VIE-DIAB: a Support Program for Telemedical Glycaemic Control

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Abstract. Ambulatory care supporting long-term treatment of type I diabetes mellitus (DM) is based on the analysis of daily notes of serum glucose measurements, carbohydrate intake, and insulin dosage. In order to improve glycaemic control, telemedicine support aims at improving communication between patients and diabetologists. Patient data are collected using mobile phone services. Weekly responses from the diabetes care centre should help the patient to optimize glycaemic control. The telemedical support system VIE-DIAB integrates data collection, visualization, and recommendation handling by using mobile phone and internet services. Its core is a module which visualizes a summary of the patient's diary data of the last 4 weeks. Traditional methods for displaying these data mainly use (coloured) scatter plots, line graphs or summary histograms to give a graphical overview of the data. VIE-DIAB supports a more intuitive view by presenting 4x7 multiples. Each multiple represents the serum glucose values of one day. First results indicate that this form of data presentation is very useful to physicians.

1. Introduction

Type I diabetes mellitus (DM) is a common chronic disease in children and adolescents with an incidence of 9 in 100.000 in Austria. Destruction of pancreatic ß-cells by autoimmune mechanisms leads to inadequate insulin secretion, hyperglycaemia and acute and late secondary problems reducing life quality and expectancy. Therapy with insulin, leading a healthy lifestyle and obeying to strict dietary restrictions may improve glycaemic control and thus reduce acute and chronic problems of DM.

Ambulatory care of patients with type I DM is based on careful teaching about glycaemic control as related to serum glucose monitoring, diet and physical activity. In addition, monitoring of glycosylated haemoglobin levels (HbA1c, percent glycosylated over total haemoglobin) provides information about medium term (one month) glycaemic control. Ambulatory care is usually scheduled every 3-6 months. More frequent consultations could possibly improve diabetic control but this is usually not considered feasible from the point of view of both, patients and diabetologists. One possibility to improve the comunication between chronically ill patients and ambulatory care centers without too much increasing the time spent at the hospital and the clinical workload has been brought about by telemedicine, the use of remote communication between patients and a health care center.

Telemedicine has been shown to improve glycemic control in adult patients with type I DM: Montori and Smith [1] found a significant decrease of glycosylated hemoglobine (HbA1c) in those patients who followed the recommendations given to the primary care provider by a diabetologist, Bellazzi et al. [2] in their type I DM telecare project found a similar HbA1c decrease of 1.23% and a significant reduction of insulin requirements. A few telemedicine projects deal with diabetes in pregnancy [3,4]. There is an international trend in developing applications for information management, physiological modeling and decision support for the clinical teams and the patients [5-8] aiming at improving diabetes control and reducing long term complications.

Telemedicine, however, has not gained widespread use, possibly because the workload associated with regularily typing in the data and supervising glycemic control is still too high. We therefore speculated that the patients compliance could be improved and the clinical workload reduced at the patients side by using mobile phone or handheld computer technology for automated data transmission and at the caretakers side by preprocessing the data applying automated data visualization and artificial intelligence (AI) techniques. Such an approach has been proven feasible in interested adults [9-13]. We therefore designed a telemedical support system with the aim to develop and to test the nesessary technical prerequisites, to evaluate the feasibility of such a telemedicine program in adolescent patients and, if possible, to prove that glycemic control can be improved at a reasonable and tolerable workload.

The present paper gives an overview of the system architecture of our telemedical diabetes care support program VIE-DIAB.

2. Diabetes management

Patients with DM are strongly motivated to keep daily records of all determined serum glucose values, insulin requirements, dietary intake and of clinical problems. These diaries serve as the basis of the regularly scheduled outpatients visits, usually 2-4 times per year. Experienced diabetologists need about 10 minutes to study the diary notes and to get an idea about glycaemic control in a specific patient. Usually, it is tolerated that about 1/3 of the blood glucose levels are out of the near-normal range of 60-180 mg/dL and only few values in the maximum (i.e. exceeding 350 mg/dL) or minimum range (less than 60 mg/dL).

Several authors attempted to simplify the diary readings or to extract additional knowledge: Kahn et al [14] possess a world patent on analysing data on diabetic control: data of the glucometer are processed online and displayed as histograms, xy plots and various statistical reports. Shahar [15] in his knowledge based RESUME project attempted to show relationships between the various data, and the working group around Bellazzi [16,17] invented a number of sophisticated trend analyses and data abstractions for simplifying the interpretation of the individual glucose metabolism.

The “Telematic management of insulin dependent diabetes mellitus”, T-IDDM project [16,17] tried to develop an infrastructure for improved communication between patients and the diabetes care centres and a bulk of programs for analysing and displaying data on glucose control. The AIDA project [18] tried to predict serum glucose levels from a simple model that analyses the individual relationship between glucose intake and blood glucose levels. None of the visualization programs has gained widespread popularity mainly because these programs are not enough intuitive or not superior to a specialist’s interpretation of the diaries.

Owing to our experience with the graphical handling of complex data in intensive care [19], we tried to invent a more intuitive data display and developed the program VIE-DIAB. The architecture of this system is shown in the next chapter.

3. VIE-DIAB’s system architecture

Following the intention of intensifying the communication between patients and physician VIE-DIAB integrates three major functions:

- Continuous data collection from the patient. Data should be submitted using mobile phone services (SMS or WAP) each time a glucose measurement is taken, an insulin dosage is delivered, or a carbohydrate intake takes places. Usually these events appears at the same time. The patient submits one set of data including all the information above. The data submitted are basically identical to the ones recorded in the diary;
- Visualization of patient data for fast comprehension by the physician;
- Feedback from the physician to the patient – usually done once a week.

To support these three functions VIE-DIAB is built as a server-client application. The server collects all data from the patient. It further keeps a history of all recommendations given by the physician. The client supports patient management, data visualization and recommendation processing. The client is a Java application (and applet) with a multilingual interface in German and English. It uses a multithreaded client-server communication for data exchange.

3.1 Data collection

VIE-DIAB collects glycaemic control data sets received from the patient in a telemedice environment. Data are usually submitted using mobile phone services (SMS, WAP) but there is also the option to enter data using an internet connection (HTML forms data). Given the fact that glucose measurements, insulin delivery, and carbohydrate intake usually appear at approximately the same time all this information is included in one data set. Each data set is structured like one line in a diabetes diary:

- date and time (ddmmyyyy, hhmm)
- serum glucose value (integer, range 30 – 1000 mg/dL)
- insulin dosage (short and long term insulin, integer, international units): Insulin is available in different preparations varying in half-life: short (4-5 hours), long (8-16 hours) and very long acting insulin (24-32 hours). There are also other “varieties”

of insulin like ultra fast short acting insulin and ultra long acting insulin and others. At present the dichotomy short and long term acting insulin seems to be sufficient for the chosen display because at present every patient has only two personal types of insulin). The insulin dosage is colour coded in the display, VIE-DIAB can easily be adapted to other types of insulin.

- treatment intention for insulin (basic, bolus and correction dosage): Usually two different insulin preparations are combined to adapt to the oscillations of the serum glucose level and to prevent hyper- and hypoglycaemia. There are two principal modes of adjusting the insulin dosage: the conventional method uses regularly distributed meals and twice daily insulin injections, and the basis-bolus method provides a baseline insulin dosage and extra amounts of short acting insulin depending on the presumptive carbohydrate intake and the recent serum glucose value. For both methods, frequent serum glucose measurements are mandatory.
- carbohydrate intake (units eq. to 12g glucose or 50 kcal)
- notes (free text or flags for sports, postprandial measurement, infectious disease present, signs of hypoglycaemia).

3.2 Data visualization

The main goal of VIE-DIAB's visualization is a means to provide the physician with an overview of the situation of the patient in the last 4 weeks. This overview should be comprehensible fast and easy. Graphic visualization using glyphs is used to support this comprehensiveness. The metaphor graphic created contains 28 glyphs in 4 rows and 7 columns. Each row includes data from one week. Each column represents one day of the week. Each glyph is an abstract object which groups all glucose measurements of one day into a graphic format by reducing complexity. This should result in ease of comparison of the situation of the patient on different days.

Complexity reduction of displayed data is done by grouping time periods and by grouping serum glucose concentration.

For grouping of time periods we use six categories of unequal length. The clinical day starts at 3:00. Most often we see data entered at e.g. 1:30 which are attached to the previous day. This has motivated us to start with "early morning" at 3:00 in order to keep consistent with the bookkeeping done in the diaries. The modal day is defined according to the following time periods:

Modal day	early morning	morning	noon	afternoon	evening	night
Hours	3-8	8-11	11-14	14-17	17-20	20-3

For each of these periods only one value, usually the highest is displayed. An exception is the case when a "low" serum glucose value (hypoglycaemia) and a normal or high value is present within one time frame. In such a case both values are presented. Serum glucose values are categorized into five groups. Each category is represented by a vertical block of different colour and height. Normal values (green) are located in the center of the time frame. Low values (blue) go down, high values (three reds of different intensity) go up. The categories are built according to the following scheme:

Serum glucose	mg/dL
extremely high	>350
very high	250-350
high	180-250
normal	60-180
low (hypoglycemia)	≤60

The glyph consists of coloured bars reflecting the categorised serum glucose value per time period. If there is no measurement for a specific time period the field remains empty (grey). In addition, a coloured summary bar at the right margin displays the relative distribution of the displayed serum glucose values. Figure 1 gives an example of the glyph display.

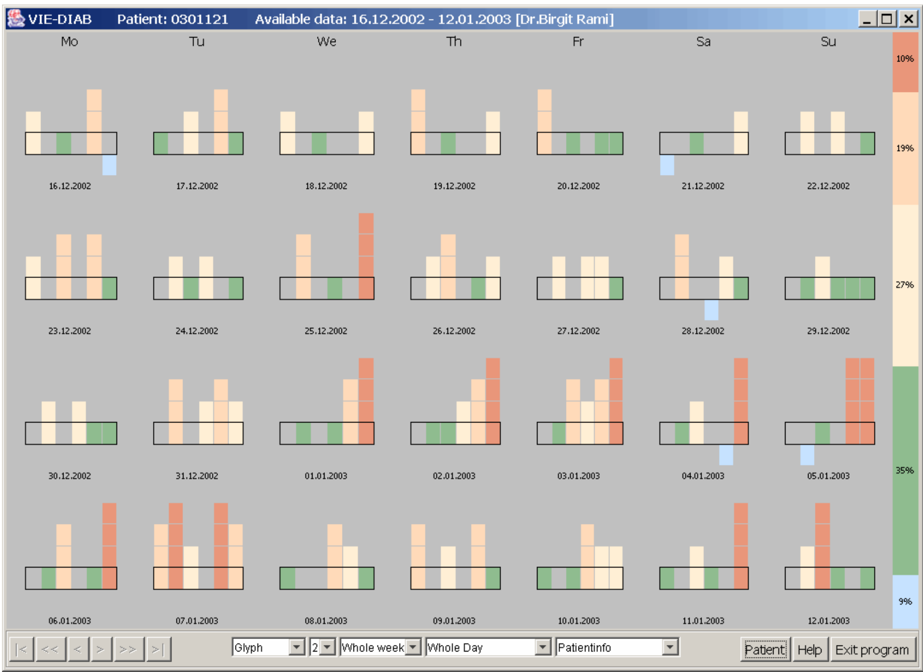

Fig. 1. VIE-DIAB's glyph data display. Serum glucose values are intuitively displayed as glyphs representing one day, 7 multiples in a row, 4 rows per sheet. The relative distribution of the serum glucose categories is displayed in the right margin.

Alternate views are available to display further details. They can be activated per mouse click. There are three alternative display modes:

- a scatter plot which displays all serum glucose values. The coloured background represents the categories of the glyph display;
- a histogram view which combines the display of serum glucose, carbohydrate intake and insulin dosage. It is intended to use this view for a more detailed analysis of the relationship between serum glucose values, carbohydrate intake and insulin dosages delivered;
- a spreadsheet containing the raw data in order to facilitate the conventional data analysis performed by the diabetologist.

The alternate views may be activated for the whole display or for specific days. An alternate specific day display can be created both inline and in a popup window. Figure 2 shows such an example of a popup window for the day “04.01.2003”. This window shows all four display modes. It gives a clue how data are represented, abstracted and drawn.

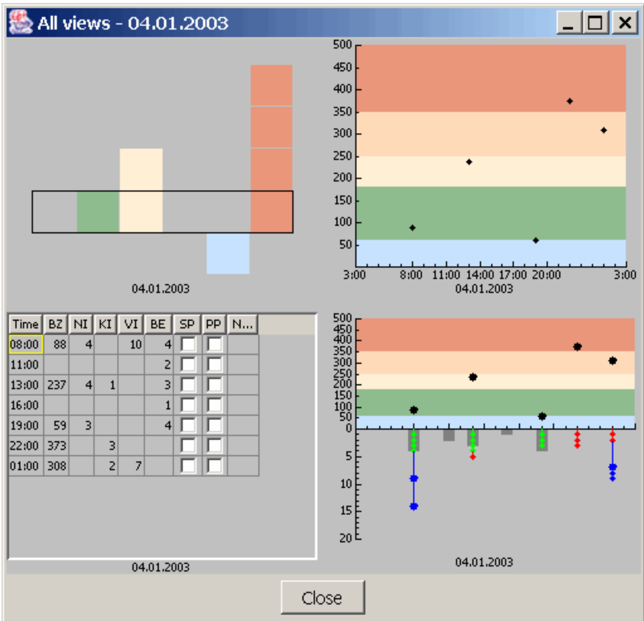

Fig. 2. Four alternative views of diabetes data from day 4 Jan 2003. glyph mode (top left), scatterplot mode (top right), spreadsheet data (bottom left) and histogram mode (bottom right). Histogram mode shows blood glucose as a scatterplot in upward direction, carbohydrates (grey blocks) and insulin dosages (green, red, and blue dots; a large dot counts 5 insulin units) in downward direction.

3.3 Recommendation processing

Once a week physicians at the health care centre inspect the data collected during the last week. VIE-DIAB visualizes the data and presents an initial (partial) recommendation. This recommendation is completed by the physician and forwarded to the server. The server stores the message and sends it to the patient via SMS.

A rule-based approach is used to computer the initial recommendation. Text blocks are composed by applying the rules to the data received in the last seven days. The four basic text blocks are:

1. Too few data received. Please supply more measurements.
2. Glycaemic control is good. No changes required.
3. Glycaemic control needs improvement. Please make the following changes: …
4. Glycaemic control is poor. Please contact the health care center.

In case message 3 is applicable the diabetologist has to give further details how to improve metabolic control.

3.4 Evaluation

The program has been technically evaluated using a data set of 14 patients with type I diabetes mellitus. A short clinical evaluation has been performed with our local diabetologists. A first evaluation has proven the usefulness of the approach. A more in-depth evaluation experiment about the usefulness of the visualization system is set up for a workshop with diabetologists in March 2003. It should gives insights into the ease of comprehensiveness of the visualization method. A more thorough clinical cross-over study with 36 patients is currently prepared. It will start in spring 2003 after setup of the mobile phones.

4. Discussion

The visualisation of data on glycaemic control in patients with DM possesses many advantages since it is most intuitive and concise. This is especially due to the reduction of the number of the displayed data and to omitting the overabundance of oscillating single values displayed in other visualisation concepts. The reduction of the displayed data is justified by the fact that the main information sought by the diabetologists is, how many values are when and how much out of range. This question can easily be answered by the chosen view and is also supported by the summary bar on the right margin. If more detailed information is needed for analysing a specific situation, the detailed views can easily be called up. The data visualisation can also be used for teaching purposes because of its simplicity and the intuitive display.

Another argument in favour of our display is time saving: preliminary data on users satisfaction suggest that a monthly overview about the quality of diabetes control can be obtained by a diabetologist for a specific patient in less than half a minute compared to at least 1-5 minutes using the diary. This sums up if several patients or a longer time period have to be analysed. Moreover, VIE-DIABs data processing module is able to produce (simple) suggestions for patients advice. This will be extended by a more knowledge-based system which automatically analyses the data to give better clues in which ways glycaemic control may be improved..

At present, there are no known disadvantages of our visualisation program, mainly because the functionality of the system has been created according to the “natural” way of assessing data on glycaemic control. The “goodness” of diabetic control can rapidly be judged and, by choosing the worst value of a given time period, the omission of the other values in the primary display will not contribute to a too optimistic view. If the reaction to a too high value is to be analysed, the detailed view can be called up, in case of a too low value, the result of a correction will be displayed in the same frame if the subsequent “corrected” serum glucose value falls into the same time frame.

In summary we present VIE-DIAB, a novel telemedical support and visualization system for data on glycaemic control that should facilitate ambulatory care of patients with DM. The combination of mobile phone and internet services allows to intensify the communication between adolescent patients and diabetologists. The disadvantage is the increased workload of physicians due to the weekly responses which have to be prepared. VIE-DIAB’s intuitive visualization system is a way to keep the workload within tolerable limits, because it supports to get a fast overview of the situation of the patient. If this proves to be true in our planned clinical evaluation study VIE-DIAB will be an essential telemedical system which improves glycaemic control.

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