Mobile Diabetes Management on iPhone

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Abstract—The rapid proliferation of mobile devices and smartphones has created a large demand for mobile information as well as electronic healthcare applications. Nowadays, 285 million people are suffering from diabetes in the world, and self-management is crucial in diabetes treatment. This paper describes a mobile diabetes management application on iPhone, which intends to simplify the bolus calculation and history recording procedure for patients under insulin pump therapy. The central part of this application is bolus calculation, which is based on the user specifications such as carbohydrate intake, carbohydrate ratio, correction factor, insulin on board (IOB), activity level and illness level. The application is tested using two glucose simulation tools, GlucoSim and AIDA. Results show that by adopting the recommended insulin doses, the blood glucose levels are mostly within the normal range.

Index Terms—Basal bolus insulin therapy, diabetes, iPhone, mobile healthcare.

I. INTRODUCTION

Diabetes mellitus, often simply referred to as diabetes, is a group of metabolic diseases in which a person has high blood sugar. It is caused by the body not producing enough insulin, or the cells not responding to the insulin that is produced. There are three main types of diabetes: Type 1, Type 2, and gestational diabetes. Type 1 diabetes develops when the pancreas stops producing insulin; Type 2 diabetes results from improper response to insulin; and gestational diabetes occurs in pregnant women, who have never had diabetes before, but have a high blood glucose level during pregnancy. Currently, an estimated 285 million people, corresponding to 6.4% of the world’s adult population, live with diabetes [1].

Insulin therapy is necessary for diabetes patients and has a history of more than 85 years. How to deliver insulin and how much to deliver are the basic considerations in insulin therapy. The efficiency and accuracy of blood glucose measurement and insulin delivery are highly improved by clinicians and industry [2] [3]. Insulin pens and insulin pumps, which developed quickly in the past 40 years, have becoming the most popular tools for insulin delivery [4]. However, in self-management, dosing accuracy remains a problem. Improper dosing will result in hyper- or hypoglycemia. Insulin dosing depends on individuals, and is affected by food intake, insulin injection history, temperature, exercises, etc.[5]. Bolus calculators were developed to make insulin-dosing calculations easier and more accurate. They are widely used together with the insulin pumps. The calculation is based on the patient’s current blood glucose level, target blood glucose level, amount of carbohydrate to be consumed, insulin-to-carbohydrate ratio, and insulin on board (IOB) [5].

The rapid proliferation of mobile devices and smartphones has created a large demand for mobile information [6] as well as electronic healthcare applications [7]. iPhone is an Internet and multimedia-enabled smartphone designed and marketed by Apple Inc. Since it was first introduced in 2007, it had become a new trend in the world. Its related products, iPad and iPod touch are also have a significant share in the market [8]. Some related works include Diabetes Log, an online diabetes logbook to record blood glucose, food intake and medicine history, and Glucose Buddy, which provide a graphical log view and an education kit for managing diabetes.

This paper describes an iPhone diabetes management application named “iDiabetes”. Its central components include a bolus calculator and a data log. The target users are patients under insulin pump therapy, or continuous subcutaneous insulin infusion.

II. THEORIES

A. Basal Bolus Insulin Therapy

Georgia Hospital Association Diabetes Special Interest Group provided the introduction of Basal Bolus Insulin Therapy in their course. In this therapy, half of the Total Daily Insulin (TDI) is given as Glargine or Detemir (basal insulin), and the other half is given in proportion to carbohydrate (CHO) consumed at mealtimes if a patient is counting carbohydrates, or give divided equally in thirds for consistent carbohydrate meals (meal bolus insulin). The meal bolus insulin can also be calculated by estimating the carbohydrate to insulin ratio. In this method, carbohydrate counting and bolus insulin calculation are necessary. They suggested the following formulas:

To calculate the initial total daily insulin (TDI), \( TDI = \text{Weight (kg)} \times 0.5 \) units for Type 2. 0.3 should be used for renal impaired patients and 0.4 for type 1 diabetics. Insulin to carbohydrate ratio (CHO Ratio) varies a lot between individuals. However, it is commonly suggested that, for adults, CHO Ratio is 10 to 15, and 20 to 30 for school-age children [9]. If the blood glucose level (BG) is greater than 140mg/dL., rapid acting insulin is needed, and the dose is calculated by \( (BG - 100)/\text{CF} \). To calculate CF, if TDI is known, \( CF = 1700/\text{TDI}, \text{otherwise } CF = 3000/\text{Weight (kg)} \).

Other commonly used parameters and formulae are given in [10] and [9]. Another clinical report shows that the mean value (Type 1) for TDI (U/kg/d) was 0.451U/kg, Total Basal
Dose(U/kg/d) was 0.153U/kg, carb-ratio(g/U) was 929/weight, and correction factor (mg/dL/U) was 4038/weight [11].

B. Continuous Subcutaneous Insulin Infusion (CSII)

Continuous Subcutaneous Insulin Infusion (CSII) was developed in the late 1970s for type 1 diabetes control [9]. It is usually referred to as insulin pump therapy, and our application is mainly designed for the pump users.

As mentioned in the Basal Bolus Insulin Therapy, the total daily insulin is divided into basal insulin and meal insulin. CSII allows continuous infusion of the daily insulin with a certain basal infusion rate (usually ranging from 0.4 to 0.2 U/hour). The basal infusion rate may vary according to the time of day. A basal rate verification method is provided in [9].

C. Insulin on Board (IOB)

Most bolus calculators take into account the amount of “insulin on board” (IOB), or the amount of insulin remaining in the body from previous insulin boluses [5].

Insulin action plots are used to predict the percentage of insulin remaining as a function of time. Curvilinear and linear plots are the two basic types of insulin action plots [5]. Curvilinear plots are better approximations of the pharmacokinetic action of insulin, while linear plots make the concept of IOB easier for patients to understand. The insulin action is adjusted by varying the IOB durations.

D. Carbohydrate Counting

Carbohydrate counting is used to estimate the carbohydrate intake, and the result is used to calculate the meal bolus insulin. It focuses the attention on food choices that most affect blood glucose levels. Detailed carbohydrate counting method was provided in Georgia Hospital Association Diabetes Special Interest Group's course: Managing Diabetes and Hyperglycemia Improving Inpatient Care.

E. Others

Activity level, illness and stress are factors that affect the blood glucose level significantly. Unfortunately, to the best of our knowledge, none of the insulin pumps in the market are able to track these factors and make adjustments accordingly.

III. DESIGN

In this section, the design, including algorithm and implementations, are illustrated.

A. Developing Platform and Tools

This diabetes management application, iDiabetes, is designed to run on iOS 4. The developing language is Objective-C and developing tools are XCode and iPhone simulator.

B. Overview

Three main parts are included in this application: the insulin dosage calculator, the data log, and the preference settings. The functionality and relationships are schematically illustrated in Fig. 1.

Firstly, in the preference settings part, the users input their basic information such as age, weight, IOB rate. Based on the information, some important parameters are estimated based on formulas mentioned in Section II (A). Information needed and parameters estimated are given in Table I and Table II respectively. Users are allowed to manually change any parameters in the application according to the doctors' advises.

Secondly, in the insulin dosage calculator part, users need to input their current blood glucose level and carbohydrate intake. The calculator will give the recommended insulin dosage. The insulin dosage consists of three parts: (1) the rapid acting insulin (to reduce current high blood glucose), (2) the meal insulin (to balance the carbohydrate intake) and (3) the IOB (the residual insulin dosage). After that, adjustments will be made based on physical activity level and illness level. At last, all the relevant data are saved to the database and can be viewed in the data log part. They are important references for doctors.

When glucose level is higher than 140mg/dL, the rapid acting insulin dose is calculated as follows,

\[ Insulin_{\text{rapid}} = \frac{(BG_{\text{current}} - BG_{\text{target}})}{CF} \]  

where \( BG_{\text{current}} \) is the current blood glucose level, \( BG_{\text{target}} \) is the target blood glucose level, and \( CF \) is the correction factor.

Meal insulin dose can be calculated using the following equation,

\[ Insulin_{\text{meal}} = \frac{CHO}{CHO_{\text{Ratio}}} \]  

where \( CHO \) is the carbohydrate intake, and \( CHO_{\text{Ratio}} \) is the insulin carbohydrate ratio.

The Insulin on Board (IOB) is estimated using a linear approach with a specified IOB duration parameter. Hence, the insulin dose without adjustment is

\[ Insulin_{\text{total}} = Insulin_{\text{rapid}} - Insulin_{\text{meal}} - IOB \]
Users are also able to add new log and recommendations in this part. All the data are well organized and ready to be retrieved and manipulate. The data is stored using the Core Data, which is convenient to reserve for any other information that needs to be specified. Another attribute called others, which stored in string type, is used to account the IOB. User can also set their target BG manually before starting the calculation.

When pressing the Compute button, the calculator will pop up a view to show the recommended dosage and ask for further adjustment. Finally, the data will be saved to the database. It records both the log data and its corresponding settings. The main attributes in the data log include the blood glucose levels, meal insulin doses, insulin on board, insulin on needle and other parameters. In the “System Preference” section, users can customize their unit preferences, i.e. switch between mmol/L and mg/dL, kg and pounds.

In the Bolus Calculator tab, the “Reading” and “Carb” fields take the input from the users. The IOB Enable Option allow user to enable or disable the calculator taking into account the IOB. User can also set their target BG manually before starting the calculation.

Lastly, all the history can be viewed in the data log part. Users are also able to add new log and recommendations in this part. All the data are well organized and ready to be manipulated and analyzed. HbA1c is estimated based on the recorded data by (4) [12].

\[
\text{HbA1c} = \frac{\text{BG}_{\text{avgs}} - 46.7}{28.7} \quad (4)
\]

These three parts form the main architecture of the application.

### IV. Simulation Results

#### A. Test on GlucoSim

GlucoSim (http://216.47.139.198/glucomsim/gsimul.html) is a web-based educational simulation package for glucose-insulin levels in the human body of both healthy persons and type 1 diabetes mellitus patients.

The simulation mode was chosen to be insulin pump with constant continuous injection rate. The “patient” is a type 1 diabetes patient with body weight 70kg. The meal time and content is shown in Table IV. The suggested meal insulin dose and injection times by iDiabetes is given in Table V. The injection rate (basal rate) was recommended to be 10 mU/min. The simulator simulates the response of the “patient” in a 24 hours interval starting from 8:00 in the morning. The result of the simulation is shown in Fig. 2 with solid line. It can be seen that most of the time, the blood glucose levels are within the normal range. Only a short period after a meal, the blood glucose level is higher than 110mg/dL. In the result, the night glucose level tends to be lower than 70mg/dL. This can be improved by adopting lower basal rate at night instead of using a constant injection rate.

### TABLE I: INFORMATION NEEDED.

<table>
<thead>
<tr>
<th>Information Needed</th>
<th>Purpose</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Identifying the case</td>
<td>N.A</td>
</tr>
<tr>
<td>Sex</td>
<td>Identifying the case</td>
<td>N.A</td>
</tr>
<tr>
<td>Delivery</td>
<td>Identifying the case</td>
<td>This application is mainly for pump users</td>
</tr>
<tr>
<td>Type</td>
<td>Identifying the case</td>
<td>This application is for type 1 users</td>
</tr>
<tr>
<td>Weight</td>
<td>Estimating parameters</td>
<td>Total daily insulin, total basal insulin, insulin carbohydrate ratio, and correction factor can be estimated based on the weight</td>
</tr>
<tr>
<td>Date of Birth</td>
<td>Identifying the case &amp; estimating parameters</td>
<td>Insulin carbohydrate ratio can be estimated</td>
</tr>
</tbody>
</table>

### TABLE II: PARAMETERS ESTIMATED.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Formulae</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Daily Insulin (TDI)</td>
<td>0.4(U/kg)×weight(kg)</td>
<td>N.A</td>
</tr>
<tr>
<td>Basal Dose</td>
<td>0.5×TDI</td>
<td>Half of the TDI</td>
</tr>
<tr>
<td>Basal Rate</td>
<td>0.22(U/kg)×weight(kg)/24(h)</td>
<td>For pump users</td>
</tr>
<tr>
<td>Insulin Carbohydrate Ratio (CHO Ratio)</td>
<td>10–15g/U for adults, 20–30g/U for school-age children</td>
<td>This parameter varies between individuals. It is better to follow the doctors’ advises</td>
</tr>
<tr>
<td>Correction Factor (CF)</td>
<td>1700(mg/dL)/TDI</td>
<td>This parameter is used only when blood glucose level is higher than 140mg/dL</td>
</tr>
<tr>
<td>Target Blood Glucose</td>
<td>90mg/dL (default)</td>
<td>Normal range is 70–110mg/dL</td>
</tr>
<tr>
<td>IOB Duration</td>
<td>3 hours (default)</td>
<td>Users are allowed to adjust it between 2 to 6 hours with minimum change of 0.5h</td>
</tr>
</tbody>
</table>

In this program, activity level and illness level are considered to adjust the insulin dose, i.e. activity or illness will reduce or increase the insulin dosage by a certain percentage. Both activity level and illness level are classified into 5 levels: very low, low, normal, high and very high. Their effects are listed in Table III.

### TABLE III: ADJUSTMENT BASED ON ACTIVITY LEVEL AND ILLNESS LEVEL.

<table>
<thead>
<tr>
<th>Level</th>
<th>Effect of activity level</th>
<th>Effect of illness level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>-10%</td>
<td>+10%</td>
</tr>
<tr>
<td>High</td>
<td>-5%</td>
<td>+5%</td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>+5%</td>
<td>-</td>
</tr>
<tr>
<td>Very low</td>
<td>+10%</td>
<td>-</td>
</tr>
</tbody>
</table>

Lastly, all the history can be viewed in the data log part. Users are also able to add new log and recommendations in this part. All the data are well organized and ready to be manipulated and analyzed.
which showed glucose levels that are higher than using GlucoSim. AIDA suggested more morning long-acting insulin as well as short-acting insulin, which can be alleviated if continuous basal insulin injection is used.

V. CONCLUSION

This paper described a mobile diabetes management application on the iPhone, which is targeted at patients on insulin pump therapy (Continuous Subcutaneous Insulin Infusion). iDiabetes is designed based on a three-part architecture, and is able to estimate important parameters, suggest insulin dose, and organize the history log. In the calculation process, insulin on board (IOB), activity level and illness level are also considered. Finally, iDiabetes is tested using two glucose simulation softwares, GlucoSim and AIDA, indicating that the insulin doses recommended stabilized the blood glucose levels mostly within the normal range. GlucoSim simulator produces better results as it is able to simulate the patient on insulin pump therapy. Future work can include comparing the simulated results of other tools with the results of iDiabetes, especially for patients who may require adjustments based on illness or activity levels.

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REFERENCES

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