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Editors

Malina Jordanova, Frank Lievens

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Blood Glucose Level Prediction for Mobile Lifestyle Counseling

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Abstract - We propose a combined absorption - blood glucose control model to predict the blood glucose levels. Our method takes nutrition, applied insulin, and initial glucose level into account during the calculations. The models have many parameters, which suits the high natural variability of the patients. In order to personalize the model, i.e. to train the parameters, two parameter identification algorithms, the Brute Force Algorithm (BFA) and Genetic Algorithm (GA), were used. The results show a significant improvement with the trained parameters. The method is currently being validated in a clinical study with 20 patients. The integration of the algorithm into the telemedical lifestyle support system Lavinia is expected later this year.

Introduction

Diabetes mellitus is one of the modern age diseases, spreading widely and causing critical problems in health care. Our aim is to help diabetics calculate their insulin need by predicting short term blood glucose courses with an efficient algorithm. Different factors affect the blood glucose level. Most obvious are diet and insulin dosage, these are the factors that the patient can control to act on the blood glucose level in short-term. Other valuable factors are the glucose metabolism, body mass index, insulin sensitivity, physical activity and stress.

This paper focuses on the prediction of blood glucose levels using mathematical model simulating the glucose and insulin absorption taking into account the initial glucose values. For the model personalization we use different parameter identification algorithms (Brute Force and Genetic Algorithm). For the testing and validating we use real life patient data series from clinical trials results logged in Lavinia [1] Lifestyle Mirror mobile application.

Method

Our method uses the combination of two state-of-the-art models reflecting the real process happening in the body. We split the whole procedure in two parts. The first part is insulin absorption, which is simulated with differential delay equations. This model includes two subcutaneous insulin depots. These depots simulate subcutaneous insulin absorption. For further details of this model and the parameters see [2].

The second part of our combined model describes the glucose absorption from meals [3]. It is a two-compartment model based on mass balance equations. The model divides the digestion into two parts; stomach and intestine. The model takes protein, lipid, monosaccharide, fiber, and starch intake as input, with each one having its own effect during the absorption. This method can deal with mixed meals with components of different Glycemic Indexes (GI) and takes into account the effect of fiber. Moreover, digestion overlap between two consecutive meals can be handled properly. For more details about the model and the parameters see [3].

Our combined model simulates the real life process efficiently, therefore has large parameter sets. The results of our tests showed that there are 3 parameters which have a remarkable impact on the results: the disappearance rate for insulin, the glucose uptake by insulin-dependent tissues, and the distribution volume for insulin. To train these 3 parameters, we used two parameter identification algorithms. The first one is the Brute Force Algorithm (BFA), which means a full search of parameters in a specific range. The other method is Genetic Algorithm (GA) that simulates the process of natural evolution. For the other parameters, we used an average value suggested by the literature [3].

We had 10 different data sets of 7 patients, one type 1 (T1D) and six Type 2 (T2D) diabetes, each one including at least 3 days of logging and 12 meals. We had a total of 200 meals and 40 days of input data. The collected data consists of blood glucose measurements, taken at every five minutes by a Medtronic Continuous Glucose Monitoring (CGM) system, and the corresponding daily meals and applied insulin doses were logged through Lavinia. We asked the patients to avoid physical exercises during the experiment, thus we ran the calculations without it.

Results

First we performed meal wise tests in which the meals were treated as separate tests. This means zero startup blood insulin level and the model starts without any glucose absorption. In this phase, 2 hour, 4 hour, and 6 hour meal wise tests were made to measure the correctness of the model in short-term and in long-term as well. We also made daily tests; one without model restarting and one with model restarting. This means that the

predicted blood glucose levels have been set back to the measured value before each meal. This approach is a transition between meal wise and daily tests, because the insulin and glucose absorption calculations are continuous, but the blood glucose levels are corrected to avoid errors accumulation.

We performed model training, i.e., parameter identification. We made whole day tests with restart using the BFA method and the GA. We observed that 3 datasets are more precise than the other hospital patient; there for we found it useful to divide it in two categories; all patients and most accurate dietary log data sets. Results are shown in Table I.

Table I: Average and Maximum Error Values in mmol/l. (Mela wise: 2h, 4h, 6h, Whole day: No restart, Restart, BFA, GA)

		Without training					Training	
		2h	4h	6h	No restart	Restart	BFA	GA
All Patient	Average error	5,05	7,92	9,28	4,20	3,30	1,81	2,18
	Max error	10,62	14,93	17,25	10,34	7,31	5,83	6,80
Accurate log	Average error	4,26	5,26	5,45	2,50	1,88	1,51	1,64
	Max error	8,10	10,04	11,08	6,94	5,45	5,24	5,49

In the case of the most accurate data sets the results were ca. 20% better on average. The all-day tests with restarts show a significant improvement in all of the results and the maximum error is also decreased by at least 3 mmol/l. With model training, the results show a nearly 25% improvement in average error, but the maximum error remained almost the same when model restarting was applied. The reason is that the model dos not handle the long-acting insulin properly.

Conclusions and Future Work

In the light of the results our method cannot reliably predict hypoglycemia because the maximum error exceeds 5 mmol/l, but it is competent to predict hyperglycemia symptoms. Since we can give an immediate feedback on the meal impact on the blood glucose level, it can be a perfect tool for learning a healthy lifestyle.

As for the difference between the most accurate and all the data, we can state that accurate logging is very important. To support this, we plan to

create detailed manuals about the important events that should be precisely logged. Our clinical study involving 20 diabetic patients is now in progress. Using a longer CGMS data for training may bring better result as well.

Future research is needed for training the model with other parameter identification algorithms e.g. multifaceted genetic algorithm, extending the model to support physical activity, stress, and weather changes, and better modeling the action of long-acting insulins. The final aim is to decrease the average error under 1 mmol/l during the first hour and under 3 mmol/l during the first 4 hours.

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