University of Groningen

Pre- and Postoperative Accuracy and Safety of a Real-Time Continuous Glucose Monitoring System in Cardiac Surgical Patients

Logtenberg, Susan J.; Kleefstra, Nanne; Snellen, Ferdinand T.; Groenier, Klaas H.; Slingerland, Robbert J.; Nierich, Arno P.; Bilo, Henk J.

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Logtenberg, S. J., Kleefstra, N., Snellen, F. T., Groenier, K. H., Slingerland, R. J., Nierich, A. P., & Bilo, H. J. (2009). Pre- and Postoperative Accuracy and Safety of a Real-Time Continuous Glucose Monitoring System in Cardiac Surgical Patients: A Randomized Pilot Study. *Diabetes technology & therapeutics*, *11*(1), 31-37. https://doi.org/10.1089/dia.2008.0028

Pre- and Postoperative Accuracy and Safety of a Real-Time Continuous Glucose Monitoring System in Cardiac Surgical Patients: A Randomized Pilot Study

Susan J. Logtenberg, M.D.,[1] Nanne Kleefstra, M.D.,[1,2] Ferdinand T. Snellen, M.D.,[3]
Klaas H. Groenier, Ph.D.,[4,5] Robbert J. Slingerland, Ph.D.,[6]
Arno P. Nierich, Ph.D.,[3] and Henk J. Bilo, Ph.D.[1,5,7]

Abstract

Background: Our objective was to evaluate the accuracy and safety of a real-time (RT) continuous glucose monitoring system (CGMS) in patients before and after cardiothoracic surgery and to investigate whether activation of the alarm function of the RT-CGMS had an effect on glucose control.

Methods: Patients scheduled for elective cardiothoracic procedures, without a history of insulin-requiring diabetes, were perioperatively monitored with RT-CGMS for 72 h and were randomized into two groups: with or without the alarm function (set at 4 and 10 mmol/L) of the device activated. Sensor values were compared with capillary, arterial, and venous blood glucose values. Percentages of time spent in various glucose ranges were compared between groups.

Results: There were no adverse effects of the RT-CGMS. Of the 1,001 sensor value comparisons with capillary or arterial measurements, 96.6% fell within Clarke Error Grid zones A and B, with relative absolute differences ranging from 15% (preoperative period) to 12% (intensive care unit period) to 14% (postoperative period on the ward). Seventeen (7.9%) arterial and 16 (2.0%) capillary comparisons fell within zone D or E. Whether or not the alarm function, as used in this pilot study, was activated did not affect time spent in different glucose ranges.

Conclusions: Although the RT-CGMS is safe and accurate according to accepted standards, there are still small aberrations, which in our opinion preclude unlimited use in its present form in a clinical setting. The effect of the alarm function at different glucose levels remains to be investigated.

Introduction

VAN DEN BERGHE ET AL.[1] reported that strict glycemic control in patients admitted to an intensive care unit (ICU) resulted in reduction of morbidity and mortality by 42.5%. Based on the results of this landmark trial, protocols in ICUs have become stricter regarding blood glucose values, and in order to strive for target values between 4.4 and 6.1 mmol/L, frequent glucose monitoring and insulin dose adjustments are required, which is time intensive.[2]

Implementing strict glucose control may be facilitated by a real-time (RT) continuous glucose monitoring system (CGMS), when continuous glucose readings can help iden-

tify and prevent periods of hypoglycemia or hyperglycemia, without increasing workload or burden for patients.[3,4] CGMS was shown to be accurate and reliable in critically ill patients admitted to the ICU.[4] That study, however, was performed using retrospective instead of RT glucose data.[4]

Recently, a new RT-CGMS received U.S. Food and Drug Administration approval (Paradigm® REAL-Time, Medtronic MiniMed, Northridge, CA). The RT-CGMS has proven to be effective in reducing hyperglycemic and hypoglycemic episodes in ambulatory patients with type 1 diabetes.[5,6] However, there is conflicting evidence from randomized controlled trials about the effect on hemoglobin A_{1c}.[7,8] Piper et al.[9] reported about the performance of RT-CGMS during and after

[1]Diabetes Centre, [3]Department of (Thoracic) Anesthesia and Intensive Care, and [6]Department of Clinical Chemistry, Isala Clinics; and [2]Langerhans Medical Research Group, Zwolle, The Netherlands.
Departments of [4]General Practice and [7]Medicine, University Medical Center Groningen; and [5]University of Groningen, Groningen, The Netherlands.

cardiac surgery in pediatric patients and found RT-CGMS to perform well in hypothermia, inotrope use, and edema when compared to 6-h arterial laboratory glucose values.

To our knowledge, this is the first study evaluating the accuracy and safety of RT-CGMS before and after cardiothoracic surgical procedures in adult patients. A second objective was to investigate the effect of the alarm function of a RT-CGMS on glucose control.

Research Design and Methods

Thirty-one patients over 18 years of age, undergoing elective cardiothoracic surgery without use of insulin before surgery, were included in this study conducted in the Isala Clinics, Zwolle, The Netherlands. Approximately 1 week before the scheduled surgical procedure, eligible patients received a letter with information about the study and were informed that on the day before that procedure, they would be contacted by a researcher for further explanation of the trial, after which informed consent was asked. After admission to the hospital, a clinical history was taken, patients underwent physical examination including measurement of blood pressure, weight, and height and waist circumference, and the Euroscore was calculated. The Euroscore provides an estimate of cardiac surgery mortality risk and is based on a range of patient- and procedure-related characteristics.[10] Higher scores indicate increased risk.

In general, after surgery, patients would be admitted to the ICU for 1 or 2 days, after which they would be transferred to the (medium care) ward for further recovery. To test whether the additional alarm function of the RT-CGMS would have an effect on glucose control, patients were randomized to RT-CGMS with the alarm setting activated or deactivated (Alarm group and Blind group, respectively). Randomization was done using sealed nontransparent envelopes. Randomization took place after informed consent was obtained. This study was conducted with approval of the local ethics committee.

RT-CGMS

The RT-CGMS consists of a needle-type sensor that is inserted in the subcutaneous tissue. The sensor is composed of a microelectrode with glucose oxidase. The sensor continuously converts small amounts of glucose from the interstitial fluid into an electronic signal, the strength of which is proportional to the amount of glucose present. The sensor is connected directly with a small oval ($\sim$3- $\times$ 4-cm) transmitter, which wirelessly sends data to a monitor. The sensor performs an interstitial glucose measurement every 10 s and stores a mean value every 5 min. The sensor lasts a maximum of 72 h. Calibration is required at least every 12 h. Alarms can be programmed in such a way that the RT-CGMS alerts whenever a sensor value is below or above a preset value.

For the present study, calibrations were performed three or four times per 24-h period (i.e., after insertion, before surgery, after arrival at the ICU, before breakfast [8 a.m.], before dinner [4 p.m.], before bedtime [10 p.m.]). Alarms were set at 4.0 and 10.0 mmol/L (during the night on the ward at 3.0 and 15.0 mmol/L).

RT-CGMS use was started the day before the planned surgical procedure. The sensor was inserted aseptically in the subcutaneous tissue of the abdomen. Sensors were calibrated as recommended by the manufacturer, using a capillary blood glucose value measured with a point-of-care system (Accu-Chek Inform® System, Roche Diagnostics, Basel, Switzerland).

Point-of-care systems are used in our hospital both on the ward and the ICU to facilitate strict glucose control with regular glucose monitoring. In our study, all blood glucose measurements were performed with this system. Laboratory analysis of glucose as a control and calibration of the point-of-care system were performed on a regular basis. Capillary, arterial, and venous blood glucose measurement with the Accu-Chek Inform has proven to be accurate during ICU admission.[11,12] Capillary blood glucose values were obtained at regular prespecified times. During the ICU period, in addition to capillary measurements, arterial and venous blood glucose measurements were performed at the same time as the capillary measurements.

In the Alarm group, whenever the RT-CGMS would alert, a blood glucose value was to be determined (either capillary and/or arterial). Treatment decisions were to be taken based on blood glucose values, according to the ICU Insulin/Glucose protocol (see Appendix); no treatment adjustments were based on sensor values. A continuous intravenous insulin regimen was started preoperatively at induction of anesthesia and was continued at the ICU aiming at a glucose level of 4.4–6.1 mmol/L.[1] On the ward, continuous or intermittent insulin infusion was initiated postoperatively at the discretion of the attending physician or the consulting internist. Whenever a sensor failed during the initiation phase, a new sensor was inserted. Whenever a sensor was removed during surgery, a new sensor was placed at arrival at the ICU. Total sensor time did not exceed 72 h in any of the patients.

Statistical analysis

Descriptive statistics include mean (standard deviation [SD]) or median (interquartile range). All data were reviewed for normality using Q-Q plots, and parametric and nonparametric tests were used as appropriate. Two-tailed tests were used, and an α of 0.05 was used as a threshold of significance.

To test accuracy, all matched points (within 5 min) from both groups were plotted on Clarke Error Grids.[13,14] Clarke Error Grid analysis was originally developed to evaluate the accuracy of capillary blood glucose testing systems taking the relevance of differences between reference and measured values into account. The reference blood glucose value is plotted on the x-axis against the sensor value on the y-axis. The graph is divided into five zones. Comparison points within zone A represent sensor values that differ from the reference value by no more than 20%. Zone B includes comparison points that differ by >20% but do not result in an alteration in treatment. Comparison points in zone C would result in an overcorrection of acceptable glucose values. Points in zone D would result in failure to detect and treat errors. Comparisons in zone E would result in opposite treatment decisions. When over 95% of points are in zones A and B, generally a system is considered accurate.[14,15]

Furthermore, the relative absolute difference (RAD) (absolute difference between sensor and reference glucose value divided by reference value expressed as a percentage) was
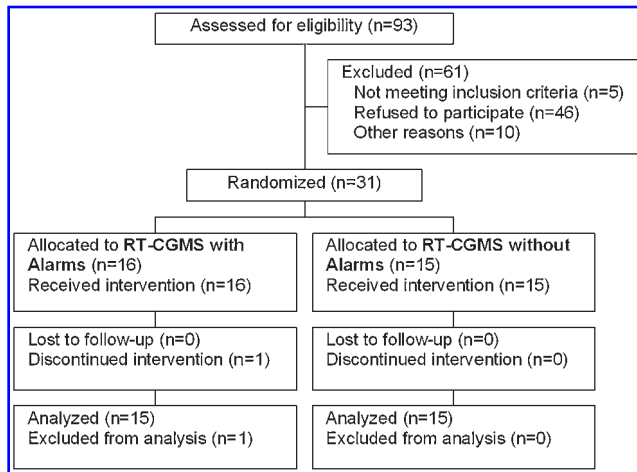
FIG. 1. Number of participants in stages of the trial. Reproduced with permission from the CONSORT flow diagram.[17]

calculated for capillary values in all periods. This statistic is valued as an easy to interpret measure of accuracy.[16]

To test glucose control, glucose values were divided into five ranges (all in mmol/L): ≤3.9; 4.0–4.3; 4.4–6.1; 6.2–10.0; and ≥10.1. Percentages of time in each range were compared between groups in all periods.

Results

A total of 31 patients were enrolled from June until October 2007, of which 30 completed the study (Fig. 1). One patient withdrew during the initiation phase of the sensor (first 2 h after sensor insertion) because of increased nervousness

due to anticipated sensor alarms. Patient characteristics are presented in Table 1. There were more males and patients with type 2 diabetes in the Blind group.

Median duration of sensor placement was 70.9 (69.9–71.5) h. Sensors were well tolerated in all patients, without occurrence of serious adverse skin reactions, infections, or bleeding.

Duration of preoperative sensor placement was 17.5 (15.3–19.2) h; duration of postoperative sensor reading was 46.3 (43.8–48.8) h. Median time of sensor reading on the ICU was 20.3 (17.6–22.5) h ($n = 29$; one sensor provided too few sensor readings during the ICU stay). Duration of postoperative sensor reading on the ward was 28.6 (26.3–29.8) h ($n = 26$; four patients stayed on the ICU for the complete postoperative study period).

RT-CGMS: accuracy

Throughout the study 818 capillary blood glucose values, 216 arterial blood glucose values, and 136 venous blood glucose values were compared with sensor values, resulting in 39 comparisons per patient on average (range, 24–52).

Median RAD (absolute difference between sensor and capillary glucose value divided by capillary value, expressed as a percentage) during the preoperative period was 14.6% (range, 7.1–25.9%), during the ICU period was 12.3% (4.7–24.8%), and during the postoperative period on the ward was 14.1% (7.0–25.4%).

Clarke Error Grids of the comparison of sensor and reference values in the difference periods are shown in Figure 2. For the comparisons with capillary glucose measurements, 96.0–99.5% fell into grid zones A and B, the acceptable zones. However, 12 capillary points (1.6%) were in zone D, indicating that the sensor value would not trigger treatment when the reference value would. Four points (0.5%) were in zone E.

TABLE 1. PATIENT CHARACTERISTICS

Characteristic	All (n = 30)	Alarm group (n = 15)	Blind group (n = 15)
Age (years)	67.8 (9.4)	66.2 (10.3)	69.3 (8.4)
Male (n)	24	10	14
BMI (kg/m^2)	26.6 (3.4)	26.6 (3.3)	26.6 (3.6)
Waist (cm)	99.9 (10.7)	98.4 (9.7)	101.4 (11.8)
BP (mm Hg)			
Systolic	121.3 (15.8)	118.2 (17.4)	124.3 (14.1)
Diastolic	68.1 (10.9)	64.4 (9.4)	71.9 (11.3)
Heart rate (bpm)	69.3 (14.6)	71.8 (12.4)	66.9 (16.6)
Type 2 diabetes (n)	6	1	5
Plasma glucose at admission (non-fasting; mmol/L)[a]	5.8 (5.0–6.9)	5.5 (5.0–6.6)	5.9 (4.8–7.8)
Smoking (n)	5	3	2
Euroscore	5.7 (3.0)	5.7 (2.8)	5.8 (3.3)
Planned procedure (n)			
CABG		2	3
VP		3	5
VS		2	1
RM		—	1
Combined CABG-VP/VS/RM		4	3
Combined VP/VS/RM		4	2

Data are mean (SD) values unless otherwise indicated. BMI, body mass index; BP, blood pressure; bpm, beats per minute; CABG, coronary artery bypass graft; RM, rhythm management; VP, valve procedure; VS, vascular surgery.
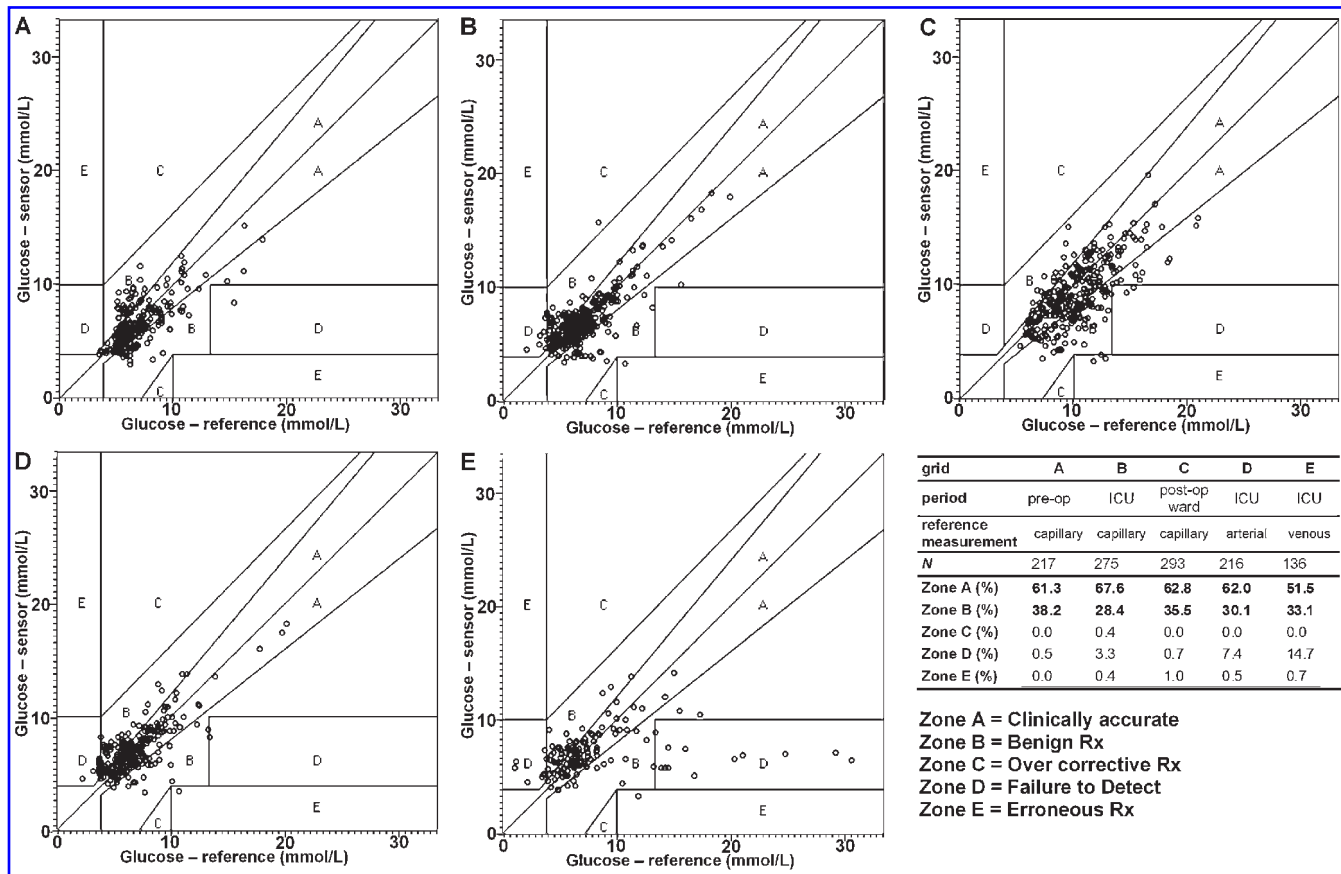[a]Median (interquartile range).

FIG. 2. Clarke Error Grids of glucose measurements. Each grid shows the comparison of sensor values on the *y*-axis with glucose values obtained with reference method on the *x*-axis: (**A**) capillary measurements in the preoperative period; (**B**) capillary measurements in the ICU period; (**C**) capillary measurements in the postoperative period on the ward; (**D**) arterial measurements in the ICU period; and (**E**) venous measurements in the ICU period.

Zone E represents sensor values that would trigger opposite treatment change than the reference value would. Comparison of sensor with arterial glucose measurements was less accurate, with 92.1% (*n* = 199) of comparison points in zones A and B. Comparison of sensor with venous glucose measurements was the least accurate, with 21 (15.4%) of comparison points outside zones A and B. Points in zones C–E were present in 24 subjects, ranging from one to six points per subject.

RT-CGMS: glucose control

Preoperative period. Mean glucose as measured with the sensor in the preoperative period was 6.5 ± 2.0 mmol/L in the Alarm group and 6.2 ± 0.9 mmol/L in the Blind group (*P* = 0.51). Mean capillary glucose was 6.8 ± 1.0 mmol/L in the Alarm group and 7.2 ± 1.6 mmol/L in the Blind group (*P* = 0.47). Figure 3a shows time in glucose ranges for both groups in the preoperative period. Time spent in euglycemia (4.0–10.0 mmol/L) was 97.2% (88.7–100.0%) in the Alarm group and 97.2% (82.8–100.0%) in the Blind group (*P* = 0.71). Exclusion of patients known with diabetes before admission did not change outcome (data not shown). During this period, only six alarms (two "High") occurred, in three subjects. On average, the same number of capillary measurements was performed in the preoperative period (Alarm group, 8.5 ± 1.2; Blind group, 9.3 ± 2.4; *P* = 0.31).

Postoperative period. Mean sensor glucose on the ICU was 6.5 ± 0.8 mmol/L in the Alarm group and 7.7 ± 1.5 mmol/L in the Blind group (*P* = 0.015). When patients with pre-admission diabetes were excluded, this difference was not statistically significant (Alarm group, 6.5 ± 0.9 mmol/L; Blind group, 7.4 ± 1.5 mmol/L; *P* = 0.08). Mean capillary glucose was 6.7 ± 0.8 mmol/L in the Alarm group and 7.5 ± 1.7 mmol/L in the Blind group (*P* = 0.11; all subjects included). Neither arterial nor venous measurements differed between groups (either with or without pre-admission diabetes patients included). Median time in target glucose range (4.4–6.1 mmol/L) was 34.8% (17.1–63.2%) and 20.2% (3.2–38.0%) in the Alarm group and in the Blind group, respectively (*P* = 0.27). Overall, percentage of time spent in the different glucose ranges did not differ significantly (Fig. 3b).

Mean sensor glucose on the ward was 8.6 ± 1.7 mmol/L in the Alarm group and 9.5 ± 1.7 mmol/L in the Blind group (*P* = 0.21). Time in euglycemia was 81.6% (55.4–96.9%) and 61.2% (30.7–86.3%) in the Alarm group and Blind group, respectively (*P* = 0.15). Overall, the percentage of time spent in the different glucose ranges did not differ significantly (Fig. 3c). Exclusion of pre-admission diabetes patients did not change outcome (data not shown).

In the postoperative phase, 104 alarms occurred (90 "High"). Interestingly, the number of reference measurements performed per hour was not statistically different be-
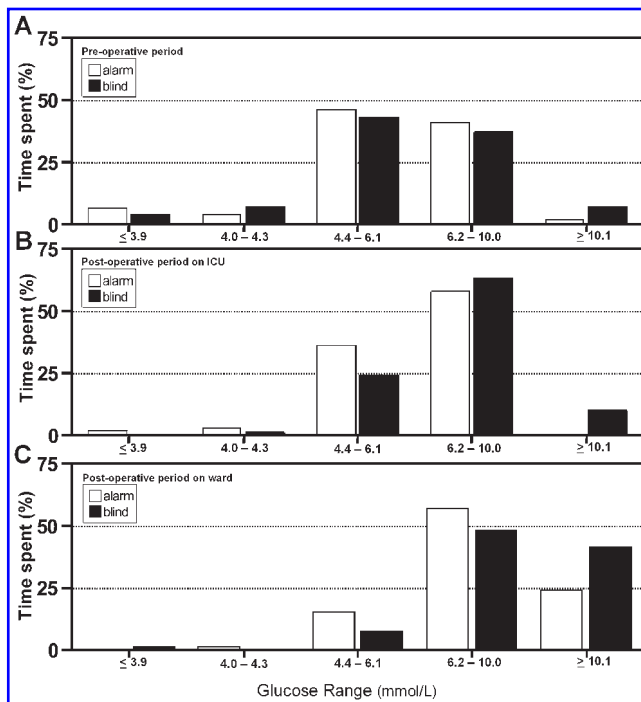
FIG. 3. Comparison of percentage of time spent in different glucose ranges during the three different study periods for both groups (white columns = alarm group; black columns = blind group): (**A**) preoperative period; (**B**) postoperative period on the ICU; and (**C**) postoperative period on the ward.

tween groups. During the ICU period, a median of 0.42 (0.37–0.48) capillary and 0.30 (0.27–0.42) arterial measurements per hour were performed in the Alarm group and 0.42 (0.36–0.44) capillary and 0.31 (0.26–0.43) arterial measurements in the Blind group (P = 0.88 and P = 1.00, respectively).

During the postoperative period of the study on the ward a median of 0.48 (0.44–0.56) capillary measurements per hour were performed per patient in the Alarm group, as compared to 0.41 (0.39–0.74) in the Blind group (P = 0.41).

Conclusions

RT-CGMS proved to be safe regarding local complications or adverse events and is accurate when compared with capillary reference values, based on accepted measures of accuracy. However, when arterial or venous glucose measurements are used as reference, accuracy is only borderline acceptable or not acceptable, respectively. The alarm function of the RT-CGMS, as used in this pilot study, had no additional effect on glycemic control.

Our results are in line with previous reported accuracy rate of CGMS; Garg et al.[6] reported 96% in Clarke Error Grid zones A and B, and Guerci et al.[18] reported even 98.8% in the acceptable zones. Our median RAD ranged from 12.3% to 14.6%. Piper et al.[9] reported a mean RAD of 17.6% in their report about the use of RT-CGMS in pediatric critical ill patients after surgery using arterial glucose values for calibration, and others also found comparable RADs.[4,18] To date, there is no uniform upper limit of acceptable deviation for

these devices, and interpretation of reported accuracy differs. Some apply the American Diabetes Association requirements for home blood glucose meters (all measurements within 5% of the reference value)[19] and conclude that accuracy is too low.[18] Others regard 15% as acceptable accuracy.[6]

In our opinion, sensor readings in the ICU setting need to be more accurate than the Clarke Error Grid currently requires, because the intended glucose target range is narrower than in ambulatory patients. Moreover, from a safety point of view, the occurrence of sensor readings in zones C, D, and E is not acceptable, and one can even argue (as De Block et al.[20] did) that points in zone B, indicating more than 20% deviation from the reference value, are also not acceptable for ICU standards.

Overall, median time in target glucose range on the ICU was 22.8%, which is in accordance with previous published data regarding glucose control on the ICU.[20,21]

The lack of difference in the number of capillary measurements between groups could be due to the relatively high number of scheduled measurements by protocol, but could also be one of the reasons for not finding an effect of the alarm function on glucose control, i.e., alarms did not elicit the required actions and reactions.

There are some limitations to our study. We used capillary measurements to calibrate the RT-CGMS throughout the study. This could have influenced the reported accuracy of the sensor compared to arterial and venous references measurements on the ICU. As can be deduced from Figure 2D, points in zone D of the Clarke Error Grid are close to the border with zone B, and one can speculate that when calibration would have been done using arterial glucose values, at least some of these points would fall in zone A or B, adding to the accuracy.

Regarding the effect on outcome, we would like to emphasize that our study was not powered to detect a pre-specified difference, but was only explorative. Furthermore, it is possible that the applied alarm setting was too wide. However, setting alarms at a narrower target might have resulted in too many unnecessary alarms whereby nurses' workload and the burden for patients would become unacceptably high. Furthermore, it was possible, because of the alarms not being very loud, that alarms were missed when patients moved around freely on the ward or were masked by other alarms and sounds on the ICU. This could have led to a delay in action. Second, although a strict glucose protocol was used at our ICU, we noticed that blood glucose levels slightly above the target range were accepted by the ICU staff and that nurses and physicians were not eager to initiate insulin therapy on the ward in the postoperative period in patients without pre-admission diabetes. On the ward, higher blood glucose values were accepted, which meant that, even when a "High" sensor value was confirmed by the reference glucose, no action was taken (or at least not immediately). Our pilot study was not intended to interfere with the current glucose protocols and insulin treatment regimens on the ICU and the ward, and therefore therapy adjustments on the ward were taken after the nurse consulted with the attending physician. This may also have affected the outcome of the study, since no proper action was taken to initiate ore alter insulin dosage after every sensor alarm all the time.

We did not measure any severely hypoglycemic glucose values. This might suggest that the fear of hazardous hypoglycemia during efforts directed towards strict metabolic control is not supported by clinical reality. In a similar patient population, Schmeltz et al.[22] reported 1.2% of glucose values <3.3 mmol/L without any episode being considered severe. Because of the limited number of blood glucose values in that range, we cannot provide a definite conclusion about the performance of the sensor in the hypoglycemic range.

We conclude that RT-CGMS can be used safely in the perioperative setting. However, with the attitude within our clinic towards perioperative glucose control, use of the RT-CGMS with alarm function, as used in this study, does not have a different effect than standard glucose monitoring on the ICU or on the medium care ward in the postoperative period. Therefore, introducing RT-CGMS does not add towards a further improvement of proper glucose control, at least not when only used as a registry device, without promptly and aggressively adapting the insulin regimen. Combining RT-CGMS with automated adjustments of insulin and/or glucose administration might change this conclusion. Nevertheless, in our opinion even the small amount of discrepant measurements outside the ranges set will impede, if not prevent, the introduction of such a computed-guided combination. Furthermore, the method of calibrating such devices is of utmost importance, and we would want to highlight its effect on accuracy and propose a head-to-head comparison of a capillary-calibrated RT-CGMS with an arterial-calibrated RT-CGMS.

Acknowledgments

Author Disclosure Statement

There are no competing financial interests.

References

1. Van den Berghe G, Wouters P, Weekers F, Verwaest C, Bruyninckx F, Schetz M, Vlasselaers D, Ferdinande P, Lauwers P, Bouillon R: Intensive insulin therapy in critically ill patients. N Engl J Med 2001;345:1359–1367.
2. Meijering S, Corstjens AM, Tulleken JE, Meertens JH, Zijlstra JG, Ligtenberg JJ: Towards a feasible algorithm for tight glycaemic control in critically ill patients: a systematic review of the literature. Crit Care 2006;10:R19.
3. Klonoff DC: Continuous glucose monitoring: roadmap for 21st century diabetes therapy. Diabetes Care 2005;28:1231–1239.
4. Goldberg PA, Siegel MD, Russell RR, Sherwin RS, Halickman JI, Cooper DA, Dziura JD, Inzucchi SE: Experience with the continuous glucose monitoring system in a medical intensive care unit. Diabetes Technol Ther 2004;6:339–347.
5. Bode B, Gross K, Rikalo N, Schwartz S, Wahl T, Page C, Gross T, Mastrototaro J: Alarms based on real-time sensor glucose values alert patients to hypo- and hyperglycemia: the Guardian continuous monitoring system. Diabetes Technol Ther 2004;6:105–113.
6. Garg SK, Schwartz S, Edelman SV: Improved glucose excursions using an implantable real-time continuous glucose sensor in adults with type 1 diabetes. Diabetes Care 2004;27:734–738.
7. Chase HP, Beck R, Tamborlane W, Buckingham B, Mauras N, Tsalikian E, Wysocki T, Weinzimer S, Kollman C, Ruedy K, Xing D: A randomized multicenter trial comparing the GlucoWatch Biographer with standard glucose monitoring in children with type 1 diabetes. Diabetes Care 2005;28:1101–1106.
8. Deiss D, Bolinder J, Riveline JP, Battelino T, Bosi E, Tubiana-Rufi N, Kerr D, Phillip M: Improved glycemic control in poorly controlled patients with type 1 diabetes using real-time continuous glucose monitoring. Diabetes Care 2006;29:2730–2732.
9. Piper HG, Alexander JL, Shukla A, Pigula F, Costello JM, Laussen PC, Jaksic T, Agus MS: Real-time continuous glucose monitoring in pediatric patients during and after cardiac surgery. Pediatrics 2006;118:1176–1184.
10. Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R: European System for Cardiac Operative Risk Evaluation (EuroSCORE). Eur J Cardiothorac Surg 1999;16:9–13.
11. Karon BS, Gandhi GY, Nuttall GA, Bryant SC, Schaff HV, McMahon MM, Santrach PJ: Accuracy of Roche Accu-Chek Inform whole blood capillary, arterial, and venous glucose values in patients receiving intensive intravenous insulin therapy after cardiac surgery. Am J Clin Pathol 2007;127:919–926.
12. Meex C, Poncin J, Chapelle JP, Cavalier E: Analytical validation of the new plasma calibrated Accu-Chek Test Strips (Roche Diagnostics). Clin Chem Lab Med 2006;44:1376–1378.
13. Clarke WL, Cox D, Gonder-Frederick LA, Carter W, Pohl SL: Evaluating clinical accuracy of systems for self-monitoring of blood glucose. Diabetes Care 1987;10:622–628.
14. Clarke WL: The original Clarke Error Grid Analysis (EGA). Diabetes Technol Ther 2005;7:776–779.
15. Gross TM, Bode BW, Einhorn D, Kayne DM, Reed JH, White NH, Mastrototaro JJ: Performance evaluation of the MiniMed continuous glucose monitoring system during patient home use. Diabetes Technol Ther 2000;2:49–56.
16. Kollman C, Wilson DM, Wysocki T, Tamborlane WV, Beck RW; Diabetes Research in Children Network Study Group: Limitations of statistical measures of error in assessing the accuracy of continuous glucose sensors. Diabetes Technol Ther 2005;7:665–672.
17. Moher D, Schulz KF, Altman DG: The CONSORT statement: revised recommendations for improving the quality of reports of parallel-group randomized trials. Lancet 2001;357:1191–1194.
18. Guerci B, Floriot M, Bôhme P, Durain D, Benichou M, Jellimann S, Drouin P: Clinical performance of CGMS in type 1 diabetic patients treated by continuous subcutaneous insulin infusion using insulin analogs. Diabetes Care 2003;26:582–589.
19. American Diabetes Association: Consensus statement on self-monitoring of blood glucose. Diabetes Care 1996;19(Suppl):S62–S66.
20. De Block C, Manuel-Y-Keenoy B, Van Gaal L, Rogiers P: Intensive insulin therapy in the intensive care unit: assessment by continuous glucose monitoring. Diabetes Care 2006;29:1750–1756.

21. Shulman R, Finney SJ, O'Sullivan C, Glynne PA, Greene R: Tight glycaemic control: a prospective observational study of a computerised decision-supported intensive insulin therapy protocol. Crit Care 2007;11:R75.

22. Schmeltz LR, DeSantis AJ, Thiyagarajan V, Schmidt K, O'Shea-Mahler E, Johnson D, Henske J, McCarthy PM, Gleason TG, McGee EC, Molitch ME: Reduction of surgical mortality and morbidity in diabetic patients undergoing cardiac surgery with a combined intravenous and subcutaneous insulin glucose management strategy. Diabetes Care 2007;30:823–828.

Address requests for reprint to:
Susan J. Logtenberg, M.D.
Diabetes Centre
Isala Clinics
P.O. Box 10400
8000 G.K. Zwolle, The Netherlands

E-mail: s.j.j.logtenberg@isala.nl

This article has been cited by:

1. M. Citlalli Perez-Guzman, Trisha Shang, Jennifer Y. Zhang, Donna Jornsay, David C. Klonoff. 2021. Continuous Glucose Monitoring in the Hospital. *Endocrinology and Metabolism* **36**:2, 240-255. [Crossref]

2. Rodolfo J. Galindo, Guillermo E. Umpierrez, Robert J. Rushakoff, Ananda Basu, Suzanne Lohnes, James H. Nichols, Elias K. Spanakis, Juan Espinoza, Nadine E. Palermo, Dessa Garnett Awadjie, Leigh Bak, Bruce Buckingham, Curtiss B. Cook, Guido Freckmann, Lutz Heinemann, Roman Hovorka, Nestoras Mathioudakis, Tonya Newman, David N. O'Neal, Michaela Rickert, David B. Sacks, Jane Jeffrie Seley, Amisha Wallia, Trisha Shang, Jennifer Y. Zhang, Julia Han, David C. Klonoff. 2020. Continuous Glucose Monitors and Automated Insulin Dosing Systems in the Hospital Consensus Guideline. *Journal of Diabetes Science and Technology* **14**:6, 1035-1064. [Crossref]

3. Georgia M. Davis, Rodolfo J. Galindo, Alexandra L. Migdal, Guillermo E. Umpierrez. 2020. Diabetes Technology in the Inpatient Setting for Management of Hyperglycemia. *Endocrinology and Metabolism Clinics of North America* **49**:1, 79-93. [Crossref]

4. Medha Satyarengga, Tariq Siddiqui, Elias K. Spanakis. 2018. Designing the Glucose Telemetry for Hospital Management: From Bedside to the Nursing Station. *Current Diabetes Reports* **18**:10. . [Crossref]

5. Guillermo E. Umpierrez, David C. Klonoff. 2018. Diabetes Technology Update: Use of Insulin Pumps and Continuous Glucose Monitoring in the Hospital. *Diabetes Care* **41**:8, 1579-1589. [Crossref]

6. David L. Levitt, Kristi D. Silver, Elias K. Spanakis. 2017. Inpatient Continuous Glucose Monitoring and Glycemic Outcomes. *Journal of Diabetes Science and Technology* **11**:5, 1028-1035. [Crossref]

7. In-Kyung Song, Ji-Hyun Lee, Joo-Eun Kang, Yang-Hyo Park, Hee-Soo Kim, Jin-Tae Kim. 2017. Continuous glucose monitoring system in the operating room and intensive care unit: any difference according to measurement sites?. *Journal of Clinical Monitoring and Computing* **31**:1, 187-194. [Crossref]

8. Federico Bilotta, Elisabetta Stazi. Blood Glucose Concentration Management in Neuro-Patients 239-247. [Crossref]

9. De Block Christophe E.M., Gios Jens, Verheyen Nina, Manuel-y-Keenoy Begoña, Rogiers Peter, Jorens Philippe G., Scuffi Cosimo, Van Gaal Luc F.. 2015. Randomized Evaluation of Glycemic Control in the Medical Intensive Care Unit Using Real-Time Continuous Glucose Monitoring (REGIMEN Trial). *Diabetes Technology & Therapeutics* **17**:12, 889-898. [Abstract] [Full Text] [PDF] [PDF Plus]

10. Roosmarijn TM van Hooijdonk, Jan Hendrik Leopold, Tineke Winters, Jan M Binnekade, Nicole P Juffermans, Janneke Horn, Johan C Fischer, Edmée C van Dongen-Lases, Marcus J Schultz. 2015. Point accuracy and reliability of an interstitial continuous glucose-monitoring device in critically ill patients: a prospective study. *Critical Care* **19**:1. . [Crossref]

11. D. Ballesteros, Ó. Martínez, R. Blancas Gómez-Casero, C. Martín Parra, B. López Matamala, B. Estébanez, M. Chana. 2015. Continuous tissue glucose monitoring correlates with measurement of intermittent capillary glucose in patients with distributive shock. *Medicina Intensiva* **39**:7, 405-411. [Crossref]

12. D. Ballesteros, Ó. Martínez, R. Blancas Gómez-Casero, C. Martín Parra, B. López Matamala, B. Estébanez, M. Chana. 2015. Continuous tissue glucose monitoring correlates with measurement of intermittent capillary glucose in patients with distributive shock. *Medicina Intensiva (English Edition)* **39**:7, 405-411. [Crossref]

13. Jeffrey I Joseph, Marc C. Torjman, Paul J. Strasma. 2015. Vascular Glucose Sensor Symposium. *Journal of Diabetes Science and Technology* **9**:4, 725-738. [Crossref]

14. Marjolein K. Sechterberger, Peter H. J. van der Voort, Paul J. Strasma, J. Hans DeVries. 2015. Accuracy of Intra-arterial and Subcutaneous Continuous Glucose Monitoring in Postoperative Cardiac Surgery Patients in the ICU. *Journal of Diabetes Science and Technology* **9**:3, 663-667. [Crossref]

15. Mikhail Kosiborod, Rebecca K Gottlieb, Julie A Sekella, Diane Peterman, Anna Grodzinsky, Paul Kennedy, Michael A Borkon. 2014. Performance of the Medtronic Sentrino continuous glucose management (CGM) system in the cardiac intensive care unit. *BMJ Open Diabetes Research & Care* **2**:1, e000037. [Crossref]

16. Iveta Poljakova, Eva Elsikova, Rudolf Chlup, Stanislav Kalabus, Petr Hasala, Jana Zapletalova. 2013. Glucose sensing module - is it time to integrate it into real-time perioperative monitoring? An observational pilot study with subcutaneous sensors. *Biomedical Papers* **157**:4, 346-357. [Crossref]

17. Yenny Leal, Magda Ruiz, Carol Lorencio, Jorge Bondia, Luis Mujica, Josep Vehi. 2013. Principal component analysis in combination with case-based reasoning for detecting therapeutically correct and incorrect measurements in continuous glucose monitoring systems. *Biomedical Signal Processing and Control* **8**:6, 603-614. [Crossref]

18. Sarah E. Siegelaar, Temo Barwari, Jeroen Hermanides, Peter H.J. van der Voort, Joost B.L. Hoekstra, J. Hans DeVries. 2013. Microcirculation and its relation to continuous subcutaneous glucose sensor accuracy in cardiac surgery patients in the intensive care unit. *The Journal of Thoracic and Cardiovascular Surgery* **146**:5, 1283-1289. [Crossref]

19. Kathleen Dungan, Kari Graessle, Colleen Sagrilla. 2013. The Effect of Congestive Heart Failure on Sensor Accuracy Among Hospitalized Patients with Type 2 Diabetes. *Diabetes Technology & Therapeutics* **15**:10, 817-824. [Abstract] [Full Text] [PDF] [PDF Plus]

20. A V Dreval', O A Dreval', E G Starostina. 2013. Continuous monitoring blood glucose level in clinical practice and new methods for its analysis. *Problems of Endocrinology* **59**:4, 41-49. [Crossref]

21. Xiao-Yan Yue, Yi Zheng, Ye-Hua Cai, Ning-Ning Yin, Jian-Xin Zhou. 2013. Real-Time Continuous Glucose Monitoring Shows High Accuracy within 6 Hours after Sensor Calibration: A Prospective Study. *PLoS ONE* **8**:3, e60070. [Crossref]

22. Baraka Floyd, Prakash Chandra, Stephanie Hall, Christopher Phillips, Ernest Alema-Mensah, Gregory Strayhorn, Elizabeth O. Ofili, Guillermo E. Umpierrez. 2012. Comparative Analysis of the Efficacy of Continuous Glucose Monitoring and Self-Monitoring of Blood Glucose in Type 1 Diabetes Mellitus. *Journal of Diabetes Science and Technology* **6**:5, 1094-1102. [Crossref]

23. Fausto Lucarelli, Francesco Ricci, Felice Caprio, Francesco Valgimigli, Cosimo Scuffi, Danila Moscone, Giuseppe Palleschi. 2012. GlucoMen Day Continuous Glucose Monitoring System: A Screening for Enzymatic and Electrochemical Interferents. *Journal of Diabetes Science and Technology* **6**:5, 1172-1181. [Crossref]

24. Carol Lorencio, Yenny Leal, Alfonso Bonet, Jorge Bondia, Cesar C. Palerm, Abdo Tache, Josep-Maria Sirvent, Josep Vehi. 2012. Real-Time Continuous Glucose Monitoring in an Intensive Care Unit: Better Accuracy in Patients with Septic Shock. *Diabetes Technology & Therapeutics* **14**:7, 568-575. [Abstract] [Full Text] [PDF] [PDF Plus]

25. Julia K. Mader, Franz Feichtner, Gerlies Bock, Gerd Köhler, Roland Schaller, Johannes Plank, Thomas R. Pieber, Martin Ellmerer. 2012. Microdialysis—A versatile technology to perform metabolic monitoring in diabetes and critically ill patients. *Diabetes Research and Clinical Practice* **97**:1, 112-118. [Crossref]

26. Kathleen M. Dungan, Wen Han, Anthony Miele, Trisha Zeidan, Karen Weiland. 2012. Determinants of the Accuracy of Continuous Glucose Monitoring in Non-Critically Ill Patients with Heart Failure or Severe Hyperglycemia. *Journal of Diabetes Science and Technology* **6**:4, 884-891. [Crossref]

27. Boaz Kalmovich, Yosefa Bar-Dayan, Mona Boaz, Julio Wainstein. 2012. Continuous Glucose Monitoring in Patients Undergoing Cardiac Surgery. *Diabetes Technology & Therapeutics* **14**:3, 232-238. [Abstract] [Full Text] [PDF] [PDF Plus]

28. Soo J. Howell. 2012. Achieving Tight Glycemic Control With New Technology. *Dimensions of Critical Care Nursing* **31**:6, 322-329. [Crossref]

29. M.Sol Ruiz-de-Adana, M.Elena Domínguez-Lopez, Alberto Machado, Natalia Colomo, M. Teresa Anarte, Federico C-Soriguer. 2011. La monitorización continua de glucosa a tiempo real y los servicios nacionales de salud. ¿Hay suficiente evidencia científica para justificar su financiación pública?. *Avances en Diabetología* **27**:6, 204-214. [Crossref]

30. Sarah E. Siegelaar, Joost B.L. Hoekstra, J. Hans DeVries. 2011. Special considerations for the diabetic patient in the ICU; targets for treatment and risks of hypoglycaemia. *Best Practice & Research Clinical Endocrinology & Metabolism* **25**:5, 825-834. [Crossref]

31. J. Hermanides, M. Phillip, J. H. DeVries. 2011. Current Application of Continuous Glucose Monitoring in the Treatment of Diabetes: Pros and cons. *Diabetes Care* **34**:Supplement_2, S197-S201. [Crossref]

32. Jonathan A. Lipton, Rogier J. Barendse, Arend F.L. Schinkel, K. Martijn Akkerhuis, Maarten L. Simoons, Eric J.G. Sijbrands. 2011. Impact of an Alerting Clinical Decision Support System for Glucose Control on Protocol Compliance and Glycemic Control in the Intensive Cardiac Care Unit. *Diabetes Technology & Therapeutics* **13**:3, 343-349. [Abstract] [Full Text] [PDF] [PDF Plus]

33. S. E. Siegelaar, T. Barwari, J. Hermanides, W. Stooker, P. H. J. van der Voort, J. H. DeVries. 2011. Accuracy and Reliability of Continuous Glucose Monitoring in the Intensive Care Unit: A Head-to-Head Comparison of Two Subcutaneous Glucose Sensors in Cardiac Surgery Patients. *Diabetes Care* **34**:3, e31-e31. [Crossref]

34. Jeffrey I. Joseph, Brian Hipszer. 2010. Real-Time Glucose Monitoring in the Hospital: Future or Now?. *Advances in Surgery* **44**:1, 165-184. [Crossref]

35. Jonathan A. Lipton, Rogier J. Barendse, K. Martijn Akkerhuis, Arend F. L. Schinkel, Maarten L. Simoons. 2010. Evaluation of a Clinical Decision Support System for Glucose Control. *Critical Pathways in Cardiology: A Journal of Evidence-Based Medicine* **9**:3, 140-147. [Crossref]

36. Francesco Valgimigli, Fausto Lucarelli, Cosimo Scuffi, Sara Morandi, Iolanda Sposato. 2010. Evaluating the Clinical Accuracy of GlucoMen®Day: A Novel Microdialysis-Based Continuous Glucose Monitor. *Journal of Diabetes Science and Technology* **4**:5, 1182-1192. [Crossref]

37. Jeroen Hermanides, Annemarie E. Engström, Iris M.E. Wentholt, Krischan D. Sjauw, Joost B.L. Hoekstra, Jose P.S. Henriques, J. Hans DeVries. 2010. Sensor-Augmented Insulin Pump Therapy to Treat Hyperglycemia at the Coronary Care Unit: A Randomized Clinical Pilot Trial. *Diabetes Technology & Therapeutics* **12**:7, 537-542. [Abstract] [Full Text] [PDF] [PDF Plus] [Supplementary Material]

38. Thomas R. Campion, Lemuel R. Waitman, Addison K. May, Asli Ozdas, Nancy M. Lorenzi, Cynthia S. Gadd. 2010. Social, organizational, and contextual characteristics of clinical decision support systems for intensive insulin therapy: A literature review and case study. *International Journal of Medical Informatics* **79**:1, 31-43. [Crossref]

39. Jeffrey I Joseph, Brian Hipszer, Boris Mraovic, Inna Chervoneva, Mark Joseph, Zvi Grunwald. 2009. Clinical Need for Continuous Glucose Monitoring in the Hospital. *Journal of Diabetes Science and Technology* **3**:6, 1309-1318. [Crossref]

40. 2009. Current literature in diabetes. *Diabetes/Metabolism Research and Reviews* **25**:5, i-x. [Crossref]