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A Retrospective Cohort Study of a Nurse-Driven Computerized Insulin Infusion Program Versus a Paper-Based Protocol in Critically Ill Patients

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Abstract

Background: There is variability in the extent of outcome achievement between computerized insulin infusion programs (CIIPs) and paper-based protocols (PBPs). This reported variability may be improved by intensive CIIP training prior to implementation. The objective was to evaluate the impact of a CIIP following intensive nurse training versus a PBP in a critical care setting.

Methods: A retrospective cohort study was performed on patients admitted to a mixed intensive care unit comparing glucose control between the CIIP following intensive training and a PBP. Consecutive patients on each protocol were assessed to obtain glucose concentrations and outcomes. The primary measure was the percentage of blood glucose values within target range (90–130 mg/dL). Patient glucose values were pooled and assessed using the χ^2 test for independence.

Results: In total, 61 patients with 5,495 glucose tests were included in the PBP group, and 51 patients with 5,645 glucose tests in the CIIP group. A greater percentage of glucose tests was within target range in the CIIP group (68.4% vs. 36.5%, $P < 0.001$). In the CIIP group, time-to-target (median [interquartile range] 5 [3–8] h vs. 7 [4–20] h, $P = 0.02$) and severe hypoglycemic events were reduced (26 vs. 6, $P < 0.0001$).

Conclusions: The nurse-driven CIIP led to a higher percentage of glucose values within target range, faster achievement of target glucose values, and a reduction in the number of severe hypoglycemic events. This improved outcome achievement compared with previous reports may be associated with intensive user training.

Introduction

Hospital systems are continuously evolving to efficiently and effectively control blood glucose (BG) concentrations in the intensive care unit (ICU). Nurse-driven computerized insulin infusion programs (CIIPs), in contrast to manual, paper-based protocols (PBPs), were developed in an attempt to reduce severe hypoglycemic events, improve compliance with BG testing and documentation, reduce the burden of complexity on nurses, and increase BG control within target ranges.[1–4] The first CIIP program, implemented in 1984, was effective at maintaining glycemic control with low rates of hypoglycemia, although not compared with a control protocol.[5]

Other nurse-driven CIIPs have been studied in the ICU and shown improvements in glycemic control compared with PBPs.[6–13] However, the safety and efficacy of these programs in achieving and maintaining a target glucose range are widely variable. A study published in 2007 showed that implementation of a nurse-driven CIIP in a mixed ICU led to 53.1% of glucose values within target range (80–135 mg/dL), with rare occurrences of hypoglycemia.[12] In another study in Belgium, implementation of a nurse-driven CIIP within a narrower glucose range (80–110 mg/dL) showed glucose values within range 42% of the time; however, approximately 60% of patients experienced a hypoglycemic event.[13] The disparity in these reports may be due to inherent differences

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in the CIIP programs and/or the training required prior to CIIP implementation.

Given the variability in previously reported safety and efficacy, our study objectives were to assess the impact of nurse-driven CIIP implementation on BG control versus a PBP in a critical care population following an intensive training program for the CIIP system. The hypothesis was intensive training of the nursing staff would result in better control within target glucose range in the ICU setting.

Subjects and Methods

Study site

The study was conducted at Wishard Health Services in Indianapolis, IN. Wishard Hospital is a 353-bed Level I trauma center that is part of a health system entity serving the patients of Marion County, with special emphasis on health care for underserved patients. Data collected in this study were obtained from patients in the medical ICU (MICU) and mixed surgical ICU (SICU). Wishard Health Services has a 24-bed SICU and MICU that includes a coronary care unit (CCU), a 24-bed progressive ICU (PICU), and 11-bed Intensive Care Burn Unit. In September 2003 the manual PBP was implemented in the MICU, SICU, and PICU to control hyperglycemia. In October 2006 Wishard Health Services introduced the CIIP in the Intensive Care Burn Unit. Under recommendations from the Wishard Health Services Department of Endocrinology and Critical Care Committee, the CIIP was expanded to the MICU, SICU, and PICU in 2009, replacing the PBP.

PBP

The PBP is detailed in Supplementary Appendix A (Supplementary Data are available online at www.liebertonline.com/dia).[14,15] The protocol directed nurses to test a patient's BG every hour until at least three consecutive readings were in target range; then, testing could occur every 2 h. Testing would revert back to hourly in the event of change in nutrition or a result outside of the target range. Adjustments made to the insulin drip rate were dependent on the current rate of infusion and a patient's BG measurement.

CIIP

The nurse-driven CIIP utilizes a computer-based algorithm to provide patient-specific insulin infusion rate adjustments. The algorithm includes a multiplier that adjusts the rate based on the patient's BG measurement:

$$(\mathrm{BG} - 60) \times \mathrm{multiplier} = \mathrm{infusion\ rate\ (units/h)} \qquad (1)$$

Initially, this multiplier is set at 0.02. If the BG measurement is above the target range, 0.01 is added to the multiplier; if the measurement is below the target range, 0.01 is subtracted. Nurses input the total number of carbohydrates consumed over the course of a defined period of time, and the CIIP provides an insulin bolus dose to administer.

The CIIP performs several additional functions beyond the PBP. The CIIP alerts nurses to perform a glucose check, it calculates carbohydrate coverage, insulin sensitivity factors, and dextrose bolus dose for hypoglycemia, and it assists in drip weaning. As displayed in Supplementary Appendix B, a screenshot of the CIIP provides a complete graphical report of a patient's BG history. Additionally, the CIIP automatically collects, stores, and organizes data for users to access and analyze on a centralized database. Thus, Supplementary Appendix C displays the reports on hospital and unit-wide BG control that can be accessed by the user.

CIIP training program

Before implementation of the CIIP program, nurses underwent system training. Initially, a webinar was conducted for nursing staff, and "superusers" were identified to handle program setup and troubleshooting. Following the webinar, in-services were provided, occurring over several weeks. Each nurse was provided with a training binder composed of screen shots of the CIIP software, a backup paper flowsheet, practice case scenarios, a copy of PowerPoint (Microsoft, Redmond, WA) slides on carbohydrate counting, and practice questions addressing correct and complete methods of documentation. Finally, training modules were completed by all nursing staff covering the above material. Training occurred during an 8-month period prior to CIIP implementation.

Study design

This study was a retrospective chart review comparing BG control between (1) a CIIP group of patients admitted to the MICU or SICU between April 1 and June 30, 2009 and (2) a PBP group of patients admitted to the MICU or SICU between April 1 and June 30, 2008. Both protocols utilized the same target glucose range during their respective time frames (90–130 mg/dL). Patients were included in the study if they were $\geq$18 years of age, had an active insulin drip order, and had at least two BG measurements. Exclusion criteria included patients with a diagnosis of diabetic ketoacidosis and burn unit patients because PBP was not being used in this unit in 2008. All patients within each specified time period were included who were on an active insulin drip ordered within the specified time period and met the inclusion/exclusion criteria. This study was approved by the Indiana University Purdue University at Indianapolis Institutional Review Board.

Data collection

Data for the PBP group were collected via the electronic medical record system. Data for the CIIP group were collected using the CIIP program.[5] The primary outcome measurement was the percentage of total BG values within target range. Secondary outcomes included time-to-target glucose, average BG, ICU and total hospital length of stay, mechanical ventilation days, nosocomial infection rate, and mortality rate. The predetermined safety outcome was the number of patients from each group with at least one severe hypoglycemic event, defined as a BG value of $<$40 mg/dL.

Statistical analysis

All categorical data including baseline characteristics were analyzed using χ^2 or Fisher's exact test, as appropriate. For the primary outcome, the BG measurements within each group's specified time range were pooled, and each glucose result

was assessed both within and outside of the target range (90–130 mg/dL). The results were calculated as the percentage of total values within this range and analyzed using the χ^2 test for independence. The Kolmogorov–Smirnov test was used to test the normality of continuous data, including age, admission BG, time-to-target, mechanical ventilation days, and length of stay. Data that were not normally distributed were analyzed using the Mann–Whitney U test and reported as median (interquartile range [IQR]). The statistical analyses were performed using GraphPad InStat version 3.06 (GraphPad Software, San Diego, CA). The a priori level of significance was set to 0.05.

Results

There were 61 patients in the PBP group and 51 patients in the CIIP group. No significant differences were found in regard to age ($P = 0.23$), sex ($P = 0.28$), race ($P = 0.35$), diagnosis of diabetes on admission ($P = 0.97$), or admission serum glucose values ($P = 0.25$). The median (IQR) serum creatinine concentrations were 0.9 (0.7–1.6) versus 1.0 (0.7–1.4) mg/dL ($P = 0.86$) in the PBP and CIIP groups, respectively. Overall, both groups had a relatively high proportion of non-white patients (56% and 53%; $P = 0.23$) and patients with diabetes (49% and 47%; $P = 0.97$) in the PBP and CIIP groups, respectively. Admission BG values were 182 mg/dL and 178 mg/dL in the PBP and CIIP groups, respectively ($P = 0.25$).

The CIIP group had a nonstatistically significant higher median (IQR) number of glucose tests completed per patient (72 [34–178] vs. 44 [25–130]) ($P = 0.18$), which corresponded to 5,645 total tests in the CIIP group and 5,495 in the PBP group. The average number of glucose tests per patient per day in the ICU was also not statistically different between the two groups as presented in Table 1. Nearly twice the number of glucose values were within target range in the CIIP group compared with the PBP group (PBP = 36.5%, CIIP = 68.4%, $P < 0.001$) as displayed in Figure 1. Additionally, the number of blood glucose concentrations that fell within the target range of 90–130 plus 130–150 mg/dL combined remained statistically significantly better in the CIIP group ($P < 0.0001$).

Table 1. Secondary Outcomes of Patients in Paper-Based Protocol Versus Computerized Insulin Infusion Program Groups

	PBP (n = *61*)	*CIIP* (n = *51*)	P *value*
ICU LOS (days)	6 (3–16)	9 (4–18)	0.28
Total LOS (days)	16 (8–30)	13 (7–23)	0.63
MVD	4 (0–11)	7 (2–14)	0.10
Nosocomial infection	20 (32)	15 (29)	0.85
Blood glucose tests/patient/day	8.6 (5.9–10.8)	9.0 (6.7–13.6)	0.26
Time-to-target (h)	7.3 (4.0–19.5)	5.0 (2.6–8.0)	0.02
Severe hypoglycemic event	9 (14.8)	2 (3.9)	0.064
Mortality	14 (23)	10 (19)	0.82

Data are median (interquartile range) values or number (%).

CIIP, computerized insulin infusion program; ICU, intensive care unit; LOS, length of stay; MVD, mechanical ventilation days; PBP, paper-based protocol.

Overall, glucose values were confined within a tighter glucose range in the CIIP group compared with the PBP group as visually represented by the kurtosis of the grouped frequency histogram ($P < 0.0001$ based on independence test). Additionally, the CIIP resulted in a lower percentage of glucose values within the hypoglycemic and hyperglycemic ranges. The percentage of total glucose values < 40 mg/dL was significantly lower in the CIIP group (0.5% vs. 0.04%, $P < 0.0001$). This corresponded to nine of 61 patients (14.8%) in the PBP group with at least one severe hypoglycemic event compared with two of 51 (3.9%) in the CIIP group ($P = 0.064$), as displayed in Table 1. Additionally, time-to-target glucose range was statistically significantly reduced in the CIIP group.

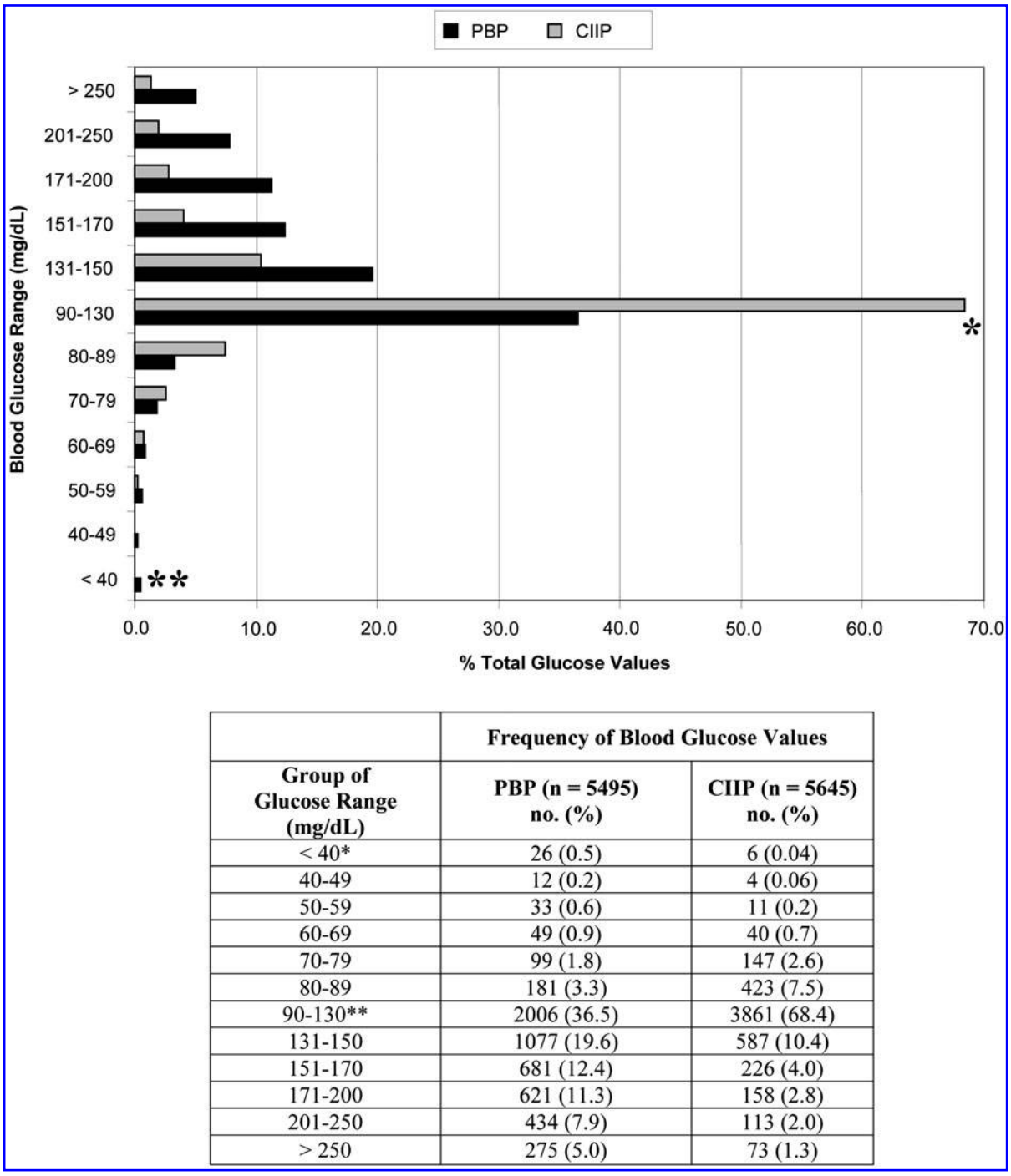
Discussion

A nurse-driven CIIP resulted in a significant increase in the proportion of BG values within the target range in comparison with the PBP in a mixed ICU population. The CIIP also led to faster achievement of target glucose values, overall tighter glucose control around the target range, and fewer total severe hypoglycemic events.

The level of training that nurses received before implementation of the CIIP may have contributed to tight glucose control. In a study by Meynaar et al.,[12] the percentage of glucose values within a wider target range was lower (56.4% vs. 68.4%) and the rate of severe hypoglycemia was higher (0.5% vs. 0.04%) in comparison with this study. Similarly, in a study by Oeyen et al.,[13] the percentage of glucose values within target range was lower compared with this study (42% vs. 68.4%), and hypoglycemia was detected in 18 of 30 patients (60%), whereas in the current study 12 of 51 patients (24%) experienced hypoglycemia according to the same definition. The improved results in the current study may be due to differences in CIIP characteristics or training between the studies. Specific training requirements for the CIIP in the previous studies included a single 30-min training in the first study[12] and a 1-h PowerPoint presentation followed by a 4-week training period in the second study.[13] Taken together, this illustrates that differences in CIIP characteristics, including the training used to orient staff, may have an impact on safety and efficacy of glycemic control.

Differences in nurse-driven CIIPs in the ICU may also partly explain the differences of outcomes from key intensive insulin studies including the data from van den Berghe et al.[14,16] and the NICE-SUGAR Study.[17] The studies of van den Berghe et al.[14,16] were conducted at a single center using strict nurse-driven protocol parameters, but the NICE-SUGAR Study[17] was a multicenter trial including several different nurse-driven protocols with limited information on training and implementation. Moreover, a study published by Kanji et al.[18] in 2004 indicated that standardization of a strict nurse-driven insulin protocol in an ICU improved the efficiency and safety of glucose control. Combined with our study, the variability of results based on different methodologies suggests that hospital systems should ensure adequate implementation of strict nurse-driven protocols along with a transition from manual PBPs to CIIP protocols to improve the safety and efficiency of glycemic control.

The direct comparison of PBPs with computer-based protocols is not completely analogous and includes differences in



	Frequency of Blood Glucose Values	
Group of Glucose Range (mg/dL)	PBP (n = 5495) no. (%)	CIIP (n = 5645) no. (%)
< 40*	26 (0.5)	6 (0.04)
40-49	12 (0.2)	4 (0.06)
50-59	33 (0.6)	11 (0.2)
60-69	49 (0.9)	40 (0.7)
70-79	99 (1.8)	147 (2.6)
80-89	181 (3.3)	423 (7.5)
90-130**	2006 (36.5)	3861 (68.4)
131-150	1077 (19.6)	587 (10.4)
151-170	681 (12.4)	226 (4.0)
171-200	621 (11.3)	158 (2.8)
201-250	434 (7.9)	113 (2.0)
> 250	275 (5.0)	73 (1.3)

FIG. 1. Grouped frequency distribution of glucose values from the paper-based protocol (PBP) and computerized insulin infusion program (CIIP) groups based on percentage of glucose values: (**top**) graphical display of the distribution with a grouped frequency histogram and (**bottom**) the numerical representation of the data. The overall *P* value for the independence test was < 0.0001. Post hoc analyses revealed the groups were significantly different in the target range (90–130 mg/dL) and the hypoglycemic range of < 40 mg/dL. $^{*}P < 0.001$, $^{**}P < 0.0001$.

process and flow. In the busy environs of the ICU, it is not surprising that BG testing can be forgotten with the consequences of either sustained hyperglycemia or hypoglycemia. The computer-based protocol in our study offers two distinct advantages: (1) visible and audible reminders for checking of BG and (2) standardized calculation of insulin doses for all patients based on BG responses. Given these differences one would expect to find differences in adherence rates to the protocols (due to prompted testing and thus increased frequency of testing) and quicker time to and remaining in target (due to standardized insulin dose calculations). These two attributes also reduce the chances of hypoglycemia and inadvertent protocol violations as were seen in other multicenter studies with paper protocols, such

as the Glucontrol study.[19] In this retrospective study, we were not able to collect data on nursing adherence to PBPs to compare with CIIP.

There are limitations in the non-randomized nature of this study. As with any retrospective analysis, there may have been baseline differences between the groups that could not be measured but impact the results of our analysis. For example, nutritional supplementation therapy was not included in our analysis because of the difficulty of collecting and classifying these data in a practical manner. Similarly, the frequency of daytime versus nighttime BG testing could not be collected in the PBP group, and therefore no comparisons could be made between the two groups.

The standard for our institution at the time of the study had a target BG concentration range between 90 to 130 mg/dL. This target range was based on the previous standard of stringent glucose control combined with the results of the NICE-SUGAR Study.[19] Although the American Diabetes Association has updated treatment guidelines regarding intensive insulin treatment in the ICU to include a more lenient range of glucose control compared with this study, there is continued debate about the appropriate target range for ICU patients.[20] Regardless of the debate, this study demonstrates that nurse-driven CIIPs produce significant improvements in target glucose range achievement and time-to-target glucose achievement, with a significant reduction in the number of severe hypoglycemic readings, with favorable results compared with similar studies. This study contributes to the growing body of literature that supports implementation of CIIP programs in the ICU and may provide an explanation for variability in results of similar studies. Thus, a strong support system of training may be useful when implementing staff-driven protocols for inpatient care.

Author Disclosure Statement

R.J. receives royalties from the sales of the computerized insulin infusion program referred to in the manuscript. The other authors have no conflicts of interest to disclose.

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