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Development of a Web-Based Decision Support System for Insulin Self-Titration

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Abstract. Insulin is the most potent agent for the treatment of diabetes mellitus. However insulin treatment requires frequent evaluation of blood glucose levels and adjustment of the insulin dose. This process is called titration. To guide patients with type 2 diabetes using once-daily long-acting insulin, we have developed a web-based decision support system for insulin self-titration. The purpose of this paper is to provide an overview of the phases of development and the final design of the system. We reviewed the literature, consulted an expert panel, and conducted interviews with patients to elicit system requirements. This revealed four important aspects: the insulin titration algorithm, the handling of hypoglycemic events, telemedicine functionalities, and visiting frequency monitoring. We used these requirements to develop a fully functional system.

Keywords. Clinical decision support systems, telemedicine, self care, diabetes mellitus, insulin

1. Introduction

The prevalence of diabetes is increasing rapidly worldwide. The total number of people with diabetes is projected to rise from 171 million in 2000 to 366 million in 2030 [1]. Diabetes, a chronic metabolic disorder, is hallmarked by increased blood glucose levels. Serious long-term effects of high blood glucose levels are blindness, kidney failure and cardiovascular disease. The main therapies for treating diabetes are dietary adjustments, oral glucose-lowering drugs, and insulin. Insulin is the most potent agent in the therapeutic arsenal but it requires frequent evaluation of blood glucose levels and adjustment of the insulin dose, a process which is called titration. Current clinical pathways for supporting type 2 diabetes patients in their titration of insulin involve either frequent clinical visits or routine visits supplemented by frequent telephone calls or e-mail contact. Both options involve exchanging information about blood glucose results and providing advice on adjusting treatment, but they are also very time-consuming. Delivery of care between visits improves how fast the patient reaches good glycemic control and reduces the risk of exposure to a high glycemic burden for prolonged periods of time.

As internet access in patients' homes will continue to increase over the coming years, a web-based system to support self-management in insulin titration has the

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potential to reach a large number of patients at low cost. There already exist systems to guide patients with type 1 diabetes in calculating the optimal pre-meal short-acting insulin dose [2;3]. Existing systems for patients with type 2 diabetes mostly focus on providing weight management, physical activity and diet [4]. However, patients with type 2 diabetes initiating once daily insulin form a specific and relatively large patient group that also requires intensive titration of the insulin dose. They do not benefit from the systems for patients with type 1 diabetes because adjustment of long-acting insulin requires a different strategy than adjustment of short-acting insulin.

For this reason, we decided to develop a web-based system that facilitates the clinical process of providing insulin dosing advice to patients with type 2 diabetes using any once-daily long-acting insulin, the Patient Assisting Net-Based Diabetes Insulin Titration (PANDIT) system. Patients should be able to access the PANDIT system on a frequent basis to receive insulin dosing advice. In addition, the system should support communication between patients and caregivers, and provide caregivers the possibility to overrule the system's advice when they deem that this is necessary for safety reasons. PANDIT should also recognize potentially unsafe situations such as hypoglycemic events. The purpose of this paper is to provide an overview of the phases of development and the final design of the PANDIT system.

2. Methods

The first step of developing the PANDIT system was to elicit the system's requirements by reviewing the literature, by consulting an expert panel, and by interviewing patients. We searched the literature using the following MeSH terms: "clinical decision support systems" OR "telemedicine" AND "diabetes mellitus" AND "insulin" to provide us with an up-to-date overview of studies focusing on insulin titration and decision support for patients with diabetes. As currently no single and uniform care standard for the titration of insulin exists, we organized several meetings with an expert panel consisting of physicians, diabetes nurses and medical informatics specialists to generate decision rules for web-based titration of insulin. The rules were assessed by considering specific premeditated consultation scenarios. We performed semi-structured interviews with five experienced patients and five patients who recently started with once-daily insulin, to investigate patients' habits and behaviors when performing self-measurements of fasting plasma glucose values, injecting insulin and adjusting the insulin dose. We also asked them if and how they could benefit from a web-based system that generates insulin dosing advices. A researcher (AS) translated the gathered information to a system requirements document. The document was repeatedly reviewed by a clinical diabetologist (FH) and a medical informatics specialist (NP) who are both part of the research team.

Based on the specified requirements, a fully functional system was developed. Because generation of insulin dosing advice is the main feature of the system, it was decided to use the GASTON framework [5]. GASTON is a state-of-the-art framework for building decision support-systems, and consists of (i) an ontology-based knowledge representation language, (ii) a graphical modeling tool for encoding clinical decision rules and decision support algorithms, and (iii) an execution engine for reasoning and generation of advice. The graphical user interface (GUI) of the system was developed using Microsoft Silverlight. Patient data are stored in a Microsoft SQL database. SSL (Secure Sockets Layer) is used to provide encrypted data exchange over the Internet.

3. Results

3.1. Requirements Specifications

The elicitation of the requirements for the web-based titration system revealed four important aspects: the insulin titration algorithm, the handling of hypoglycemic events, telemedicine functionalities and visiting frequency monitoring.

Insulin titration algorithm – The effect of diabetes treatment is evaluated by the widely accepted marker HbA1c (glycosylated hemoglobin), which reflects the blood glucose levels over a period of six to eight weeks. We used an existing treat-to-target titration algorithm for once-daily basal insulin in type 2 diabetes patients that has already been proven to be effective in lowering HbA1c when used systematically [6]. Discussions with the expert panel revealed that it would be advisable to adapt the existing treatment algorithm in such a way that it incorporates the variables weight and age, e.g. a patient with a higher weight requires more insulin and if the patient is older than 70 years it was deemed safer to titrate less aggressively (Table 1). The expert panel also concretized the necessity to choose a glycemic target that would preserve the benefits of intensive therapy but minimize the risk of severe hypoglycemia. If a patient experiences frequent hypoglycemic events, the caregiver should be able to tailor the target value of the PANDIT system to the individual patient.

Table 1. Insulin titration algorithm

Lowest Fasting Plasma Glucose of the Preceding Three to Six Days	Insulin Dose Adjustment for People < 70 Yrs	Insulin Dose Adjustment for People > 70 Yrs
< 4 mmol/l	-0,02 IU/kg (min* -2 IU)	-0,02 IU/kg (min -2 IU)
4,0 – 5,5 mmol/l	Stable dose	Stable dose
5,6 – 9,9 mmol/l	+0,02 IU/kg (min +2 IU)	+0,02 IU/kg (min +2 IU)
> 10 mmol/l	+0,04 IU/kg (min +4 IU)	+0,02 IU/kg (min +2 IU)

* min = minimum

Safety: handling of hypoglycemic events - Achieving lower blood glucose levels carries an increased risk for hypoglycemia. The literature review showed that hypoglycemia and fear of hypoglycemia are considered the main barrier to attain good glycemic control by patients and clinicians [7]. Therefore, the expert panel set up decision rules with the purpose to prevent patients from experiencing hypoglycemic events. Firstly, the expert panel stated that increases of the basal insulin should be based on the lowest of three recent fasting plasma glucose (FPG) measurements, collected in the preceding three to six days. Patients sometimes measure a single fasting blood glucose value that is disproportionally high or low due to measurement errors and general variations in lifestyle (e.g. exercise, food intake). Using these values could cause overdosing of insulin and lead to hypoglycemia. Titration on the lowest FPG value from multiple measurements will prevent the system from using an erroneous measurement. Secondly, the expert panel concluded that if the patient reached the target value, the titration should be based on the lowest of six recent FPG measurements, collected in the preceding six to twelve days.

Most importantly, the system should also include a procedure for handling hypoglycemic events. As currently no uniform care standards for handling hypoglycemic events exist, we used both the literature and expert opinion to set up this procedure. The expert panel stated that every hypoglycemic episode should be graded in terms of severity and safety risks, and if the episode is considered a reason for more intensively guided treatment, the patient should be redirected to the caregiver.

Telemedicine functionalities - Several patients emphasized the importance of the involvement of the caregiver. Also the expert panel stated that caregivers should be able to maintain their responsibility while delegating the task of providing insulin advices to the system. Telemedicine functionalities should therefore enable caregivers to access their patients' records of blood glucose values. Furthermore, caregivers should be warned by the PANDIT system when patients experience hypoglycemic events. In such cases caregivers should have the opportunity to overrule the system's algorithm and directly provide insulin dosing advice through the PANDIT interface for a certain period of time.

Visiting frequency monitoring - The expert panel stated that patients should be encouraged to use the PANDIT system frequently in order to achieve good glycemic control. It was decided that patients would be reminded automatically by e-mail or SMS to use the system if they had not entered FPG values for more than three days. According to the patient interviews not all patients would appreciate receiving such reminders from the system; consequently this feature should be optional.

3.2. System Architecture and Implemented Functionalities

The PANDIT system consists of three different components: a decision support system, a GUI and a database. The system architecture is shown in Figure 1.

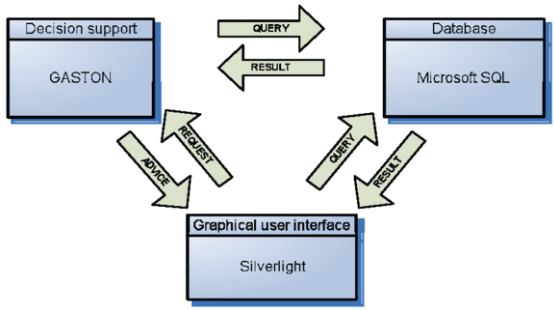

Fig 1. System architecture of the PANDIT system

The PANDIT system uses an interface resembling a plasma glucose diary to facilitate the collection of fasting blood glucose values[2]. Upon each consultation of the system, the patient updates the diary with recently measured FPG values and the amounts of insulin used, and reports whether he or she has recently experienced hypoglycemic events. Subsequently, the GUI performs a store-operation on the database and sends a request to GASTON. GASTON runs the applicable query on the database and executes the PANDIT algorithm. If necessary, GASTON executes the additional hypoglycemia algorithm. Finally, an advice will be transmitted to the GUI. The GUI stores the advice in the database and displays the advice to the user. The diary also facilitates adding annotations to the blood glucose values. These annotations could have an added value if the titration is redirected to the caregiver. In addition to the automated reminders sent by the PANDIT system, the system includes an e-mail functionality enabling the patient to directly contact the caregiver if considered necessary by the patient.

[2] A video presenting the main features of the system is available at www.pandit-online.nl/demo

4. Discussion

In the current study we developed a web-based insulin titration system with telemedicine functionalities, the PANDIT system. PANDIT distinguishes itself from existing web-based self-titration systems as it focuses on patients with type 2 diabetes using once daily long acting insulin. In addition, while most existing systems do not involve the caregiver, the PANDIT system is specifically developed to be embedded in routine care.

Earlier studies have already shown that frequent insulin dose adjustments which are set by clinicians according to a predefined algorithm can lead to substantial decreases in HbA1c. Even greater reductions are achieved when such an algorithm is applied by patients themselves [6]. A web based algorithm, like the PANDIT system, will spare the patients calculating a new insulin dose themselves. The challenge of providing automated insulin dosing advices at a patient's home is enabling caregivers to maintain their responsibility in this process.

A strength of the study is that we involved both patients and care professionals in clarifying the system requirements. We therefore believe that the results of our study are useful for the development of future telemedicine tools for diabetes patients. A web-based titration system such as the PANDIT system could be extended to patient groups using multiple injection therapy. Additionally, future studies should aim to develop web-based systems for diabetes patients addressing multiple treatment targets and facilitating integrated care involving a diabetes nurse, a dietician and other health care providers. A limitation of our study is that dietary and lifestyle aspects of diabetes were not considered to be implemented in the system.

In the near future we will perform a pilot study and a randomized controlled study to investigate the efficacy of the PANDIT system. During the pilot we will also perform a usability test with patients.

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