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ORIGINAL ARTICLE

Blood glucose control using an artificial pancreas reduces the workload of ICU nurses

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Abstract Blood glucose management is one of the important therapies in the intensive care unit (ICU). However, blood glucose management using the sliding-scale method increases the workload of ICU nurses. An artificial pancreas, STG-22, has been developed to continuously monitor blood glucose levels and to maintain them at appropriate levels. In this study, we examined the hypothesis that compared to conventional methods, blood glucose management using the STG-22 reduces the workload of ICU nurses and has a positive impact on awareness regarding the management of blood glucose. This study included 45 patients who underwent elective surgery and were treated at the ICU postoperatively. The patients were separated into the following two groups: (1) blood glucose was maintained using the STG-22 (AP group) and (2) blood glucose was maintained using the sliding-scale method (SS group). In addition, a questionnaire was developed for an awareness survey of ICU nurses ($N = 20$). The frequency of blood sampling and number of double checks were significantly lower in the AP group (1.3 ± 1.4 vs. 8.9 ± 8.1 times/admission, $P < 0.001$; 1.0 ± 1.4 vs. 9.8 ± 8.5 times/admission, $P < 0.001$). The time needed for glucose management per admission was significantly shorter in the AP group (9 ± 13 vs. 27 ± 24 min/admission; $P = 0.003$). Use of STG-22 for glucose management in the ICU increased the degree of attention given by nurses to glucose management and contributed to an improved sense of security. In conclusion, using the STG-22 in the ICU reduces the workload of ICU nurses compared to using the sliding-scale method. It also contributed to the reduction of the ICU nurses' anxiety related to the management of blood glucose.

Keywords Artificial pancreas · Workload · Intensive care unit

Introduction

Perioperative patients are likely to develop hyperglycemia because of an exacerbation of insulin resistance [1]. Perioperative hyperglycemia is known to lead to a poor prognosis because of an increased risk of infection [1, 2]. Since Van den Berghe et al. [3] reported that the prognosis of intensive care unit (ICU) patients can be improved through strict management of blood glucose (intensive insulin therapy), clinical studies have been conducted in many institutions. However, subsequent studies have revealed major problems related to the strict management of blood glucose, such as hypoglycemic events [4]. The results of the NICE-SUGAR study showed that the prognosis was poorer in patients who underwent strict management of blood glucose [5]. However, Bellomo et al. [6] emphasized that the findings of the NICE-SUGAR study do not justify neglect of glycemic control.

We presented the related clinical study at JSAO 2010 (Nurse Award).

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The sliding-scale method is widely performed in many ICUs for the management of blood glucose. However, with these methods, it is often difficult to manage blood glucose levels and reach the desired values [7]. In fact, only 22.7% of the patients achieved the target range after 12 h of blood glucose management using the sliding-scale method. In addition, if the protocol is strictly observed, substantial effort is needed to improve the achievement rate in managing blood glucose levels [2]. In practice, measuring blood glucose levels and changing the administered insulin dosage are tasks attributed to nurses, whose workload would increase in that case. In addition, incidents related to the management of blood glucose levels, such as hypoglycemic attacks and mistakes in the units of insulin administered, account for the majority of the total number of incidents. A multicenter study conducted in France showed that the most common medical error was that of insulin administration, with a frequency of 185.9/1,000 days of insulin treatment [8].

The STG-22 (Nikkiso CO., Ltd., Tokyo, Japan) system has been developed to continuously monitor blood glucose levels and to maintain appropriate blood glucose levels by automatic infusion of insulin and glucose; the target range of blood glucose concentrations is set manually. We have already reported that the STG-22 system can maintain optimal blood glucose levels without causing hypoglycemia in patients admitted to the ICU [9]. In addition, this system does not require blood glucose measurement by the ICU staff [2, 9].

In this study, we examined the hypothesis that compared to conventional methods, the management of blood glucose through the use of an artificial pancreas helps to reduce the workload of ICU nurses and has a positive impact on awareness regarding the management of blood glucose.

Subjects and methods

After approval by the ethics review board of Kochi Medical School, written informed consent was obtained from the patients. This study included 45 patients who underwent elective surgeries, such as major abdominal surgery and cardiovascular surgery, and were treated at the ICU postoperatively between October 2007 and March 2010 (Table 1). All postoperative management other than the management of blood glucose was entrusted to the judgment of the individual surgeon and/or anesthesiologists. The management of blood glucose was performed from immediately after admission to the ICU until discharge from the ICU, and the patients were separated into the following two groups. One group was the artificial pancreas group (AP group: target blood glucose level, 80–110 mg/dl; $N = 26$), which consisted of patients in whom management of blood glucose was performed using an artificial pancreas. The other group was the conventional blood glucose management group, which consisted of patients in whom the management of blood glucose was conducted by using the sliding-scale method (SS group: target blood glucose level, 150–200 mg/dl; $N = 19$). The measurement of blood glucose levels was conducted once every 4 h in the SS group. Since the artificial pancreas poses no risk of hypoglycemia, the target blood glucose levels were set low on the basis of the Leuven study [3, 9]. In contrast, in the sliding-scale method, the target blood glucose levels were set high in order to avoid the risk of hypoglycemia.

Table 1 Surgical method

	AP group ($N = 26$)	SS group ($N = 19$)
Hepatectomy	11	6
Pancreaticoduodenectomy	10	6
Esophagectomy	4	3
Cardiovascular surgery using CPB	0	3
Surgery for peritonitis	1	1

CPB, cardiopulmonary bypass

The frequency of hypoglycemic events, the mean blood glucose levels and insulin consumption were recorded. Hypoglycemia was defined as a condition in which the blood glucose level was less than 70 mg/dl. The mean blood glucose level in the SS group was calculated as the average of all measured blood glucose values and that in the AP group was calculated by using data stored on a personal computer attached to the STG-22 and retrieved as Excel (.xls) files. The following were recorded as items related to the workload: number of hours spent working on the management of blood glucose, number of blood samplings, number of double checks, and number of calls made to the physician. A double check was defined as the confirmation of blood glucose, the protocol instruction, and insulin doses by two nurses. The number of hours spent working on the management of blood glucose in the SS group was defined as the time period comprising the sampling of blood, the simple measurement of blood glucose levels using a blood glucose meter, and the confirmation of the protocol instructions, up to the time of completion of the administration of insulin. The number of hours spent working on the management of blood glucose in the AP group was defined as the time period spent on correspondence to alarms such as interruption of blood sampling. A questionnaire was made for an awareness survey of ICU nurses, and the answers were obtained using the visual analog scale (VAS).

Data are presented as mean ± standard deviation (SD). Statistical analyses were performed using a statistical software package (JMP 8; SAS Institute Japan, Tokyo, Japan). The data for the groups were compared using the Mann-Whitney U test, and dichotomous variables were analyzed using the chi-square test. P values less than 0.05 were considered statistically significant.

Our hospital ICU

Our hospital ICU has five beds and is staffed by 20 nurses. The nurses work under a two-shift system with a 9-h day shift and a 15-h night shift. At least six nurses work during the day shift and three during the night shift. Each nurse takes care of one or two patients.

Artificial pancreas STG-22 [9, 10]

A 20-G catheter was placed into a peripheral vein, and a measurement tube for the artificial pancreas was inserted into the lumen of the catheter. Continuous blood sampling was performed through the tube by drawing 2 ml of blood per hour. The collected blood samples were passed through a glucose sensor, which displayed the glucose levels in real-time by measuring them using the glucose oxidase method. By entering the target blood glucose levels beforehand, the optimal doses of insulin and/or glucose were determined every minute on the basis of the device's algorithm, and the management of blood glucose was performed by the artificial pancreas pump, which injected insulin and/or glucose automatically. The algorithms used for calculating the insulin infusion rate and glucose infusion rate are as follows: $\mathrm{IIR}(t) = \mathrm{IA}\cdot(\mathrm{BG}(t)-\mathrm{ID})/100 + \mathrm{IB}\cdot\Delta\mathrm{BG}(t)/100 + 0.225$ and $\mathrm{GIR}(t) = \mathrm{GA}\cdot(\mathrm{GD}-\mathrm{BG}(t))-\mathrm{GB}\cdot\Delta\mathrm{BG}(t)$. IA, IB, GA, and GB are set manually as the definition of the degree of blood glucose control. BG refers to the current blood glucose level. ID and GD refer to the blood glucose levels at the start of insulin and glucose infusion, respectively.

The sliding-scale method

This blood glucose management method consists of measuring blood glucose levels at times designated in advance, followed by continuous intravenous insulin administration on the basis of the measured blood glucose levels, as described in the protocol instruction (Table 2). Blood glucose was measured using arterial blood and the glucose oxidase method (Antsense III, Horiba Ltd., Kyoto, Japan). Specifically, nurses collect the blood and measure the blood glucose levels. The measured blood glucose levels are verified by checking the protocol instruction, and the indicated dose of insulin is prepared and administered to the patient. In case insulin is injected continuously, the infusion rate is modified in accordance with the protocol instruction.

Table 2 Protocol instruction in SS group

Blood glucose (mg/dl)	Action
Less than 70	Calls made to the physician
70–100	Insulin 0.4 ml/h down
101–150	Insulin 0.2 ml/h down
151–200	Insulin 0.2 ml/h up
201–250	Insulin 0.4 ml/h up
More than 250	Calls made to the physician

SS Sliding scale

Questionnaire

The survey targeted all ICU nurses. The questionnaire comprised three questions, all of which consisted of a comparison between the artificial pancreas and the sliding-scale method. The questions were as follows:

(1) Has there been any change in the degree of attention you give (awareness) to the management of blood glucose?
(2) How much burden does the management of blood glucose place on the workload?
(3) How secure do you feel about the management of blood glucose?

VAS

VAS 100 means the highest awareness, the heaviest workload, and the highest sense of security. On the other hand, VAS 0 means lack of awareness, absence of workload, and lack of a sense of security.

Results

The two groups showed no significant differences in terms of background factors, including the time of admission (Table 3). The number of patients who received major abdominal surgery was 21 (81%) in the AP group and 12 (63%) in the SS group. The Acute Physiology and Chronic Health Evaluation II (APACHE II) score of the patients after admission to the ICU was 12.3 ± 3.3 (mean ± SD) in the AP group and 11.5 ± 3.4 in the SS group, whereas the Sequential Organ Failure Assessment (SOFA) score was 2.4 ± 0.4 in the AP group and 3.4 ± 0.5 in the SS group. The AP group had significantly higher insulin consumption and significantly lower mean blood glucose levels (136 ± 135 vs. 25 ± 25 units/admission, $P = 0.001$; 123 ± 34 vs. 198 ± 60 mg/dl, $P < 0.001$). The frequency of blood sampling (1.3 ± 1.4 vs. 8.9 ± 8.1 times/admission, $P < 0.001$), the number of double checks (1.0 ± 1.4 vs. 9.8 ± 8.5 times/

Table 3 Patient characteristics and perioperative date

	AP group ($N = 26$)	SS group ($N = 19$)	P value
Age (years)	65 ± 10	65 ± 11	0.93
Gender (F/M)	9/17	10/9	0.23
Body mass index (kg/m^2)	23.4 ± 3.2	22.7 ± 4.9	0.55
Diabetes mellitus, N (%)	16 (62)	10 (52)	0.55
HbA1c (%)	5.5 ± 0.8	6.1 ± 1.0	0.11
APACHE II score on admission	12.3 ± 3.3	11.5 ± 3.4	0.77
SOFA score on admission	2.4 ± 0.4	3.4 ± 0.5	0.10
TPN on first day, N (%)	23 (88)	13 (68)	0.10
Glucose infusion on first day (g/kg/h)	0.16 ± 0.03	0.14 ± 0.07	0.23
Sepsis patient, N (%)	1 (4)	1 (5)	0.82
Total amount of bleeding (ml)	725 ± 748	818 ± 728	0.69
Duration of ICU stay (days)	2.1 ± 0.3	2.7 ± 1.7	0.10
Average control time of glucose (h)	20 ± 22	37 ± 49	0.11
Insulin infusion (units/24 h)	136 ± 135	25 ± 25	0.001
Mean blood glucose (mg/dl)	123 ± 34	198 ± 60	<0.001
Hypoglycemia, N (%)	0 (0)	1 (5)	0.42

Data are mean ± SD (standard deviation) mg/dl

BMI body mass index, *ICU* intensive care unit, *APACHE*, Acute Physiology and Chronic Health Evaluation, *TPN* total parenteral nutrition

Table 4 Workload date

	AP group ($N = 26$)	SS group ($N = 19$)	P value
Frequency of blood sampling (times/Ad)	1.3 ± 1.4	8.9 ± 8.1	<0.001
Number of double checks (times/Ad)	1.0 ± 1.4	9.8 ± 8.5	<0.001
Number of Dr. calls (times/Ad)	0.6 ± 1.1	2.2 ± 1.8	0.001
Time needed for management of BG (min/Ad)	9 ± 13	27 ± 24	0.003

Data are mean ± SD (standard deviation) mg/dl

Ad Admission, *Number of Dr. calls* number of calls made to the physician, *Time needed for management of BG* time needed for the management of blood glucose per admission

admission, $P < 0.001$), and the number of calls made to the physician (0.6 ± 1.1 vs. 2.2 ± 1.8 times/admission, $P = 0.001$) were significantly lower in the AP group (Table 4). The time needed for the management of blood glucose per admission was significantly shorter in the AP group (9 ± 13 vs. 27 ± 24 min/admission, $P = 0.003$).

Responses to the questionnaire were received from all ICU nurses ($N = 20$). Awareness regarding the management of blood glucose increased significantly after adoption of using the artificial pancreas (76 ± 14 vs. 54 ± 17 mm, $P < 0.001$). The burden caused by the management of blood glucose on the workload was significantly heavier with the sliding-scale method than with the artificial pancreas (33 ± 21 vs. 68 ± 25 mm, $P < 0.001$). Management of blood glucose by using an artificial pancreas provided more sense of security for the nurses compared with management using the sliding-scale method (62 ± 22 vs. 37 ± 19 mm, $P < 0.001$).

Discussion

This study has shown that management of blood glucose using an artificial pancreas reduces the burden on the workload of nurses significantly compared to that using the sliding-scale method. In addition, adopting the use of an artificial pancreas for the management of blood glucose in the ICU increased the degree of attention given by nurses to blood glucose management and contributed to an improved sense of security.

Postoperative patients admitted to the ICU are likely to develop insulin-resistant hyperglycemia as a biological stress reaction associated with surgical stress [1,2]. Moreover, the persistence of perioperative hyperglycemia is a risk factor that may induce postoperative infections, and thus, strict perioperative management of blood glucose is extremely important [1, 2]. With more invasive surgery, perioperative blood glucose levels would not decrease with the management of blood glucose through intermittent insulin infusion according to the conventional sliding-scale method [11]. In addition, intensive insulin therapy is also associated with the risk of developing hypoglycemic events [2, 4]. Other problems with the conventional method are the workload associated with frequent blood glucose measurements [2]. For example, the Surviving Sepsis Campaign Guidelines recommends that blood glucose levels should be measured every 1–2 h until they are stabilized and subsequently every 4 h [12]. In the present study, the number of blood samplings was 8.9 ± 8.1 times because blood glucose was measured in accordance with this guideline. In addition, risk management is performed by ensuring that physicians or nurses conduct double checks when preparing and loading insulin, and when modifying the infusion rate of insulin in our ICU. The number of double checks was 9.8 ± 8.5 times, and nearly 30 min per patient was spent on the management of blood glucose in the SS group. The number of doctor calls made to the physician was 2.2 ± 1.8 times/admission, and the reason for calling the physician was that the blood glucose was not within the target levels (less than 70 mg/dl or more than 250 mg/dl), for which the physician had to be called as described in the protocol instructions. Comparatively, in the AP group, the frequency of blood sampling, the number of double checks, the number of doctor calls and the time needed for management of blood glucose were all significantly lower than in SS group. Blood sampling and double checks were performed in the AP group to confirm the blood glucose level of an artificial pancreas when the automatic glucose control using an artificial pancreas started and restarted after the control was interrupted because of the interruption of blood sampling [9]. In the AP group, the physician was called when blood sampling was interrupted. The greatest benefit of the artificial pancreas is that its use does not increase the workload even if we set a stricter target range. The questionnaire survey showed that nurses themselves realized an actual reduction of their workload, showing that the introduction of an artificial pancreas led to a subjective and objective reduction of the workload. The cost simulations of our hospital's five-bed ICU suggested that this may allow cost cuts of US $14,000 per year in personnel expenses related to nurses.

The high number of incidents has also been quoted as the second issue in the management of blood glucose using the sliding-scale method [13]. Nurses dealing with the care of critically ill patients in the ICU are constantly under tension and stress [14]. Under these situations, a great deal of stress for ICU nurses is caused by the need for frequent measurements of blood glucose levels and the repetitive handling of insulin, which is likely to cause incidents. The use of an artificial pancreas for the management of blood glucose liberates nurses from tasks involving the handling of insulin. This could be expected to lead to reduced stress among nurses. In fact, the results of this questionnaire survey also showed that the use of an artificial pancreas provided more sense of security for the nurses. By using an artificial pancreas, the amount of labor spent per patient was reduced by about 20 min, and stress was substantially relieved. Because this allows nurses to devote more time and concentration to other care-giving tasks, it may contribute to improvement of the overall quality of care and to the reduction of the risks of other incidents occurring.

The results of our questionnaire study also showed the drawbacks of an artificial pancreas. In fact, the nurses became interested in blood glucose control because this device always provides them with the patients' blood glucose level. However, they were not satisfied with this device. Although the sampling frequency and number of checks were reduced, they faced other problems. First, because blood sampling depends on peripheral veins, changes in posture and body movements may result in a failure to draw blood properly. When blood cannot be properly drawn, the measurement and automatic management of blood glucose are temporarily interrupted, and accurate data on blood glucose levels cannot be obtained [9]. In addition, it takes time until the alarm responds to the failure to draw blood. As ICU nurses assume a major role in managing blood glucose by artificial pancreas after admission to the ICU, they need to change the patients' posture while continuously paying attention to the catheter in order to prevent failure to obtain blood properly. Technological improvements that would allow blood sampling from central veins are desired. This innovation might reduce the workload of the nurses and improve the safety of blood glucose management.

The present study has several limitations. One is the fact that everything else other than the management of blood glucose, including nutrition, was entrusted to the attending physician. Therefore, the possibility of an influence of differences in doses of nutrients on blood glucose levels, on the number of times of adjustment of insulin doses, and on the number of hours of work spent to perform the tasks cannot be denied. The second limitation consists of the fact that the target blood glucose levels were different in the sliding-scale method and in the method using an artificial pancreas. Since the artificial pancreas poses no risk of hypoglycemia, the target blood glucose levels were set low on the basis of the Leuvan study [3, 9]. On the other hand, in the sliding-scale method, the target blood glucose levels were set high in order to avoid the risk of hypoglycemia. We had to set the same target range because these different targets might have affected our result. In particular, the amount of labor might be affected. However, if the target blood glucose level is set to 80–110 mg/dl while using the sliding-scale method, there might be further differences in the amount of labor. In other words, these different target ranges have little direct effect on our discussion about the use of an artificial pancreas reducing the workload of ICU nurses. In the future, research studies that include a decrease in the other incidents mentioned earlier among their outcomes would be desirable. The third limitation is that the mean blood glucose level in the AP group was not within the target range. This could be for two reasons. First, almost all patients received parenteral nutrition on the day of admission. After parenteral nutrition was initiated, the blood glucose level was elevated despite the use of an artificial pancreas. Although the blood glucose level decreased to 110 mg/dl in a few hours, mean blood glucose was higher than the target range. Second, if the target blood glucose level in the AP group is less than 80 mg/dl, glucose infusion starts, and if the blood glucose level is more than 110 mg/dl, insulin infusion starts. Therefore, when the blood glucose level approaches 110 mg/dl, automatic insulin infusion is discontinued or very low. In our result, mean the blood glucose level was higher than the target range.

In conclusion, the use of an artificial pancreas for the management of blood glucose in the ICU reduces the workload of ICU nurses compared to that during the use of the sliding-scale method. In addition, according to the questionnaire survey, it also contributed to the reduction in the ICU nurses' anxieties related to the management of blood glucose. Therefore, this study indicated that the artificial pancreas could be a useful device for the management of blood glucose in the ICU.

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