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A Closed-Loop Artificial Pancreas Based on Risk Management

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Abstract

Background:

Control algorithms that regulate blood glucose (BG) levels in individuals with type 1 diabetes mellitus face several fundamental challenges. Two of these are the asymmetric risk of clinical complications associated with low and high glucose levels and the irreversibility of insulin action when using only insulin. Both of these nonlinearities force a controller to be more conservative when uncertainties are high. We developed a novel extended model predictive controller (EMPC) that explicitly addresses these two challenges.

Method:

Our extensions to model predictive control (MPC) operate in three ways. First, they explicitly minimize the combined risk of hypoglycemia and hyperglycemia. Second, they integrate the effect of prediction uncertainties into the risk. Third, they understand that future control actions will vary if measurements fall above or below predictions. Using the University of Virginia/Padova Simulator, we compared our novel controller (EMPC) against optimized versions of a proportional-integral-derivative (PID) controller, a traditional MPC, and a basal/bolus (BB) controller, as well as against published results of an independent MPC (IMPC). The BB controller was optimized retrospectively to serve as a bound on the possible performance.

Results:

We tuned each controller, where possible, to minimize a published blood glucose risk index (BGRI). The simulated controllers (PID/MPC/EMPC/BB) provided BGRI values of 2.99/3.05/2.51/1.27 as compared to the published IMPC BGRI value of 4.10. These correspond to 73/79/84/92% of BG values lying in the euglycemic range (70–180 mg/dl), respectively, with mean BG levels of 151/156/147/140 mg/dl.

Conclusion:

The EMPC strategy extends MPC to explicitly address the issues of asymmetric glycemic risk and irreversible insulin action using estimated prediction uncertainties and an explicit risk function. This controller reduces the avoidable BGRI by 56% ($p < .05$) relative to a published MPC algorithm studied on a similar population.

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Abbreviations: (BB) basal/bolus, (BG) blood glucose, (BGRI) blood glucose risk index, (DCCT) Diabetes Complication and Control Trial, (EGP) endogenous glucose production, (EMPC) extended model predictive controller, (HbA1c) hemoglobin A1c, (HBGI) high blood glucose index, (IMPC) independent model predictive control, (LBGI) low blood glucose index, (MPC) model predictive control, (PID) proportional-integral-derivative, (UVa) University of Virginia

Keywords: artificial pancreas, closed loop, MPC, risk, simulator

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