Online monitoring system for emergency diabetes mellitus patients

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Abstract. In this research, an online monitoring system was designed to detect emergency due to uncontrolled blood glucose fluctuations in patients with diabetes mellitus. Hyperglycemia in the morning causes dawn phenomenon and Somogyi effect. This incident is very fast, and its uncontrollable time of occurrence can inflict a fatal condition causing death. Unfortunately, there are no systems able to detect such events, currently. This study proposes an online monitoring system with the input of the patient's blood glucose measurement into the smartphone. Blood glucose values are sent and stored in the webserver, and the results are used to determine the incidence of dawn phenomenon and the Somogyi effect. The study was able to produce an online monitoring system which can be monitored by nurses, doctors, and administrators via the dashboard.

1. Introduction

Diabetes mellitus is a serious health problem [1]. An estimated 30.3 million or 9.4% of people of all ages of the population in the United States was suffering from diabetes in 2015 [2]. Around the world, every seven seconds, a person dies due to the diabetes, approximately four million deaths every year [3,4]. The hyperglycemic crisis is one of the most serious complications in patients with diabetes mellitus [5,6]. The risk of death in diabetes mellitus varies greatly with age, glycemic control, and renal complications [7]. Uncontrolled blood glucose jeopardizes the body organs especially the nervous and cardiovascular systems [4]. The primary key preventing chronic complications is suppressing the rise in blood glucose, blood pressure, and lipids [8].

Hyperglycemia in the morning causes dawn phenomenon [9] when it is preceded by a hypoglycemia condition, it is called Somogyi effect [10]. Both conditions can result the patient's blood sugar instability if they are not monitored [11]. Blood glucose management is the best way to prevent disease progression. However, blood glucose monitoring as a prevention or cure for diabetes has not been widely developed [12,13].

Monitoring blood glucose levels was proved to prolong life expectancy by allowing diabetics controlling hypoglycemic episodes or hyperglycemia, thus it provides better control of their condition, and the diabetics can manage the condition of their hypoglycemia or hyperglycemia thereby it provides more control to prevent complications. Currently blood glucose monitoring involves the invasive method [10,14].
Management of diabetes mellitus uses a comprehensive approaches including medical care, psychosocial, lifestyle changes, education, continuous monitoring, and self-management [15,16]. Those targets cannot be achieved without the involvement of patients through diabetes self-care management for the diabetes mellitus treatment [17].

Diabetes self-care management is an important part of diabetes care. Some research showed diabetes self-care management improves life quality and prevents the severity of long-term diabetes complications [12]. However, self-management is a complex process. The patient is responsible for treating her illness, and requiring commitment, special skills, knowledge, and confidence. Diabetes self-care management is long life and complicated treatment, where patients need to adapt to new lifestyles, make decisions, and perform certain tasks [17]. The stability of blood glucose levels within normal limits is an important goal for the patient [18].

All this time, the monitoring of the dawn phenomenon and the Somogyi effect is very rare to be conducted. The invasive glucometer method makes it difficult for patients to measure blood glucose regularly. Routine blood glucose measurement using the invasive method is not recommended for all people with diabetes mellitus [19]. Unfortunately, blood glucose measurement of invasive methods cannot provide real-time information with data accessed by health personnel on a daily basis. The problem can be solved by regular, fast, and accurate monitoring for patients.

This paper proposes wireless area health technology from electronic medicine that is under the domain of telemedicine. This method is effective for improving communication between health care providers and patients with diabetes mellitus. Wireless technology can be used worldwide, and transmit the information about health [4].

System realizations
The built system consists of devices those are remote areas adjacent to the patient, and data station located in the cloud web service. The online system of emergency monitoring in patients with diabetes mellitus proposed in this paper is shown in Figure 1.

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![Diagram integration of dawn effect emergency online monitoring system.](image)

Blood glucose levels of patients with diabetes mellitus was measured using noninvasive method. Blood glucose value data was sent via smartphone to web service. There are three categories of data in each
patient, first, the demographic data include the patient's identity, age, body mass index, occupation, education. Second datum is blood glucose values before and after meals, accompanied by measurement time and normal range of blood glucose. This measurement is performed periodically at the time of a diabetic patient's crisis. Third datum is self-management education feedbacks matched suitable to the patient's condition. Web services receive data and save to web database. The measurement results are shown to the dashboard. Access rights holders to the website are patients, nurses, doctors and administrators. The nurse collaborates directly with the doctor and provides feedback on the received blood glucose result.

3. Results
Total of 83 diabetic patients were regularly monitored for three days using an online monitoring system. There were 67 patients that had dawn phenomenon, 6 patients had Somogyi effect, and 10 patients were died. The average speed of blood glucose data transfer from measurement to the graph in the smartphone is 15 seconds. The process of measuring blood glucose using smartphones and web services employed "my sugar" applications designed by researchers. Patient data input includes identity, body mass index, gender, education, employment and self-care management education was conducted to prevent the occurrence of diabetes mellitus emergency. In the measurements using non-invasive glucometer, the value of blood glucose is automatically appeared on the smartphone screen, and stored in the web database www.mysugar.cf in the form of numbers and graphs. This application was equipped with measurement time, normal range of blood glucose, and self-management education that can be given directly to the patient. The measurement system of dawn phenomenon and Somogyi effect using my sugar application can be seen in Figure 2.

![Figure 2](image.png)

**Figure 2.** Web-based graphic displays online monitoring system for diabetes mellitus patients.

Dawn phenomenon begins with an increase in blood glucose above the normal limit of 126 mg/dL [20], this condition is called hyperglycemia in the morning. Patient 1’s blood glucose value at midnight measurements reached 348 mg/dL, and patient 2’s blood glucose value reached 280 mg/dL, then in the
morning before meal, the blood glucose value for both patients were decreased but still above the normal value of 220 mg/dL and 171 mg/dL, while at noon and the afternoon, the values began to decline. This case occurred on the second day with blood glucose values of 241 mg/dl and 251 mg/dL higher than normal, day and afternoon began to decline near normal. The third day of measurement was also found 239 mg/dL and 279 mg/dL, so that both respondents experienced an increase in blood glucose or three days’ measurements.

Online monitoring system using noninvasive method to make fluctuations in blood glucose value can be monitored automatically whereas this phenomenon is not monitored properly, previously. Detection results of dawn phenomenon are shown in Figure 3.

![Figure 3. Dawn phenomenon warning detections.](image)

The second emergency condition is the Somogyi effect. The occurrence of Somogyi effect is different from the dawn phenomenon. It begins with a decrease in blood glucose levels below normal (70 mg/dL) [20]. Blood glucose value of patient 9 was at 40 mg/dL, increased to 190 mg/dL decreased to 70 mg/dL and increased again to 122 mg/dL, diminished to 74 mg/dL on the third day, and rose again to 204 mg/dL. This condition was observed for three days. It can be seen initial blood glucose value of Patient 6 was at 59 mg/dL then that is increased to 98 - 139 mg/dL, decreased again to 44, 49, 65 mg/dL on the second day, and fixed blood glucose value was fixed below the normal range then increased, and became on its normal limits on the third day. The use of an online monitoring emergency system is supporting the control of the patient's blood glucose fluctuations. The result of detection of Somogyi effect can be seen in figure 4.

![Figure 4. Somogyi effect warning detections.](image)
4. Discussion

Telemedicine is telecommunication to support health care. Telemedicine timely transmission and remote interpretation of the patient provide follow-up and preventive interventions. By using various forms of information technology such as internet, cell phone calls, short messaging services and television programs, the provision of care is more effective. The media used to distribute health care are mobile phones, digital diaries, computers, and laptops. Most of the electronic healthcare and telemedicine services provided in developed countries are based on the diagnosis and clinical management of chronic diseases [4].

In addition to medical feedback, patient satisfaction associated with tissue plays an important role in the management of blood glucose. Blood glucose monitoring based on smartphone applications becomes more effective, and it is important to serve patients with high-quality and well-functioning devices that can increase patient satisfaction and willingness to use them [21].

The use of online monitoring helps each patient to routinely measure their blood glucose four times a day without hurting the patient's fingers. This is in line with NICE Guideline [22]. Blood glucose monitoring results good glycemic improvement in patients with diabetes mellitus without increasing the risk of hypoglycemia, prevents cardiovascular risk, and improves life quality [23]. The ignorance to general self-care among patients with type 2 diabetes results severe complications [24].

Advantage of Online monitoring system in diabetes mellitus emergency is self-care based web service program that can be done easily, not injuring, and designed in such a way that diabetes patients can be trained independently using glucometer, with time automatically performed periodically in one day that is very comfortable. Diabetes mellitus patients is receiving intensive care with insulin performed self-monitoring appropriately that is significantly reduced the patient's blood glucose level [19,25]. Remote health monitoring for home-stay patients can reduce health care costs [26].

Advances in smartphone technology combined with data connectivity and web services in mobile applications support self-management of diabetes. The mobile application offers several advantages for patient upgrading, such as converting record book to an electronic system. Data stored on mobile devices can be sent by online to health care workers or diabetes educators [27].

The web-based blood glucose monitoring system facilitates the feedback of health care providers. Patients regularly monitor their glucose level, and upload the result data to the service website. The data is reviewed by a professional health team, which provides feedback on outcomes, offers encouragement, and recommends changes to patient monitoring practices, insulin administration, or diet [23,27].

Mobile devices can not only be employed to monitor health conditions, but also as patient interactive interfaces to communicate with nurses on how to deal with certain health or emergency situations. The provision of real-time data is of significantly benefit, especially to patients who have chronic conditions requiring attention, remote locations that are not accessible or disaster situations [26].

Mobile devices provide low cost, and efficient remote health monitoring through service provisioning mobile web approach. This method is more agile, flexible, and economical [26].

Web-based health monitoring allows faster data access. The privacy of patient data is maintained because each patient can only see the results of his own measurement. Web application is an independent platform compared to original mobile apps (like Android or iPhone application). Patients who have chronic conditions and require 24-hour monitoring [26].

Web-based applications support diabetes self-management and decisions (decisions support system), and functions as an electronic notebook, automated analysis, and device to predict glucose level based on the obtained data. This application is used to process large, complex data and provide feedback related to insulin dose and healthy behavior.

Web-based self-care management of diabetes patients research resulted that the smartphone applications provide moderate benefits for the management of type 2 diabetes mellitus. However, further studies with valid study designs and longer follow-up are required to evaluate the impact of effective mHealth applications for self-care management for diabetes mellitus patients. Web-based diabetes treatment strongly supports the self-management of patients with diabetes mellitus [28].
Smartphone interventions vary in approach to strengthen lifestyle changes, healthy diet, and physical exercise. These results indicate that mobile utilization leads to improved A1C and self-management in diabetes care [29]. Diabetes mellitus patients are advised to check glucose levels at least four to five times a day to avoid hyperglycemic/hypoglycemic. Glucose monitoring often plays an important role to improve the life quality [30]. Internet-based monitoring can provide long-term glycemic benefits. After 5 years of follow-up, patients in the Internet intervention group showed a mean decrease in HbA1c levels from 7.43% to 7.09% compared to 7.45% to 7.38% in the conventional care group [23].

Patients can read the results through a device connected to a telephone line transmitting all data to a special officer which analyzes in graphical, numerical and static formats with specific programs. Doctors can determine new therapies, previous therapy changes, or just check the same information. The usefulness of this system in the treatment of diabetes mellitus is to increase the information available for therapeutic adjustment, improve communication between patient and physician, improve the education and empower the patients, positive trend toward increased metabolic control, and blood glucose stability, especially in patients with diabetes mellitus [31].

Remote monitoring improves clinical outcomes, care coordination, and patient satisfaction, enabling patients to inform health care providers about glycemic control, and diabetes educators or other providers to monitor glucose test results, and to provide real patient feedback. This is the time to improve knowledge, self-efficacy, and behavioral change. The repetition of this physiological data collection and interpretation feedback combined with feedback to the patient enables a care plan modified by health care providers, and improved outcomes [32].

The effectiveness of web-based care programs in controlling diabetes were compared to regular care. There was a much greater decrease in HbA1c levels in persistent users compared to intermittent users among web-based treatment patients [33]. Other clinical outcomes also depend on patient compliance with telemonitoring [34].

The results show that conventional blood glucose measurement is less able to describe plasma glucose changes from high to low values characteristic of type 1 diabetes in children. Hyperglycemia Postprandial plays very important role in the development of vascular complications in diabetes. In contrast to methods non-invasive, continuous glucose monitoring for 3 consecutive nights provides a much more complete description of the blood glucose [35]. Periodic blood glucose measurement is the most useful method for evaluating glycemic variability in detail. Predicting glycemic variability in the morning before and after meals based on patient characteristics without frequent finger injury, this information can provide appropriate guidance in drug selection. [36] CGMS, a non-invasive method, is a useful tool for diagnosing asymptomatic nocturnal hypoglycemia [37].

Clinical studies show that hypoglycemia is strongly associated with death in diabetes mellitus patients. Nocturnal hypoglycemia is not only related to hyperglycemia during the day, but also increasing glucose levels in the morning. The relationship between glucose levels before and after breakfast and nocturnal hypoglycemia in patients with type 2 diabetes were studied. Reduction glucose levels before and after meals increased glycemic variability for 24 hours was performed by adjusting patient care to avoid nocturnal hypoglycemia. Knowledge of morning glycemic variability is important to increase glycemic variability for 24 hours. Measurement of blood glucose levels before and after breakfast is complicated for the patient. The non-invasive method predicts morning glycemic variability more easily. This method employs univariate and gradual (increasing and decreasing variable method) multivariate regression analysis. The p value (<0.05) was considered significant [36]. Nocturnal hypoglycemia often occurs in prolonged duration, related to glucose values before sleep (≤100 to 150 mg/dL), especially occurring in the early part of the night [37]. Research on the difference in intravenous blood glucose measurement is better than conventional in patients with critical conditions [38].

5. Conclusion
Blood glucose monitoring is an important component in the diabetes mellitus patient’s treatment. Online monitoring system for blood glucose measurement can detect the occurrence of blood glucose fluctuations in patients with diabetes mellitus. Online monitoring system monitoring model contributes
the early detection of emergency conditions due to dawn phenomenon and Somogyi effect in diabetes mellitus patients. The advantages of online monitoring system are a modality to support the patient's decision in real-time as an alarm for hypoglycemia or hyperglycemia, and an integrated device connected the patient monitoring system and health services, easy tools to use, wireless connectivity, and online recorded data.

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