

Technical University of Denmark



Closed-Loop and Semi Closed-Loop Strategies for Control of Blood Glucose in People with Type 1 Diabetes

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Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Boiroux, D., Finan, D. A., Jørgensen, J. B., Poulsen, N. K., & Madsen, H. (2011). Closed-Loop and Semi Closed-Loop Strategies for Control of Blood Glucose in People with Type 1 Diabetes. Poster session presented at Advanced Technologies and Treatment for Diabetes 2011, .

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Abstract

Comparison between 4 insulin administration strategies

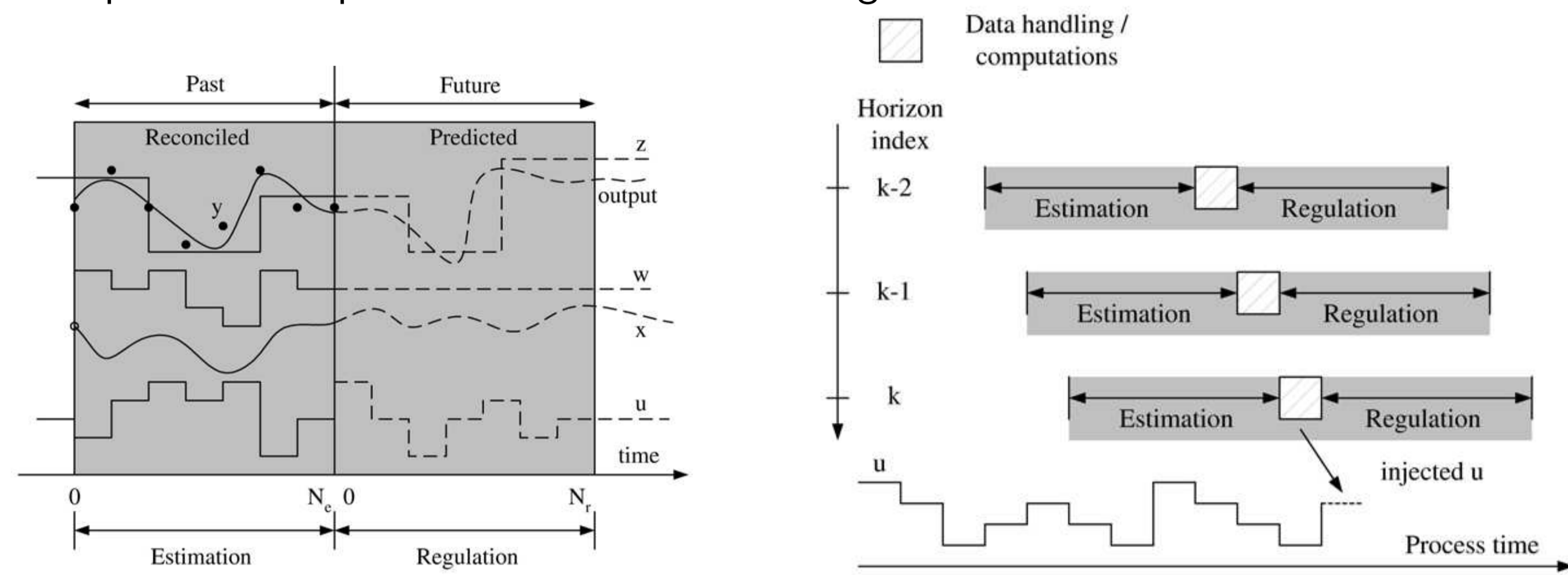
- Nonlinear model predictive control (NMPC) without meal announcement.
- NMPC with meal announcement in advance.
- NMPC with meal announcement at mealtimes.
- Feedforward-feedback controller.

Feedforward-feedback controller

- A time-varying reference signal based on meal announcement reduces the risk of hypoglycemia
- Feedback from a glucose sensor
- Differentiate between basal insulin and boluses
 - Basal insulin compensates for small mismatches
 - Boluses are given at mealtimes

Nonlinear Model Predictive Control (NMPC)

Principle of model predictive control and receding horizon



Discrete-time formulation

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \frac{1}{2} \sum_{k=0}^{N-1} \int_{t_k}^{t_{k+1}} g(x(t), u(t)) dt$$

$$s.t. \quad \begin{aligned} x(t_0) &= x_0 \\ \dot{x}(t) &= f(x(t), u(t), d(t)) \\ y(t) &= g(x(t)) \\ u(t) &= u_k \quad t_k \leq t < t_{k+1} \end{aligned}$$

$$\begin{aligned} u_{\min} &\leq u_k \leq u_{\max} \\ \Delta u_{\min} &\leq \Delta u_k \leq \Delta u_{\max} \end{aligned}$$

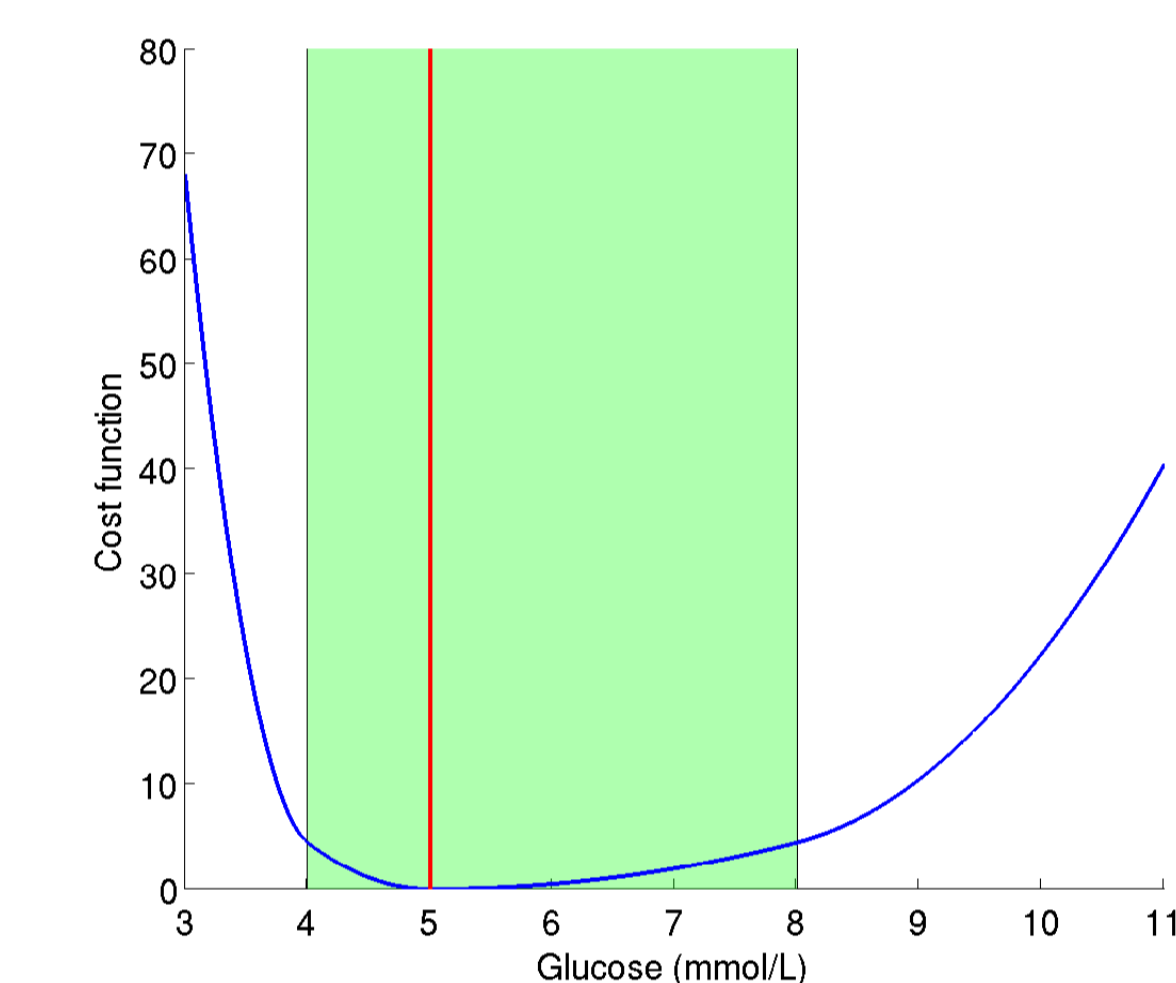


Figure 1: The cost function.

Numerical simulations of NMPC

Scenario

Meal sizes and times

- Breakfast 62g CHO at 6AM
- Lunch 55g CHO at 12PM
- Dinner 50g CHO at 6PM

Simulations

Insulin administration strategies

- Meals are not announced.
- Meals are announced in advance.
- Meals are announced at mealtimes only.

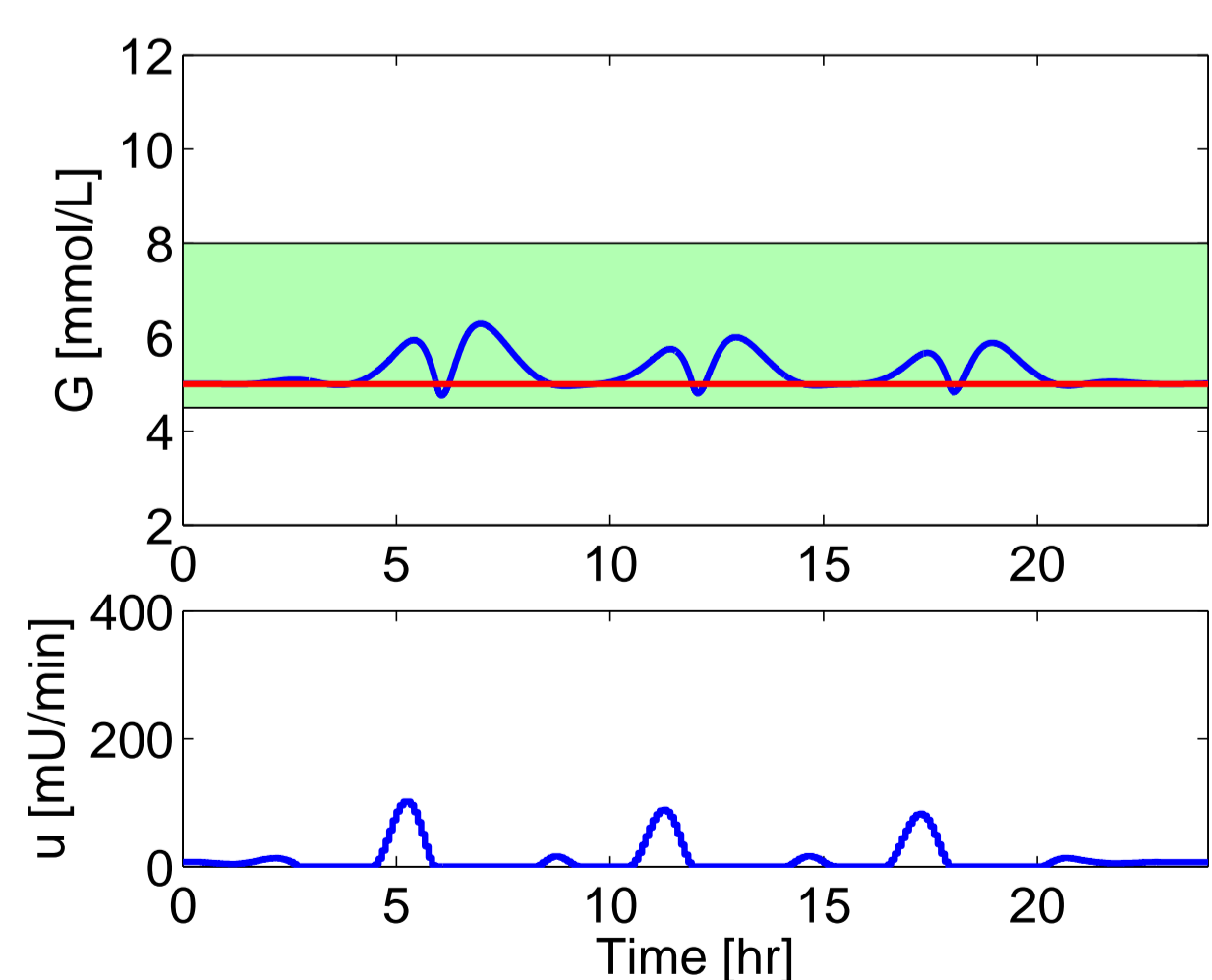


Figure 3: The case with meal announcement in advance of the meal.

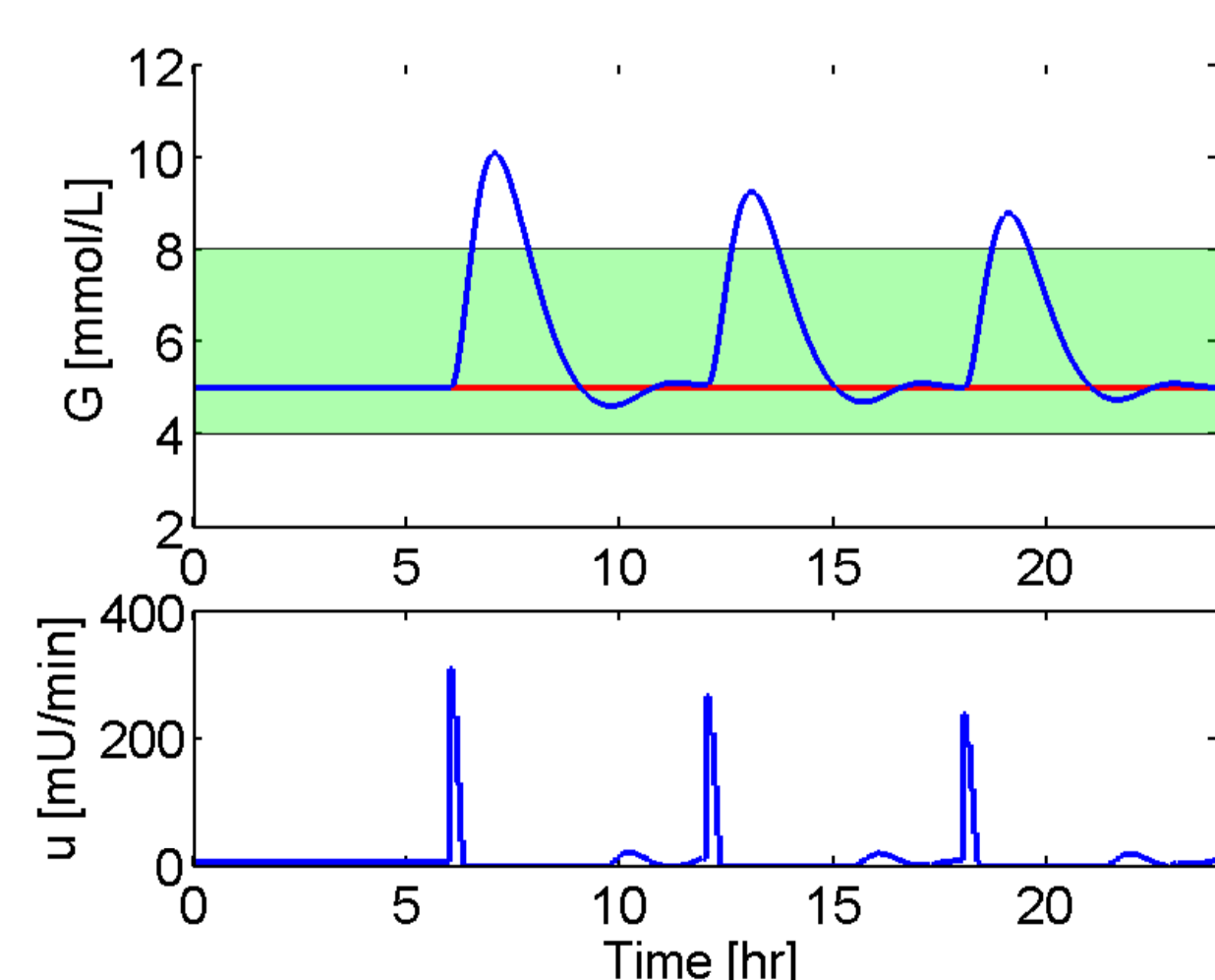


Figure 4: The case with meal announcement at mealtimes.

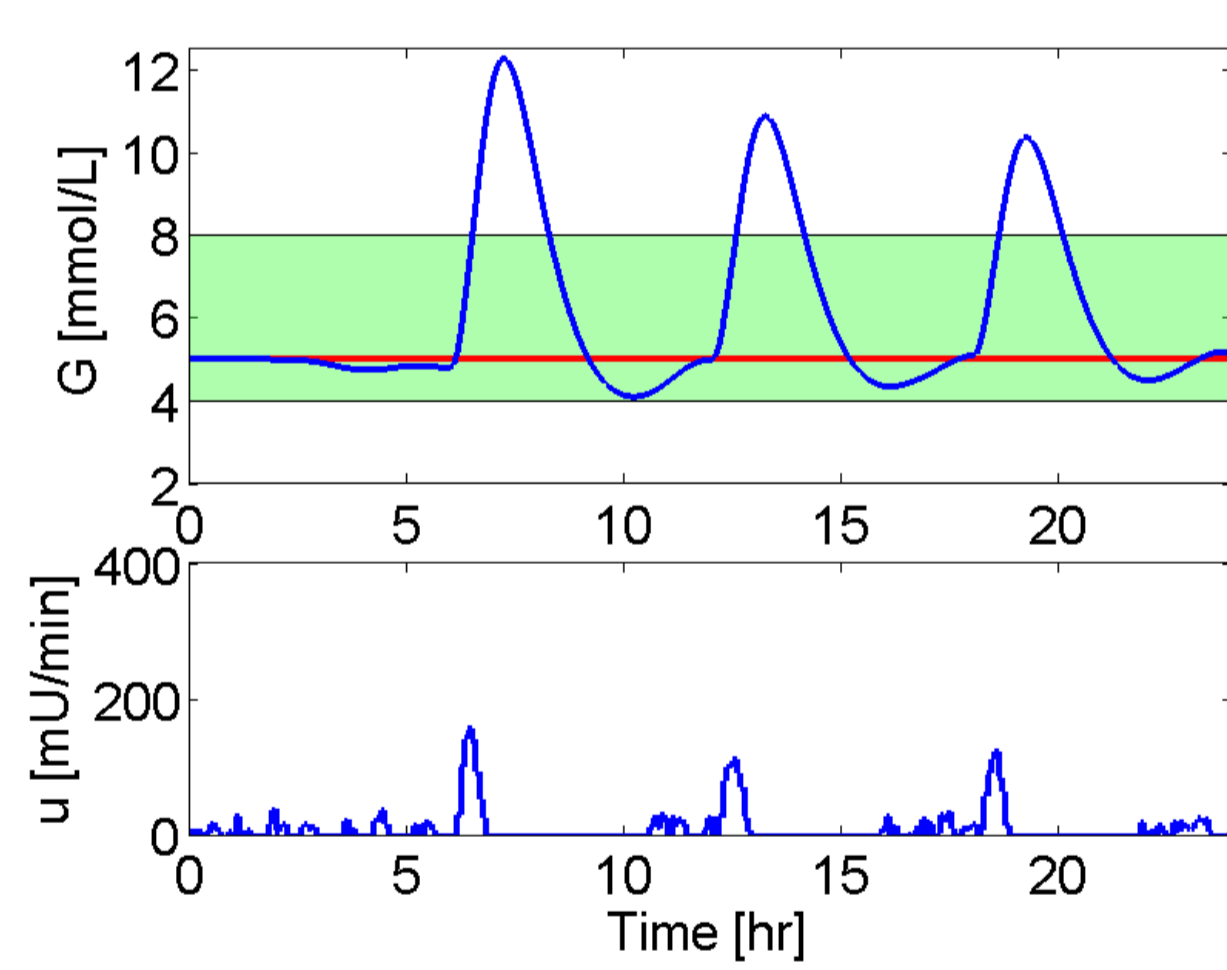


Figure 2: The case without meal announcement.

Numerical simulations of the feedforward-feedback controller

Scenarios

- A decrease by 50% in insulin sensitivity while fasting
- A 75g CHO meal with sensor noise
 - right meal announcement
 - meal size underestimated by 50%
 - meal size overestimated by 50%

Simulations

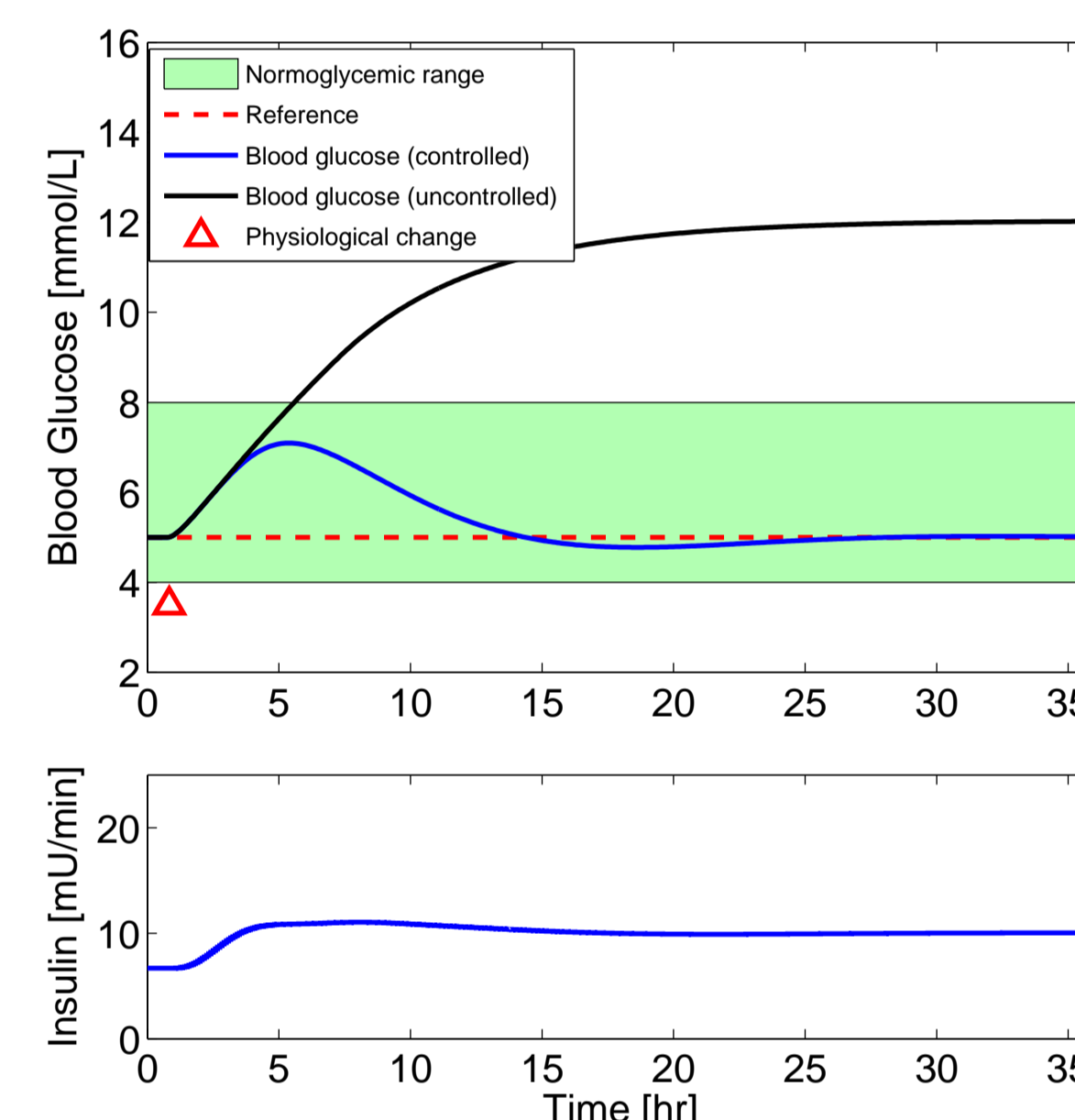


Figure 5: Insulin sensitivity is decreased by 50%.

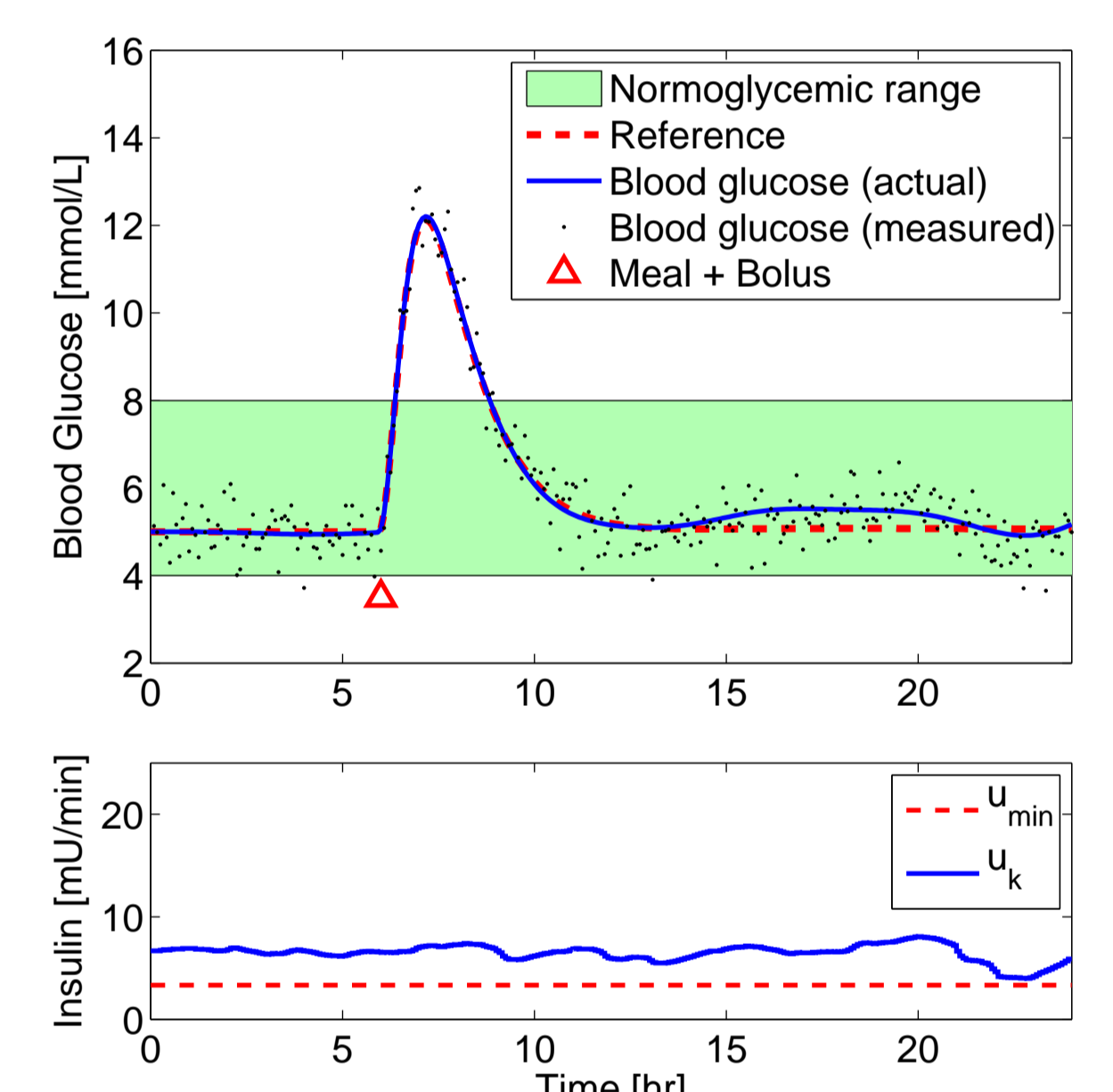


Figure 6: Exact meal size announced.

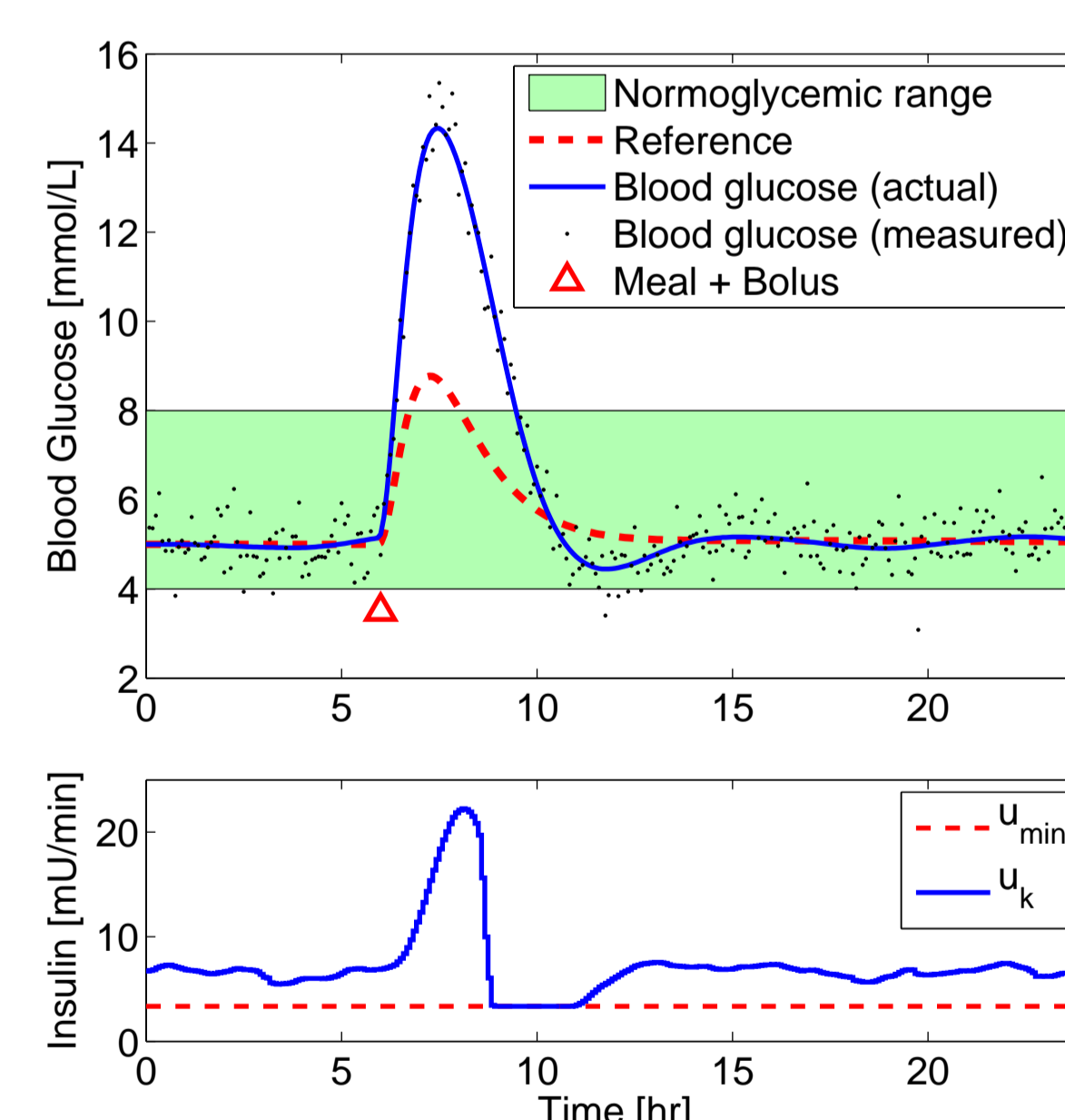


Figure 7: Meal size underestimated by 50%.

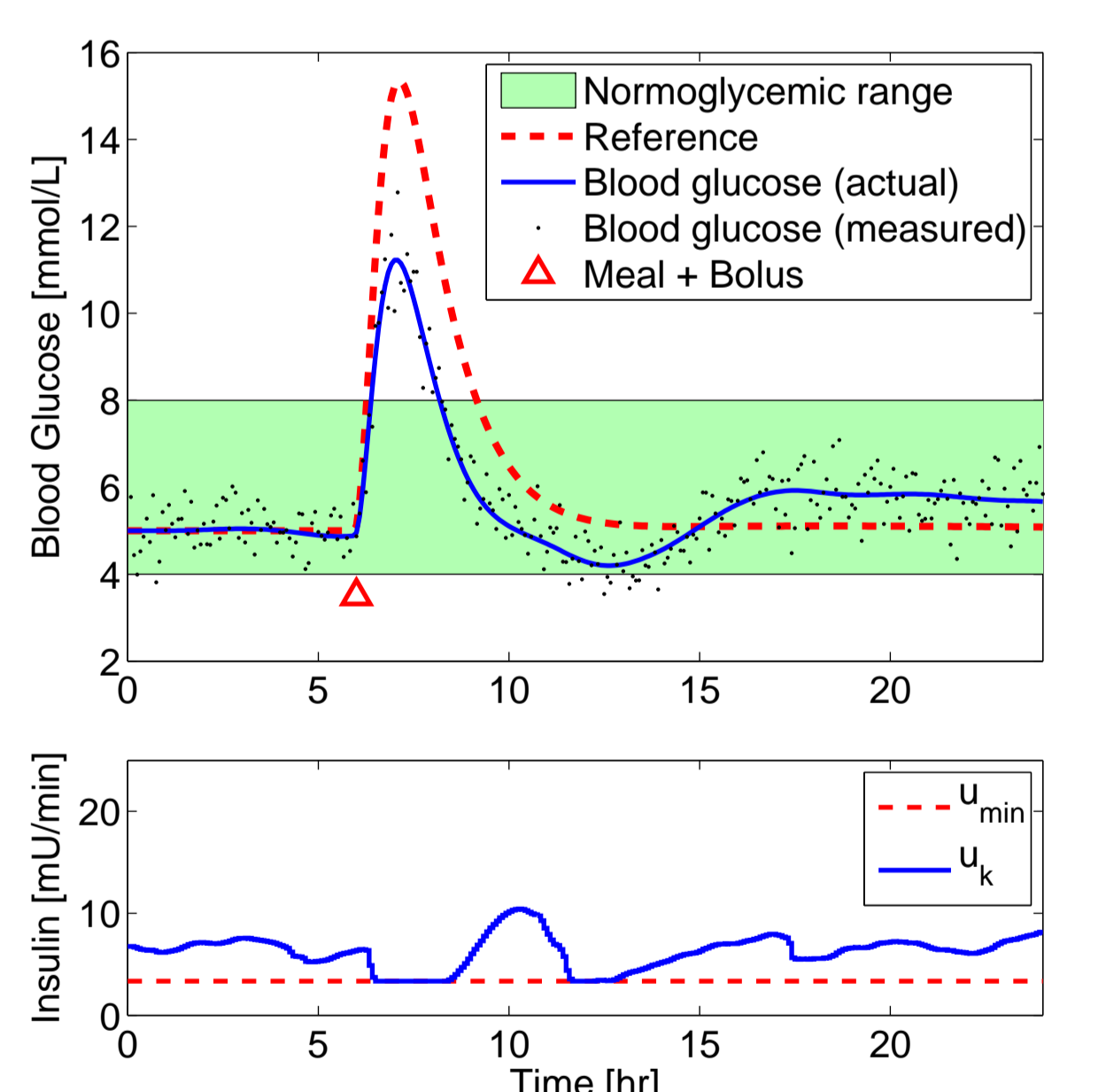


Figure 8: Meal size overestimated by 50%.

Conclusion

- NMPC simulations give an upper-bound on the maximal achievable performance for different meal announcement strategies.
- Utilization of the bolus-like nature of the optimal insulin profile to design a feedforward-feedback controller based on linear MPC.
- Demonstration of the robustness of the feedforward-feedback controller wrt. changes in insulin sensitivity and mismatches in meal announcement in the case where an accurate enough model of the patient is available.