ICRAMCS 2026

THE EIGHTH EDITION OF THE INTERNATIONAL CONFERENCE ON RESEARCH IN APPLIED MATHEMATICS AND COMPUTER SCIENCE
April 23-24-25, 2026 | Marrakech, Morocco

Incorporating meal absorption as a dynamic compartment: A novel extension of Bergman's model for T1D optimal control

Communication Info

Authors:
Amina ESSAMY[1]
Imane DEHAJ [2]
Hanane FERJOUCHIA [3]

[1] Laboratory Analysis, Modeling and Simulation LAMS, Hassan II University of Casablanca, Morocco

Keywords:
(1) T1D
(2) Bergman Model
(3) Optimal control

Abstract

Managing Type 1 Diabetes (T1D) effectively requires precise modeling of glucose dynamics, especially the sharp postprandial spikes that contribute to long-term complications. Current models often treat meals as mere external disturbances, a simplification that limits both physiological accuracy and therapeutic potential. This study addresses that gap by introducing a novel Four-compartment extension of Bergman's minimal model, where meal absorption is represented as an internal dynamic state rather than an external input. The proposed framework captures the time-dependent release of glucose into the bloodstream following a meal. Mathematical Analysis confirms the model's consistency, establishing existence, uniqueness, boundedness, and positivity of solutions under biologically relevant parameters. Application of Pontryagin's Maximum Principle yields an optimal insulin administration strategy explicitly linked to meal dynamics, producing a feedback control law that adjusts insulin delivery in response to real-time nutrient absorption. Numerical simulations confirm the approach's effectiveness in dampening postprandial glucose excursions and improving overall glycemic stability. By integrating meal dynamics directly into the physiological model, this work provides a more realistic foundation for designing adaptive insulin therapies and supports the development of next-generation artificial pancreas systems.

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