Journal of Diabetes Science and Technology
Volume 2, Issue 4, July 2008

ORIGINAL ARTICLES

Closed-Loop Control and Advisory Mode Evaluation of an Artificial Pancreatic β Cell: Use of Proportional–Integral–Derivative Equivalent Model-Based Controllers

Matthew W. Percival, M.Eng.,[1,2] Howard Zisser, M.D. ,[2] Lois Jovanovič, M.D.,[2] and Francis J. Doyle III, Ph.D.[1,2]

Abstract

Background:
Using currently available technology, it is possible to apply modern control theory to produce a closed-loop artificial β cell. Novel use of established control techniques would improve glycemic control, thereby reducing the complications of diabetes. Two popular controller structures, proportional–integral–derivative (PID) and model predictive control (MPC), are compared first in a theoretical sense and then in two applications.

Methods:
The Bergman model is transformed for use in a PID equivalent model-based controller. The internal model control (IMC) structure, which makes explicit use of the model, is compared with the PID controller structure in the transfer function domain. An MPC controller is then developed as an optimization problem with restrictions on its tuning parameters and is shown to be equivalent to an IMC controller. The controllers are tuned for equivalent performance and evaluated in a simulation study as a closed-loop controller and in an advisory mode scenario on retrospective clinical data.

Results:
Theoretical development shows conditions under which PID and MPC controllers produce equivalent output via IMC. The simulation study showed that the single tuning parameter for the equivalent controllers relates directly to the closed-loop speed of response and robustness, an important result considering system uncertainty. The risk metric allowed easy identification of instances of inadequate control. Results of the advisory mode simulation showed that suitable tuning produces consistently appropriate delivery recommendations.

Conclusion:
The conditions under which PID and MPC are equivalent have been derived. The MPC framework is more suitable given the extensions necessary for a fully closed-loop artificial β cell, such as consideration of controller constraints. Formulation of the control problem in risk space is attractive, as it explicitly addresses the asymmetry of the problem; this is done easily with MPC.

J Diabetes Sci Technol 2008;2(4):636-644

Author Affiliations: [1]Department of Chemical Engineering, University of California, Santa Barbara, California, and [2]Sansum Diabetes Research Institute, Santa Barbara, California

Abbreviations: (ICU) intensive care unit, (IMC) internal model control, (IOB) insulin on board, (IV) intravenous, (MAC) model algorithmic control, (MPC) model predictive control, (PID) proportional–integral–derivative, (T1DM) type 1 diabetes mellitus

Keywords: artificial pancreas, artificial pancreatic β cell, model predictive control, physiological modeling, PID control, type 1 diabetes mellitus

Corresponding Author: Francis J. Doyle III, Ph.D., Department of Chemical Engineering, University of California, Santa Barbara, CA 93106-5080; email address frank.doyle@icb.ucsb.edu