Anesthesia eJournal /AEJ
Volume 4 - Issue 1 2016

An Institutional Perioperative Intravenous Insulin Infusion Algorithm: Evaluation and Recommendations

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KEYWORDS: perioperative, insulin, diabetes, glycemic, pump

Abstract

The purpose of this retrospective medical record analysis was to examine our noncardiac surgery insulin infusion algorithm for efficacy, safety, and provider adherence. The sample included 132 hyperglycemic patients who were placed on intravenous insulin infusions (standard group). Nineteen patients using insulin pumps at home that had been converted for surgery to intravenous infusions were studied separately (insulin pump group). Efficacy, safety, and adherence definitions were developed and the data were extrapolated to address the research purpose. Captured data did not reflect any incidences of blood glucose (BG) measurements <50 mg/dL; however, 2 BG measurements in the standard group were <70 mg/dL. In the standard group, 73% of patients achieved BG of 100-179 mg/dL and an 85% mean proportion of subsequent time within range throughout the remaining perioperative period. Algorithm adherence metrics were 54-58%. Lower time-weighted average BG (190 vs 206 mg/dL; p=0.03) was achieved where providers adhered to the intravenous insulin maintenance table at least 67% of the time. In the insulin pump group, mean proportion of subsequent time within range was 81% after conversion to intravenous infusions. Increased insulin algorithm adherence was associated with improved perioperative glycemic control. In the insulin pump group, successful conversion was attributed to glycemic nurse practitioner collaboration and algorithm reference. Algorithm modifications based on the study results were proposed to increase adherence and safety.

INTRODUCTION

Practice guidelines specific to managing hyper- and hypoglycemia (glycemic derangements) in the perioperative setting have changed significantly over the past several years. Clinical trial findings have identified associations between glycemic control and decreased postoperative morbidity in several noncardiac surgery specialties.[1-5] Experts have encouraged anesthesia practitioners to develop institutional guidelines for the care of patients with diabetes and to target specific blood glucose values.[6] The United Kingdom National Health Service (UKNHS) has advocated for a perioperative blood glucose target range of 6-10 mM (108-180 mg/dL) and an acceptable range of 4-12 mM (72-216 mg/dL).[7,8] Blood glucose values of 150 mg/dL or 180 mg/dL have been recommended for triggering insulin administration by several groups, including the Society for Ambulatory Anesthesia.[9-12]

Hypoglycemia is a potential untoward effect whenever exogenous insulin is administered.[13] The risk of hypoglycemia may be greater in the perioperative setting than in other areas in the hospital. Signs and symptoms of low blood glucose can be obscured by sedation and anesthesia. Blood glucose testing may be postponed during critical points such as airway maneuvers, invasive line insertion, hemodynamic stabilization, and emergence from anesthesia. Perioperative units may not have consistent processes in place for transfer of care that ensure continuity of treatment and blood glucose testing.

Practice guidelines continue to evolve for monitoring blood glucose and managing glycemic derangements in the perioperative setting.[6] Insulin administration via intravenous (IV) infusion is the preferred delivery method for patients undergoing major surgeries or surgeries with expected, prolonged postoperative fasting. A desirable perioperative IV insulin infusion guideline efficiently attains and maintains a moderate blood glucose target range while safeguarding against severe hypoglycemia. Anesthesia providers may use existing institutional IV insulin infusion algorithms previously developed for intensive care units (ICUs). However, ICU algorithms often offer tighter and more aggressive target ranges than generally considered feasible in the dynamic perioperative setting.

A growing number of patients are presenting for surgery with existing insulin pumps [continuous subcutaneous insulin infusions (CSII)]. These individuals sometimes warrant conversion to IV insulin infusions owing to postoperative incapacity for pump self-management. Successful conversion coordinates the commencement of IV insulin infusion with the lessening effect of the residual subcutaneously delivered insulin, while correcting for hypoglycemia or hyperglycemia. Two experts recommend starting the IV insulin infusion at a lower percentage of the usual basal insulin pump rate for blood glucose ≤180 mg/dL and at the usual basal insulin pump rate if >180 mg/dL.[14,15] No studies were found on the efficacy of any particular protocol for converting patients from insulin pumps to IV insulin infusions.

Adoption of a validated IV insulin infusion protocol is advised to promote more consistent glycemic control and favorable surgical patient outcomes. Institutional modification to specific inpatient populations may improve adherence and efficacy.[16] An existing paper-based algorithm was altered at the Beaumont Health System, Royal Oak, Michigan, campus to target the 2009 American Diabetes Association/American College of Clinical Endocrinologists consensus blood glucose range of 140-179 mg/dL.[9] Guidelines for conversion from insulin pump therapy (CSII) to IV insulin infusions were constructed and incorporated into the algorithm. The purpose of this research was to evaluate this IV insulin infusion algorithm (Figure 1) for (1) efficacy, (2) safety, and (3) assessment of practitioner adherence to algorithm dose recommendations and hourly blood glucose monitoring.

Figure 1. Perioperative Insulin Infusion Algorithm for Use in Adult Cases, Except Cardiac Surgery (Target Blood Glucose: 140-179 mg/dL)

Beaumont | Health System

Perioperative Insulin Infusion Algorithm
Target Blood Glucose (BG): 140-179 mg/dl

For Use in Adult Cases, except Cardiac Surgery

(1) Initiating Infusion – Must be agreed on by an anesthesiologist prior to starting

INITIATING INFUSION

1. Insulin Infusion must be made by pharmacy
2. Concentration 100 units/100 ml in .9% Sodium Chloride
3. Monitor BG every 1-hour
4. Consider D5W IVPB at 75 ml/hr for BG <179 mg/dl
5. Monitor and treat electrolytes, (especially K+)
6. Converting from insulin pump: **NO bolus** at initiation

***see footnote below

Blood glucose Mg/dl	Infusion Starting Rate (units/hour)	IV insulin bolus (units)
180-239	2	2
240-299	3	3
300-359	4	4
360-419	5	5
>419	6	6

(2) Titrating Infusion

TITRATING INFUSION

Current Blood Glucose mg/dl	*Previous* Blood Glucose mg/dl							
mg/dl	<100	100-139	140-179	180-239	240-299	300-359	360-419	>419
<41	Hold Give 50ml of D50W		Recheck BG q 15 min. Repeat treatment until BG >79 mg/dl (D5W at 75 ml/hr should also be infusing)					
41-60	Give 30ml of D50W		Restart infusion at 50% former rate when BG >139 mg/dl					
61-79	Give 20ml of D50W		Notify Anesthesiologist					
80-99	Hold; recheck BG in 15-30 min.							
100-139	Hold	Decrease by 25%	Decrease by 25%	Decrease by 50%	Hold; recheck BG in 15-30 min.			
140-179	Begin at 50% of former rate	Continue	Continue	Continue	Decrease by 25%	Decrease by 50%	Decrease by 50%	Hold; recheck BG in 15-30 min.
180-239		Increase by 50%*	Increase by 25%*	Increase by 25%*	Continue	Decrease by 25%	Decrease by 25%	Decrease by 50%
240-299		Increase by 50%*	Increase by 50%*	Increase by 25%*	Increase by 25%*	Continue	Continue	Decrease by 25%
300-359		Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 25%*	Increase by 25%*	Continue
360-419		Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 50%*	Increase by 25%*
>419	Increase by 50%* and Notify Anesthesiologist							

*See calculation chart below; with increase in rate give additional IVP insulin bolus

(3) Calculation Chart - Use with Maintenance Table above

CALCULATION CHART

Decrease Rate (units/hr) by: ↓ 50% New Rate	↓ 25% New Rate	Units / hour CURRENT RATE	Bolus and Increase Rate (units/hr) by: ↑ 25% + Bolus New Rate		↑ 50% + Bolus New Rate	
OFF	OFF	0.5	1	0	1	1
0.5	0.5	1	1.5	0	1.5	1
1	1	1.5	2	1	2	2
1	1.5	2	2.5	1	3	3
1.5	2	2.5	3	2	3.5	3
1.5	2	3	4	2	4.5	4
2	2.5	3.5	4.5	2	5	5
2	3	4	5	3	6	6
2	3	4.5	5.5	3	6.5	6
2.5	3.5	5	6.5	3	7.5	7
2.5	4	5.5	7	4	8	8
3	4.5	6	7.5	4	9	9
3	4.5	6.5	8	4	9.5	9
3.5	5	7	9	5	10.5	10
3.5	5.5	7.5	9.5	5	11	11
4	6	8	10	5	12	12

***Insulin Pump Patients: BG 100 – 179: Initial dose equals basal dose. Start 30- 60 minutes after pump stopped. BG > 179: same; initiate as soon as pump stopped. Restart Insulin pump 30 minutes before discontinuing IV infusion.

Approved indications for Insulin Regular IV: treatment of Hyperglycemia and/or Hyperkalemia.

SQ: ONLY approved for use in the obstetric population, or patients on tube feeding or TPN

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MATERIALS AND METHODS

After Human Investigation Committee approval, which included a waiver of authorization for consent, a list was generated by the pharmacy of patients receiving insulin infusion admixtures in perioperative areas between August 2010 and July 2013. The list was narrowed and inclusion criteria for analysis were as follows:

- patients who had a noncardiac surgical procedure,
- age > 17 years,
- nonparturient ,
- insulin infusion newly initiated in the perioperative setting, and
- 3 or more blood glucose tests performed in the perioperative setting after infusion initiation.

Data were extracted from the medical and anesthesia records by investigators and were entered into an Excel (Microsoft Corp, Redmond, WA) spreadsheet. The documented demographic data included hyperglycemia etiology, glucose-lowering medications, perioperative length of stay, surgery length, surgery type, American Society of Anesthesiologists classification, and anesthesia type. Perioperative blood glucose values after infusion initiation, blood glucose test times, and first blood glucose value on arrival in the postoperative nursing care unit were collected.

Operational definitions used to assist the research purpose were developed. *Efficacy* was determined by both achievement of a blood glucose value <180 mg/dL and maintenance of subsequent blood glucose values in the 100-179 mg/dL target range. Maintenance in the target range was measured by the proportion of time that blood glucose values remained in the 100-179 mg/dL range from the first value <180 mg/dL to the last perioperative value before post-anesthesia care unit discharge. Additionally, the time from the initiation

of insulin infusion to achievement of blood glucose target and the average perioperative blood glucose values after infusion initiation were recorded.

Safety was defined as avoidance of hypoglycemia (blood glucose <70 mg/dL) and severe hypoglycemia (blood glucose <50 mg/dL). The highest rate of insulin infusion, the presence of IV dextrose initiation, and the occurrence of insulin infusion discontinuation, either temporarily or permanently during the perioperative time frame, were documented.

Practitioner adherence to algorithm dose recommendations was defined as compliance with algorithm directives for insulin infusion initiation and titration. For infusion initiation, the algorithm's Initiating Infusion table, shown as (1) in Figure 1, details standard group initiation directives, while the Insulin Pump Patients directives at the bottom of the algorithm state the insulin pump group directives. For infusion titration, the algorithm's (2) Titrating Infusion table and (3) Calculation Chart direct infusion titration and insulin bolus administration for both the standard group and the insulin pump group. Insulin administration that did not comply with the initiation and titration tables was examined for type of deviation. Practitioner adherence to glucose monitoring frequency was defined as the occurrence of extended intervals between blood glucose testing. A lapse of more than 30 minutes beyond the hourly recommended blood glucose monitoring frequency was designated as an extended interval.

The data from each individual medical record were entered into spreadsheets and 2 different groups were identified: (1) the insulin pump group or those whose outpatient glycemic control was managed by an existing insulin pump, and (2) the standard group, or the remainder of the cohort.

Statistical Analyses

Side-by-side descriptive analyses were performed. Continuous variables were summarized by using means ± standard deviations, unless otherwise noted. Categorical variables were summarized by using frequencies

Table 1. Baseline Characteristics of the Two Study Groups

	Standard Group (n=132)	**Insulin Pump Group** (n=19)
Age, years	63.5 ± 11	56.3 ± 13
Gender (% male)	51.5	52.6
Body mass index, kg/m²	33.4 ± 9	31.8 ± 7
Hyperglycemia etiology, %		
Type 1 diabetes	6.8	57.9
Type 2 diabetes	87.9	42.1
Steroid-induced hyperglycemia	4.5	0
Pancreatic pseudocyst	0.8	0
Diabetes regimen, %		
Insulin with/without other glucose-lowering agents	62.8	100
Glucose-lowering agents (without insulin)	29.8	0
No glucose-lowering agents	7.4	0
ASA classification status, %		
2	18.9	31.6
3	65.9	68.4
4	15.2	0
Anesthesia type, %		
General	88.6	94.7
Regional	3.8	5.3
Sedation	7.6	0
Surgical procedure length, hours	4.3 ± 3	2.2 ± 1
Perioperative length of stay, hours	9.7 ± 3	7.1 ± 1
Postoperative ICU admission, %	14.4	0
Surgical service, %		
General (including bariatric and pancreatic)	34.1	21.1
Vascular	17.4	0
Neurosurgery (not spine)	15.2	0
Orthopedic (not spine)	8.3	21.1
Spine	7.6	26.3
Other (urology, gynecology, thoracic, combined cases)	17.4	31.5
Mean BG before insulin infusion initiation, mg/dL	266.5 ± 75	189.8 ± 73
Median BG before insulin infusion initiation, mg/dL	255	173
Area of infusion initiation, % (BG before initiation)		
Preoperative area (mean BG; mg/dL)	28 (319.3)	63.2 (212.8)
Operating room (mean BG; mg/dL)	70.5 (246.3)	36.8 (150.3)
Post-anesthesia care unit (mean BG; mg/dL)	1.5 (229.0)	0
Number of BG tests performed	5.5 ± 1.2	5.5 ± 1.8

Note. Abbreviations: ASA, American Society of Anesthesiologists; BG, blood glucose; ICU, intensive care unit. Values are mean ± *SD*, unless otherwise indicated.

and percentages. Estimated time-to-target was calculated via a straight-line interpolation between blood glucose levels at successive measured time points. Proportion of subsequent time spent within range after target achievement—again using the interpolation method—was measured per subject for both the narrower algorithm target and the broader perioperative target. Time-weighted average (TWA) area under the curve blood glucose was calculated per subject from all blood glucose values from the first test after infusion initiation to the last perioperative area test. TWA area out of target was calculated per subject from all blood glucose values <100 mg/dL and >179 mg/dL from the first test after the infusion initiation to the last perioperative test. Hyperglycemic index, which addressed only TWA area above target (blood glucose >179 mg/dL), was also examined.

RESULTS

Inclusion criteria were met for 151 of 456 accessed records. Cases of cardiac surgery (n=192) and fewer than 3 perioperative blood glucose tests after infusion initiation (n=98) were excluded. There were 132 patients in the standard group and 19 patients in the insulin pump group. The baseline characteristics of the 2 groups are shown in **Table 1**.

Efficacy, safety, and adherence metrics are displayed in **Table 2**. In both groups, nearly 80% of patients presented with or achieved blood glucose <180 mg/dL before post- anesthesia care unit discharge. After the first blood glucose <180 mg/dL, the mean proportion of subsequent time spent in the 100-179 mg/dL range was >80%. The mean proportion of subsequent time in the algorithm target range (140-179 mg/dL) was 64% (standard group) and 43% (insulin pump group). The mean time to target achievement was <2.5 hours for patients presenting with blood glucose >180 mg/dL.

Table 2. Efficacy, Safety, and Compliance Results

	Standard Group (n=132)	Insulin Pump Group (n=19)
Efficacy		
Patients in which infusion was initiated at BG* < 180 mg/dL, %	4.5	57.9
Patients achieving BG < 180 mg/dL after infusion initiation, %	72.7	26.3
Mean time to achieving BG < 180 mg/dL, hours	2.4	1.2
Mean proportion subsequent time in algorithm target	0.639	0.428
Mean proportion subsequent time in perioperative target	0.849	0.808
Mean TWA of perioperative BG after initiation, mg/dL	200.9 ± 42	168.0 ± 41
Median TWA of perioperative BG after initiation, mg/dL	194.1	156.6
Mean TWA BG above target range, mg/dL[a]	33.6	14.8
Median TWA BG above target range, mg/dL[a]	23.9	2.3
Mean TWA BG of area out of perioperative target, mg/dL	33.9	15.3
Median TWA BG of area out of perioperative target, mg/dL	23.9	4.5
Mean BG on postoperative nursing unit arrival, mg/dL	171.7 ± 54	179.3 ± 51
Median BG on postoperative nursing unit arrival, mg/dL	164	174
Safety		
Patients with any BG < 70 mg/dL during infusion, %	1.5	0
Patients with any BG < 50 mg/dL during infusion, %	0	0
Adherence		
Infusion initiation adhered with algorithm initiation table, %	53.8	57.9
Infusion maintenance adhered with algorithm tables, % total BG	55.6	54.9
Mean interval between BG tests, minutes	59.7 ± 10	52.9 ± 8

Note. Abbreviations: BG, blood glucose; TWA, time-weighted average. Algorithm target = 140-179 mg/dL; broader perioperative target = 100-179 mg/dL. Values are mean ± SD, unless otherwise indicated.

*Hyperglycemic index measurements; total BG = tests for all patients in group (700 BG tests in standard group; 102 BG tests in insulin pump group).

Two patients in the standard group experienced hypoglycemia. The first patient's blood glucose value of 69 mg/dL was attributed in part to receipt of 10 units of insulin aspart subcutaneously in the perioperative area before the start of the insulin infusion. In the second patient, a blood glucose decline from 167 mg/dL to 83 mg/dL resulted in stopping the infusion; however, the subsequent blood glucose tested 20 minutes later was 53 mg/dL. The second patient's hypoglycemia occurred despite 100% adherence to algorithm tables and hourly blood glucose monitoring. As a result of this finding, institutional approval was sought and obtained to add the directive of "Begin D5W at 75 mL/hr" to the 80-99 mg/dL cell.

The mean highest insulin infusion rates were 4.6 ± 2 units/hour for the standard group and 2.8 ± 1.8 units/hour for the insulin pump group. Insulin pump patients (63.2%) and standard patients (32.6%) had concurrent IV dextrose infusions during at least a portion of the time on the IV insulin infusion. In the standard group, 28.8% of patients had the IV insulin infusion permanently stopped before leaving the perioperative area. Another 6.8% of the standard group had the infusion temporarily stopped and later restarted. Three patients had the insulin infusion permanently discontinued in the insulin pump group while still in the perioperative area. Two other insulin pump patients had the infusion stopped and later restarted.

Practitioner adherence to the algorithm dose recommendations was found to be between 53.8% and 57.9% for both groups (Table 2). In the standard group, the deviations at initiation were as follows: wrong/omitted bolus (29.5%), wrong/omitted bolus and wrong rate (13.6%), and wrong rate only (3%). In the insulin pump group, the deviations at initiation were as follows: received a bolus (10.5%), infusion not started at basal rate (10.5%), time interval deviated from guidelines (10.5%), combination of any 2 preceding deviations (10.5%). Titration deviations were classified as wrong rate (standard group, 14.4%; insulin pump group, 27.5%), wrong/omitted bolus (standard group, 13.9%; insulin pump group, 2.9%), and wrong rate and wrong/omitted bolus (standard group, 15.7%; insulin pump group, 14.7%). Two standard group patients had deviations from recommended hypoglycemia treatment but neither incidence resulted in subsequent hypoglycemia.

The mean blood glucose monitoring interval was under 1 hour. In the standard group, 29.5% of patients experienced at least one blood glucose monitoring interval >90 minutes. In the insulin pump group, 30.1% of patients had one or more intervals of >90 minutes between tests.

Post hoc analyses were performed to determine if there was a relationship between glycemic control and adherence because algorithm deviations were higher than anticipated. The insulin pump group was not examined owing to the small sample. Patients in the standard group were split into 2 categories based on the proportion of their adjustments that deviated from the maintenance algorithm: "less than 1/3" (low deviation), and "1/3 and up" (high deviation). A t-test of difference was performed for time to target, mean TWA blood glucose, and mean TWA area out of target (**Table 3)**. Closer algorithm adherence was associated with a lower mean TWA blood glucose.

Table 3. Comparison of Glycemic Control in Low vs. High Deviators[a] from the Intravenous Insulin Infusion Algorithm Recommendation (Standard Group Only)

	Low Deviators (n=44)	High Deviators (n=88)	P Value[b]
Time to BG <180 mg/dL, hours	2.0	2.6	0.14
TWA perioperative BG after initiation, mg/dL	190.0	206.4	0.03
TWA time out of perioperative target, mg/dL	27.1	37.2	0.09

Note. Abbreviations: BG, blood glucose; TWA, time-weighted average. Values are means.

[a]High deviators had one-third or more deviations in intravenous insulin titrations from the algorithm recommendations; low deviators had less than one-third deviation from the algorithm.

[b]T-test of differences.

DISCUSSION

The intent of this research was to critically evaluate the performance of Beaumont Health's perioperative paper-based IV insulin infusion algorithm with incorporated insulin pump (CSII) conversion directives. This algorithm is believed to be an efficacious option for use in noncardiac surgery patients. The investigators cautiously offer this conclusion because about 55% of insulin administration across all patients adhered with algorithm recommendations and 30% of patients experienced at least one glucose monitoring interval of greater than 90 minutes. In post hoc analyses, increased algorithm adherence was associated with improved perioperative glycemic control. The insulin pump conversion directives avoided severe hypo- and hyperglycemia.

The Standard Group

Even with suboptimal adherence and monitoring lapses, over 70% of patients achieved the target and 85% of the subsequent time was spent in the glycemic target range of 100-179 mg/dL. There was a progressive gradual decline in median blood glucose values from the one at the initiation of insulin infusion to the first postoperative nursing unit value (255 mg/dL to 194.1 mg/dL to 164 mg/dL). A median hyperglycemic index of 23.9 mg/

dL indicates that despite blood glucose excursions, most patients remained within the 72-216 mg/dL wider UKNHS glycemic target range.

This algorithm's moderate target range (140-179 mg/dL), preemptive downward titration, and early discontinuance of the insulin infusion likely contributed to the low rate of hypoglycemia. One of two hypoglycemic incidences was mild and was associated with a residual insulin effect from a prior subcutaneous insulin injection. Circumstances surrounding the other incidence of moderate hypoglycemia (53 mg/dL) exposed a weakness in the algorithm. With the decline in blood glucose from 167 to 83 mg/dL, initiation of an IV dextrose 5% infusion in addition to turning off the insulin infusion at the 83 mg/dL value may have prevented the subsequent blood glucose of 53 mg/dL. As a result of this study, Beaumont Health has since revised the algorithm to include "Begin D5W at 75 mL/hr" in addition to stopping the infusion for any blood glucose in the 80-99 mg/dL range.

Neither glycemic targets nor glucometrics for perioperative settings have been unequivocally established. This IV insulin infusion algorithm targets the 140-179 mg/dL range. Beaumont Health's perioperative blood glucose acceptable range (100-179 mg/dL) for all patients with diabetes is similar to the UKNHS 108-180 mg/dL recommended range.[7,8] The metrics in this study (time-to-target, subsequent time within target, TWA blood glucose, and hyperglycemic index) have been most often used in nonperioperative hospital settings and over longer time periods.

The investigators found only one other study that presented metrics validating a paper-based IV insulin infusion protocol during the perioperative period in noncardiac surgery patients. Abdelmalak et al[17] examined subjects who had been randomly assigned for the DeLiT clinical trial. Similar to this study, the Abdelmalak algorithm was based on blood glucose trend and incorporated IV insulin boluses and infusion rate increases to treat hyperglycemia. Unlike this study, the Abdelmalak algorithm had a lower, narrower blood glucose target (80-110 mg/dL) and higher blood glucose monitoring frequency (every 30 minutes). Also, the Abdelmalak sample had a lower mean preoperative blood glucose (118 mg/dL) and lower percentage of subjects with diabetes (28%). Abdelmalak et al concluded that their algorithm was efficacious, with minimal resulting hypoglycemia. Glucometric comparison between studies is difficult because of differences in algorithm target ranges.

The investigators concede that this algorithm is moderately complex with 3 tabular components and adjunctive IV insulin boluses. Complex algorithms that require multiple steps and calculations have been found to have high rates of error.[18,19] Practitioners frequently omitted the adjunctive insulin boluses recommended with the rate increases in the Calculation Chart [see (3) in Figure 1]. Lack of insulin boluses may have been due to failure to note the asterisk in the cell, which referred to rate and bolus instructions in the Calculation Chart. As a result of this finding, the words "and bolus" have replaced the asterisk in each algorithm titration cell where an increase in infusion rate is recommended. Additionally, with this retrospective review, the investigators could not ascertain if a given algorithm deviation was purposeful. Anesthesia practitioners had the latitude to deviate from the algorithm, whereas preoperative and post-anesthesia care nurses should only have deviated by a physician or nurse practitioner order. Atypical fractional infusion rate adjustments led us to believe an older institutional algorithm version had been erroneously used in 5 cases.

The Insulin Pump Group

In this study of 19 insulin pump patients, glycemic control was primarily attained or maintained during conversion, without any hypoglycemic events. Glycemic nurse practitioners collaborated with anesthesia providers, surgeons, and endocrinologists for management of insulin pump patients at this institution. Strict adherence to the insulin pump directives, without clinical judgment of glycemic nurse practitioners, may or may not yield similar results.

These conversion directives resulted in no severe glycemic derangements. Two theoretical concerns were identified when this algorithm's Titrating Infusion and Calculation Chart were used for insulin pump patients. First, because the algorithm target was 140-179 mg/dL, the algorithm did not direct upward titration of the infusion until the blood glucose reached >179 mg/dL. Most insulin pump patients had type 1 diabetes and thus would have inherently become at increased risk for diabetic ketoacidosis as blood glucose approached 250 mg/dL. Earlier intervention to abate a steady rise in blood glucose seemed warranted for this population. Second, at the other end of the spectrum, the algorithm twice directed titration off of the insulin infusion at blood glucose values of 80-99 mg/dL. In patients with absolute insulin deficiency, preserving the infusion at the basal rate with concurrent IV dextrose 5% infusion administration seemed to be more appropriate. These observations suggest that a separate IV insulin infusion algorithm for insulin pump patients would be advantageous.

Study Limitations

This was a single-institution, retrospective review using a convenience sample. The sample for the insulin pump conversion group was small. Nova Stat Strip (Nova Biomedical Corporation, Waltham, MA), the predominant instrument for blood glucose measurement, was a point-of-care testing device, which has less accuracy than hospital laboratory testing devices.[20] Some infusions were temporarily or permanently discontinued during the perioperative time; however, for simplicity, our analyses included all subsequent blood glucose tests from the infusion initiation until discharge from the perioperative area.

In post hoc analyses, improved glycemic control was associated with higher compliance. Whether lack of adherence caused worse glycemic control or whether providers tended to deviate more on the harder-to-control patients was impossible to say. Strong conclusions from these post hoc results were not possible because the study was purely based on chart review and the choice of a one-third deviation as a cutoff point for "low deviators" was arbitrary. A survey examining clarity and general satisfaction with the algorithm among nurses and nurse anesthetists could perhaps illuminate the findings on adherence.

Paper algorithms, such as the one evaluated in this study, may have a limited future. Computer-based algorithms have consistently demonstrated improved glycemic control with minimal hypoglycemia over paper-based algorithms.[21-25]

Commercial software integrates or interfaces to the electronic medical record and guides the practitioner in initiation and titration of the IV insulin infusion. Software features include the ability to individualize care on the basis of underlying patient characteristics and glycemic trend. Audible reminders are incorporated for blood glucose monitoring, which is performed by health care providers. Although no reports were yet found evaluating the computer-based algorithms to paper-based algorithms in the perioperative setting, the software is approved for use and available in some institutions during surgery. Newer concept closed-loop IV insulin delivery systems consist of totally automated dual infusions of dextrose and insulin based on continuous venous or subcutaneous glucose measurements.[1,26,27] The closed-loop systems are not currently retailed in the United States. Refinement of new technologies and overcoming obstacles for translation into practice should be the focus of future studies.

Conclusions

This Beaumont Health algorithm generally provided appropriate directives in initiation and maintenance of IV insulin infusions in the noncardiac surgery perioperative setting. In 132 patients presenting with a median blood glucose of 255 mg/dL, 73% attained the goal of <180 mg/dL while in the perioperative area. After goal achievement, the blood glucose values were in the 100-179 mg/dL target range for an 85% mean proportion of time. One incidence of moderate hypoglycemia (53 mg/dL) and one incidence of mild hypoglycemia (69 mg/dL) occurred.

Patients were safely converted from insulin pumps to IV insulin infusions. There were no incidences of hypoglycemia (<70 mg/dL). Of the 19 insulin pump patients, 58% arrived in the preoperative area with blood glucose values <180 mg/dL, whereas another 26% achieved values <180 mg/dL after the commencement of the IV insulin infusion. For these patients, the 100-179 mg/dL blood glucose range was maintained a mean 80% of the subsequent time. Further research is needed to elucidate the ideal pathway when transitioning between subcutaneous insulin pump delivery and IV insulin infusion.

Low algorithm adherence (approximately 55%) was the study's main limitation. To further examine efficacy, our post hoc analysis demonstrated improved glycemic control in patients where two-thirds or more of algorithm directives were followed. The effect of glycemic nurse practitioner collaboration in managing the insulin pump conversions makes it difficult to generalize results to anesthesia departments without this support.

As a result of this project, 2 proposed algorithm changes were implemented at Beaumont Health. Both are editions to the Titrating Infusion table in Figure 1. First, IV insulin boluses in the Calculation Chart had often been omitted. These omissions were likely due to failure of the provider to note the asterisk directive in the Titrating Infusion table. Cell asterisks have been replaced by the words "and bolus" for better clarity. Second, a patient experienced a blood glucose value of 53 mg/dL 20 minutes after the discontinuance of the insulin infusion for a blood glucose of 83 mg/dL. The commencement of a D5W infusion in addition to discontinuing the insulin infusion would likely have abated this decline to hypoglycemia. "Stop Infusion and Begin D5W at 75 cc/hr; Recheck BG in 15-30 minutes" has replaced "Hold, Recheck BG in 15-30 minutes" in the BG 80-99 mg/dL range cell.

Summary of Key Points

- Paper-based institutional IV insulin infusion algorithms, derived primarily for intensive care settings, are believed to be commonly used for perioperative glycemic management.
- An evaluation was done of this Beaumont Health algorithm (Figure 1), which targets the 140-179 mg/dL blood glucose range, employs adjunctive insulin boluses, and aims for aggressive prevention of hypoglycemia. Accompanying directives for conversion from continuous subcutaneous insulin infusion (insulin pump) to the IV insulin infusion were also examined.
- Glycemic control was generally attained and maintained with use of this algorithm, and no severe hypoglycemia occurred.
- Algorithm adherence was lower than anticipated. The investigators believe that some deviations were intentional clinical judgments and others were errors. Post hoc findings seem to indicate improved glycemic control with greater algorithm adherence.
- Two revisions have been incorporated into the algorithm. The first edition more clearly demonstrates when insulin boluses are indicated and the second directs use of dextrose 5% infusion with any blood glucose <99 mg/dL.

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