A Continuous Glucose Monitoring System in Critical Cardiac Patients in the Intensive Care Unit

A Murakami[1,2], MA Gutierrez[1,2], SHG Lage[1], MFS Rebelo[1], RHG Guiraldelli[2], JAF Ramires[1]

[1] Heart Institute, University of Sao Paulo, Medical School, Sao Paulo, Brazil
[2] Polytechnic School, University of Sao Paulo, Sao Paulo, Brazil

Abstract

Some studies show that a tight glucose control appears to have clinical benefits for cardiac patients at Intensive Care Unit (ICU). However, it requires glucose readings every few hours in a tiresome operation.

In the present study, a real time glucose monitoring system was implemented to control critical cardiac patients at ICU. For this, a commercially available Holter-like glucose monitor was used. A PocketPC was connected to the glucose monitor, downloading the collected data every 5 min, so real time readings could be obtained. The readings were transmitted using the HL7 communication standard to an Electronic Patient Record and to a bedside monitor at the ICU in real-time.

These results have shown that the proposed methodology is a promising application to the ICU, providing a better treatment for critical cardiac patients.

1. Introduction

The association between diabetes mellitus and cardiopathies is very common, leading patients to a poor prognosis. Since the Diabetes Control and Complications Trial (DCCT), it is well known that a tight glucose control, i.e, keeping glycemia in a restricted normal range, is beneficial for diabetic outpatients [1]. Van den Berghe showed that the same procedure could reduce mortality between Intensive Care Unit (ICU) patients [2]. Though these works did not confirm the relationship between tight glucose control and cardiopathies, others give some evidences. Tight glucose control, according to the DIGAMI study group, reduces mortality between diabetic patients after a myocardial infarction [3]. Furnary et al. showed the reduction of the incidence of deep sternal wound infection after open heart surgery [4]. Despite of its benefits, implementing a tight glycemic control on an ICU patient requires glucose readings every few hours, along with insulin infusion rate adjustments, in a tiresome operation.

Due to the difficulties of the conventional methods, several new ways of continuously measuring glycemia has been studied in the last decades [5]. The research efforts generated a few commercially available glucose sensors, like the MiniMed CGMS (Medtronic Diabetes), GlucoWatch (Cygnus) and GlucoDay (A. Menarini). Still, there are several open issues, like accuracy, generation of real time readings, applicability at ICU and integration to hospital information systems.

In the present study, a real time glucose monitoring system for ICU patients, named as "vMonGluco", was implemented. For this purpose, a commercially available Holter-like glucose monitor was used. The readings were transmitted through a WiFi network using the Health Level Seven (HL7) communication protocol, a standard for integration of medical systems [6]. The collected information was stored in an Electronic Patient Record. They were also shown on a bedside monitor at the ICU, so the medical staff could easily access the glucose readings.

2. Methods

2.1. Real-time glucose readings

To produce the glucose readings the MiniMed Continuous Glucose Monitoring System (CGMS, Medtronic Diabetes) was used [7]. The MiniMed CGMS consists of a disposable subcutaneous glucose sensor, connected by a cable to a pager-sized glucose monitor.

The CGMS uses a glucose oxidase based platinum electrode, which produces an electrical current when in contact with glucose. This sensor is inserted under the skin, in contact with the interstitial fluid. The electrical current is linearly dependent upon the concentration of the glucose. Hence, by scaling the current with appropriate constants, an estimation of the glucose concentration can be determined. A linear regression calibration method is used to estimate these constants.

CGMS readings must be calibrated at least 4 times daily against standard capillary glucose measurements, which are used to retrospectively calibrate the sensor readings at the time of data analysis. Each sensor is meant to be worn for up to three days.

The sensor readings collected by CGMS must be downloaded into a PC at the end of using period. A MiniMed Com-Station, physically linked to the PC through a serial connection, acts as a docking station for CGMS to transfer the data to the PC. When initialized, MiniMed Solution Software V3.0C downloads the data stored onboard and applies a regression calibration algorithm, finally obtaining the glucose readings.

CGMS is approved for use in outpatients by the Food and Drug Administration (FDA), but it is not designed for producing real-time glucose information. The glucose data calibration, as performed by MiniMed's software, is a once off process, based on all the calibration points entered on the measuring period. To use CGMS in real-time, it is necessary to download the sensor readings every 5 min. Also, the calibration must be performed each time the monitor produces a new current value.

We implemented a software module into a PocketPC (HP/COMPAQ iPAQ) to address the two issues. The PocketPC is connected to the Com-Station through a serial cable (Figure 1). A software module, named as "vMonGluco Client", periodically downloads the data stored into the CGMS memory every 5 min. The data interpretation, i.e., the translation of the current generated at the electrode into blood glucose concentration is performed by vMonGluco. After data calibration, the glucose values are plotted in real-time at the PocketPC screen. The values are also parsed into a HL7 message and transmitted to a HL7 server.

Figure 1. MiniMed CGMS connected to the palmtop.

2.2. Integration to the electronic patient record

The HL7 messages, containing the glucose readings, are received by a HL7 server, named as "vMonGluco Server". The vMonGluco Server transmits the glucose readings to the bedside monitoring system using the HL7 protocol.

The bedside monitoring system is based on Siemens monitors (Siemens Medical Solutions), models SC7000 and SC6002XL, linked to a dedicated network. All communication between the dedicated monitoring network and the hospital network are performed through a gateway using HL7 messages.

The vMonGluco Server also stores the collected information into the Electronic Patient Record. The information can be easily accessed through a Web interface (Figure 2).

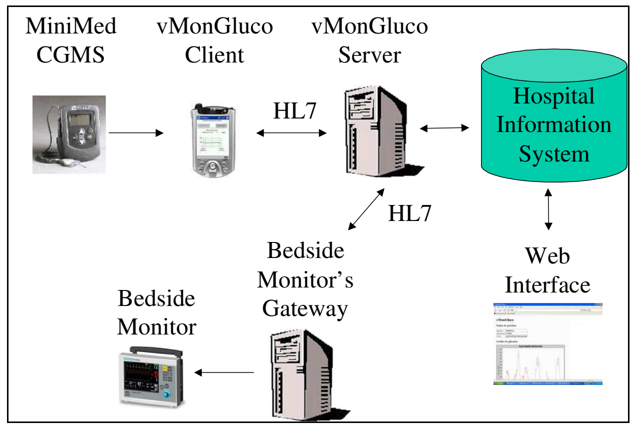

Figure 2. The vMonGluco architecture.

2.3. Accuracy tests on patients

To verify the accuracy of the glucose readings, 12 (twelve) hyperglycemic patients, with some kind of cardiopathy, were selected at the Heart Institute's clinical ICU to use the equipment for a few days. The patients had an average age of 70.6 ± 15.4 years. After consent was obtained, a glucose sensor was placed subcutaneously on the patient's abdomen or upper arm using a proper insertion device. The sensor was connected to the MiniMed CGMS monitor. One hour after the insertion a standard capillary glucose reading (fingerstick) was performed and the result was registered into the CGMS for calibration. Fingersticks were performed using the Accu-Check Advantage glucometer (Roche Diagnostics) every two hours. Every six hours, the CGMS was calibrated using a fingerstick reading.

To allow the periodic download of the sensor's data, the CGMS was mounted on the MiniMed Com-Station. A PocketPC computer, running the vMonGluco Client software, was connected to the MiniMed Com-Station. This way, real-time glucose readings were obtained

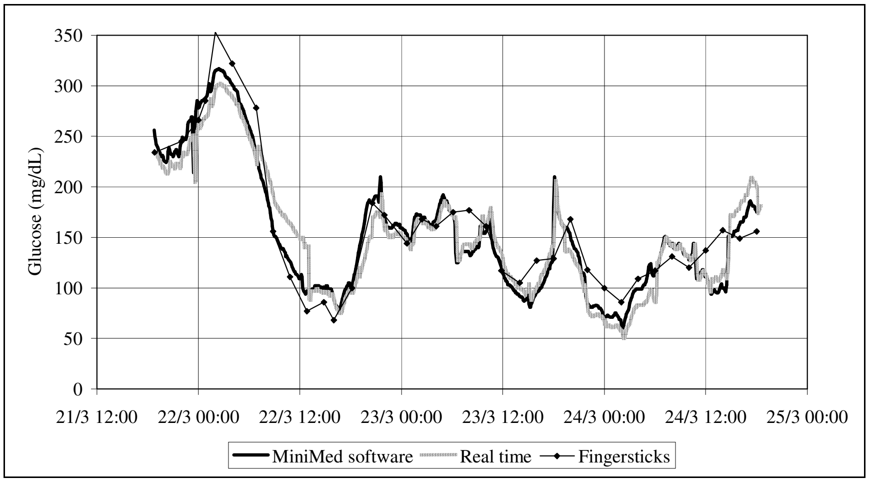

Figure 3. Glucose readings from one of the patients.

Following the data acquisition period, the values stored into the MiniMed CGMS were downloaded into a standard PC. In a retrospective way, the MiniMed Solutions Software (version 3.0C) generated glucose readings, which were compared to the fingersticks and to the real-time readings registered by vMonGluco software (Figure 3).

3. Results

Using the MiniMed as a "gold-standard", the difference between post-processing and vMonGluco readings (real-time) was -1.4 ± 23.5 (n=9,008). The correlation coefficient between the two types of measurements was r=0.92. Table 1 shows the complete statistics.

When comparing the vMonGluco readings (real-time) to the fingersticks, we obtained a difference of -13.8 ± 49.2 (n=318) and the correlation coefficient between the two types of measurements was r = 0.77 (Table 2).

The Clarke grid [8] was also used for the analysis. When comparing the MiniMed software readings to the fingersticks, the following results were obtained: zone A = 81.4%, B = 17.5%, C = 0%, D = 1.1%, E = 0%. For the real time readings, the results were: zone A = 66.5%, B = 31.8%, C = 0%, D = 1.1%, E = 0.6%.

Table 1. Comparison between MiniMed software readings and vMonGluco (correlation coefficient r = 0.92).

Range	N	MiniMed average	vMonGluco average	Difference	Difference (%)	Absolute Difference
< 100 mg/dL	1,125	81.9	88.1	6.1 ± 17.6	9.2 ± 26.2	13.9
100 - 149 mg/dL	3,495	126.3	128.1	1.8 ± 17.9	1.3 ± 13.9	12.1
150 - 199 mg/dL	2,599	170.4	168.2	-2.2 ± 21.2	-1.3 ± 12.3	14.0
200 - 249 mg/dL	1,041	222.3	213.0	-9.3 ± 34.5	-4.1 ± 15.6	22.6
>= 250 mg/dL	748	298.0	284.2	-13.9 ± 33.3	-4.8 ± 11.2	22.6
Total	**9,008**	**158.8**	**157.4**	**-1.4 ± 23.5**	**0.4 ± 16.1**	**15.0**

Table 2. Comparison between real time readings and fingersticks (correlation coefficient r = 0. 77).

Range	N	Fingersticks average	vMonGluco average	Difference	Difference (%)	Absolute Difference
< 100 mg/dL	45	82.0	103.0	21.0 ± 27.4	35.6 ± 61.1	27.1
100 - 149 mg/dL	95	123.1	124.0	0.9 ± 28.5	1.2 ± 23.2	21.6
150 - 199 mg/dL	87	170.9	158.5	-12.4 ± 33.0	-7.0 ± 19.5	25.1
200 - 249 mg/dL	52	219.6	197.5	-22.1 ± 42.4	-10.0 ± 19.5	36.1
>= 250 mg/dL	39	328.8	247.4	-81.5 ± 74.2	-23.8 ± 19.8	85.0
Total	**318**	**171.4**	**157.6**	**-13.8 ± 49.2**	**-1.1 ± 34.4**	**33.5**

4. Discussion and conclusions

The results obtained by the MiniMed software are comparable to the ones found in the literature [7,9]. As shown on Table 1 and 2, greater deviations can be found at low (< 100 mg/dL) and high (> 250 mg/dL) glucose values. As suggested by Goldberg et al. [9], this could be explained by fingersticks inaccuracy during hypoglicemia in hypotensive patients [10]. However, a larger study must be addressed for a more conclusive analysis.

The results of the vMonGluco, the proposed real-time method are similar (r=0.92) to the ones obtained by post-processing using MiniMed software. The Clarke grid analysis result (98.3% of the readings in zones A an B) suggests that the real-time glucose readings are clinically meaningful and, thus, a promising tool at the ICU work, especially when used together with other glucose measuring methods.

The implemented vMonGluco architecture offers a reasonable solution for fast communication and storage of the generated information. The use of a standard communication protocol, such as HL7, allowed an easy integration to prior existing systems.

In conclusion, the results suggest that the proposed methodology is a promising application at the ICU, providing a better treatment for critical cardiac patients.

Acknowledgements

This work was partially supported by the National Council for Scientific and Technological Development (CNPq), grants 471143/2001-4 and 303664/2002-9, and Zerbini Foundation. This project would not be possible without Medtronic Diabetes support, offering CGMS monitors, sensors, software, and standard hospital glucose meters. The authors are especially grateful to Medtronic group based in Brazil. The authors wish to thank the medical and nursing staff at the Heart Institute's ICU for their assistance. The whole IT team at the Heart Institute has contributed in different ways, and the authors are thankful to them.

References

[1] The Diabetes Control and Complications Trial Research Group. The Effect of Intensive Treatment of Diabetes on the Development and Progression of Long-Term Complications in Insulin-Dependent Diabetes Mellitus. The New England Journal of Medicine 1993;329(14):977-86.

[2] Van den Berghe G. How does blood glucose control with insulin save lives in intensive care? The Journal of Clinical Investigation 2004;114(9):1187-95.

[3] Malmberg K. Prospective randomised study of intensive insulin treatment on long term survival after myocardial infarction in patients with diabetes mellitus. British Medical Journal 1997;314:1512.

[4] Furnary AP, Zerr KJ, Grunkemeier GL, Starr A. Continuous Intravenous Insulin Infusion Reduces the Incidence of Deep Sternal Wound Infection in Diabetic Patients after Cardiac Surgical Procedures. Annals of Thoracic Surgery 1999;67(2):352-62.

[5] Pickup J, McCartney L, Rollinsky O, Birch D. In vivo glucose sensing for diabetes management: progress towards non-invasive monitoring. British Medical Journal 1999;319(7220):1–4.

[6] Health Level Seven. Health Level Seven Implementation Support Guide for HL7 Standard Version 2.3. USA: Health Level Seven, 1998.

[7] 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 Technology and Therapeutics 2000;2(1):49-56.

[8] 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(5):622-28.

[9] Goldberg PA, Siegel MD, Russel 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 Technology and Therapeutics 2004; 6(3):339-347.

[10] Atkin SH, Dasmahapatra A, Jaker MA, Chorost MI, Reddy S. Fingerstick Glucose Determination in Shock. Annals of Internal Medicine 1991;114:1020-24.

Address for correspondence:

Marco Antonio Gutierrez
Av. Dr. Eneas de Carvalho Aguiar, 44
05403-900 – Sao Paulo – SP – Brazil
marco.gutierrez@incor.usp.br