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ORIGINAL ARTICLE

A Closed-Loop Artificial Pancreas Using a Proportional Integral Derivative with Double Phase Lead Controller Based on a New Nonlinear Model of Glucose Metabolism

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Abstract

Background:

Most closed-loop insulin delivery systems rely on model-based controllers to control the blood glucose (BG) level. Simple models of glucose metabolism, which allow easy design of the control law, are limited in their parametric identification from raw data. New control models and controllers issued from them are needed.

Methods:

A proportional integral derivative with double phase lead controller was proposed. Its design was based on a linearization of a new nonlinear control model of the glucose–insulin system in type 1 diabetes mellitus (T1DM) patients validated with the University of Virginia/Padova T1DM metabolic simulator. A 36 h scenario, including six unannounced meals, was tested in nine virtual adults. A previous trial database has been used to compare the performance of our controller with their previous results. The scenario was repeated 25 times for each adult in order to take continuous glucose monitoring noise into account. The primary outcome was the time BG levels were in target (70–180 mg/dl).

Results:

Blood glucose values were in the target range for 77% of the time and below 50 mg/dl and above 250 mg/dl for 0.8% and 0.3% of the time, respectively. The low blood glucose index and high blood glucose index were 1.65 and 3.33, respectively.

Conclusion:

The linear controller presented, based on the linearization of a new easily identifiable nonlinear model, achieves good glucose control with low exposure to hypoglycemia and hyperglycemia.

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Abbreviations: (BG) blood glucose, (CHO) carbohydrate, (EMPC) extended model predictive controller, (HBGI) high blood glucose index, (LBGI) low blood glucose index, (MPC) model predictive control, (PID) proportional integral derivative, (PIDD) proportional integral derivative with double phase lead, (T1DM) type 1 diabetes mellitus, (UVa/Padova metabolic simulator) University of Virginia/Padova T1DM metabolic simulator

Keywords: closed-loop control, diabetes, nonlinear control model, proportional integral derivative

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