in place. When any facility's patient load exceeds the available technology, nurses must perform manual mathematical calculations. Use of the dosing chart eliminates the need for such calculations. The critical-care team in the large metropolitan hospital stated, "The approach we used, with nurses as quality improvement leaders armed with a method to identify patients with hyperglycemia and an insulin infusion algorithm—is a system that can be used as a model for other hospitals in Georgia. The novel chart-based insulin infusion algorithm was an effective tool for reducing blood glucose to target range with no clinically significant hypoglycemia."[13]

> Use of the Columnar Insulin Dosing Chart eliminates the need for mathematical calculations.

CONCLUSIONS

The D-SIG aimed to increase the awareness of the importance of tight glycemic control during hospitalization and to eliminate the use of multiple protocols and standing order sets within the hospital. The goal was to develop a process that could be used in all types of hospitals with variable staffing situations. The Columnar Insulin Dosing Chart and sample clinical guidelines were developed in a collaborative effort to formulate and facilitate a safer method for IV insulin infusion. The D-SIG piloted these calculation-free IV insulin guidelines in 3 different settings and found them to be user-friendly, reliable, and effective; they were administered safely by nurses in all areas of care, regardless of the size of the facility. In the short time that these tools have been available, the number of informational requests and the number of facilities that have adopted or are in the process of adopting the guidelines have exceeded the D-SIG's expectations.

It was not the D-SIG's intent to demonstrate superiority of the Columnar Insulin Dosing Chart and standing order set over other mathematically calculated methods. The intent was to provide an alternative tool and process for hospitals to consider when developing their own hyperglycemia management program.

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Information on the D-SIG's work can be found at http://diabetes.gha.org.

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