Mobile Diabetes Management on iPhone

Di Zhu and Flora S. Tsai

***Abstract*—The rapid proliferation of mobile devices and smart phones 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 become 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 phones 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 Determir (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* = Weight (kg) × 0.5 units for Type 2. 0.3 should be used for renal impaired patients and 0.4 for type 1 diabetics. Insulin 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)/CF. To calculate CF, if TDI is known, *CF* = 1700/TDI, otherwise *CF* = 3000/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

Manuscript received August 11, 2012; revised October 3, 2012.

D. Zhu is with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore (e-mail: zhud0005@e.ntu.edu.sg).

F. S. Tsai is with the Singapore University of Technology and Design, Singapore (e-mail: fst1@columbia.edu).

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.

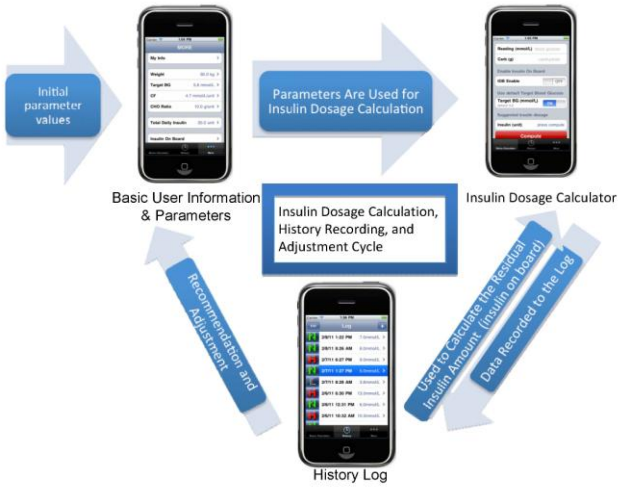

Fig. 1. 3-Tab Architecture of the design of idiabetes.

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,

$$Insulin_{rapid} = (BG_{current} - BG_{target}) / CF \qquad (1)$$

where BGcurrent is the current blood glucose level, BGtarget is the target blood glucose level, and CF is the correction factor.

Meal insulin dose can be calculated using the following equation,

$$Insulin_{meal} = CHO / CHORatio \qquad (2)$$

where CHO(g) is the carbohydrate intake, and CHO Ratio(g/unit) 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

$$Insulin_{total} = Insulin_{rapid} - Insulin_{meal} - IOB \qquad (3)$$

TABLE I: INFORMATION NEEDED.

Information Needed	Puropose	Description
Name	Identifying the case	N.A
Sex	Identifying the case	N.A
Delivery	Identifying the case	This application is mainly for pump users
Type	Identifying the case	This application is for type 1 users
Weight	Estimating parameters	Total daily insulin, total basal insulin, insulin carbohydrate ratio, and correction factor can be estimated bsed on the weight
Date of Birth	Identifying the case & estimating parameters	Insulin carbohydrate factor can be estimated

TABLE II: PARAMETERS ESTIMATED.

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

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.

Level	Effect of activity level	Effect of illness level
Very high	-10%	+10%
High	-5%	+5%
Normal	0	0
Low	+5%	-
Very low	+10%	-

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].

$$HbA1c = (BG_{average} - 46.7) / 28.7 \tag{4}$$

These three parts form the main architecture of the application.

C. Implementation

To achieve the three parts design, a tab bar with three tabs is adopted. The three tabs are named Bolus Calculator, History, and More, respectively.

In the More tab, there are 8 cells. They are “My Info”, “Weight”, “Target BG”, “CF”, “CHO Ratio”, “Total Daily Insulin”, “Insulin On Board”, and “System Preference”. In “My Info” section, users need to input their name, date of birth, sex, type and delivery type. In the “Target BG”, “CF”, “CHO Ratio”, and “Total Daily Insulin” sections, user can choose to either automatically generate or manually input the 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.

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 level, carbohydrate intake, insulin injected, physical activity and type of meal (breakfast, lunch or dinner). Another attribute called others, which stored in string type, is reserved for any other information that needs to be specified. The data is stored using the Core Data, which is convenient to retrieve and manipulate.

In the History tab, users can view and add/delete the history entries. High, normal and low blood glucose indicators are placed in front of each cell for quick view.

IV. SIMULATION RESULTS

A. Test on GlucoSim

GlucoSim(http://216.47.139.198/glucosim/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 IV: TIME AND CARBOHYDRATE CONTENT OF MEALS IN GLUCOSIM. TEST.

Meals	Breakfast	Lunch	Snack	Dinner
Time(hhmm)	0830	1330	1800	2000
Carbohydrate (g)	30	30	10	30

TABLE V: MEAL INSULIN SUGGESTED BY IDIABETES.

Time (hhmm)	0800	1300	1730	1930
Insulin (U)	3	3	1	2.7

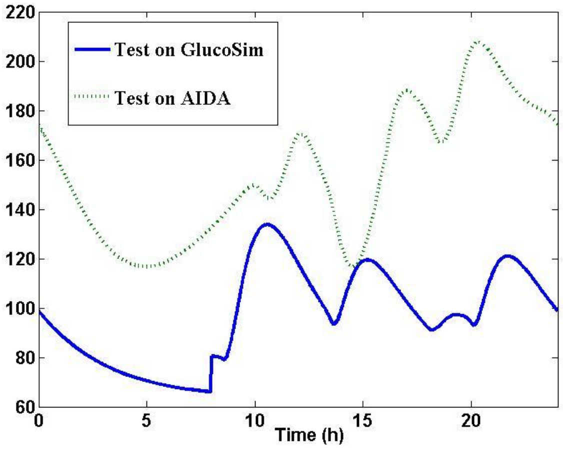

Fig. 2. Blood glucose simulation results.

B. Test on AIDA

The application was also tested on AIDA (http://www.2aida.org). AIDA contains a simple model of glucose-insulin interaction in the human body, and is intended for simulating the effects on the blood glucose profile of changes in insulin and diet for a typical insulin-dependent (type 1) diabetic patient (IDDM). Some information was specified in simulation scenario (see Table VI). In this case, the "patient" is 75kg.

TABLE VI: DATA ENTERED IN AIDA.

Meals	Breakfast	Lunch	Snack	Supper	Snack
Time (hhmm)	1000	1330	1530	1800	2330
Carbohydrate (g)	20	40	10	30	0
Time (hhmm)	0930	1300	1500	1730	2300
Blood Glucose (mg/dL)	180	163	140	126	162

There are several limitations in AIDA. Firstly, it cannot simulate for pump users, i.e. continuous basal insulin injection is not allowed. Secondly, maximum number of injections (boluses) is limited to 4. Thirdly, only integer doses can be delivered. With this limitation, the Total Basal Dose is divided into two parts: pre-bedtime and morning. The long-acting insulin, humulin N, was used. According to the meal content and corresponding blood glucose reading, iDiabetes gave the insulin dose recommendations as shown in Table VII.

TABLE VII: INSULIN DOSE SUGGESTED BY IDIABETES.

Time (hhmm)	093 0	130 0	173 0	230 0
Actrapid (U)	5	5	3	1
Humulin N (U)	7	0	0	8

The simulation results are shown in Fig. 2 with dashed line, 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.

ACKNOWLEDGMENT

We wish to acknowledge the funding support for this project from Nanyang Technological University under the Undergraduate Research Experience on Campus (URECA) programme.

REFERENCES

[1] International Diabetes Federation (IDF). (2009). *Diabetes Atlas*. 4th ed. Brussels: IDF. [online]. Available: http://www.diabetesatlas.org/
[2] Y. M. Liujf and J. H. Devries, "Dosing accuracy of insulin pens versus conventional syringes and vials," *Diabetes Techono. Ther.*, vol. 12, pp. S73-7, 2010.
[3] R. Perfetti, "Reusable and disposable insulin pens for the treatment of diabetes: Understanding the global differences in user preference and an evaluation of inpatent insulin pen use," *Diabetes Techno. Ther.*, vol. 12, pp. S79-S85, 2010.
[4] G. Shetty and H. Wolpert, "Insulin pump use in adults with type 1 diabetes-practical issures," *Diabetes Technol. Ther.*, vol. 12, no. 1, pp. S11-6, 2010.
[5] H. Zisser, L. Robinson, W. Bevier, E. Dassau, C. Ellingsen, F. J. Doyle, and L. Jovanovic, "Bolus calculator: A review of four "smart" insulin pumps," *Diabetes Technol. Ther.*, vol. 10, no. 6, pp. 441-4, 2008.
[6] F. S. Tsai, M. Etoh, X. Xie, W.-C. Lee, and Q. Yang, "Introduction to mobile information retrieval," *IEEE Intelligent Systems*, vol. 25, no. 1, pp. 11-15, 2010.
[7] F. S. Tsai, "Security issues in e-healthcare," *Journal of Medical and Biological Engineering*, vol. 30, no. 4, pp. 209-241, 2010.
[8] J. Ong. (October 2010). JP Morgan: Apple's fourth quarter revenue estimate rasied to $18.71B. [Online]. Available: http://www.appleinsider.com/articles/10/10/07/jp_morgan_apples_fourth_quarter_revenue_estimate_raised_to_18_71b.html (accessed in March 2011).
[9] I. Hirsch and S. Edelman, "Practical management of type 1 diabetes," *Professional Communications*, 2005.
[10] R. R. Walsh, *Pumping Insulin*, 3rd ed. Dan Dego: Torrey Pines Press, 2000.
[11] A. B. King and D. U. Armstrong, "Basal bolus dosing: A clinical experience," *Curr Diabetes Rev*, vol. 1, no. 2, pp. 215-20, 2005.
[12] D. M. Nathan, J. Kuenen, R. Borg, H. Zheng, D. Schoenfeld, and R. J. Heine, "Translating the a1c assay into estimated average glucose values," *Diabetes Care*, vol. 31, no. 8, pp. 1473-1478, 2008.

Di Zhu is currently an undergraduate student in School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He is also attached at Singapore Institute of Manufacturing Technology (SIMTech). He is a Singapore Ministry of Education (MOE) scholar and Nanyang President Research Scholar. His research interests include mobile application development and fiber optics.

He is a student of member of IEEE and IEEE Photonics Society.

Flora S. Tsai is currently with Singapore University of Technology and Design. She is a graduate of MIT, Columbia University, and NTU with degrees in Electrical Engineering and Computer Science. Her current research focuses on developing intelligent techniques for data mining in text and social media, which aims to balance the technical significance and business concerns to create techniques that are useful in real-world scenarios. She was a recipient of the 2005 IBM Faculty Award, 2007 IBM Real-time Innovation Award, 2010 IBM Faculty Innovation Award, and has published over 60 international journal and conference papers. She is currently a senior member of IEEE.