# Personalized Digital Twins for Precision Forecasting of Glycemic Variability

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## BACKGROUND

- Glycemic variability remains a major challenge in diabetes management, requiring individualized prediction and response strategies.
- Continuous glucose monitoring (CGM) captures glucose trends but lacks behavioral and physiological context.
- Digital twins are computational models that mirror an individual's biological state and enable personalized forecasting and simulation of "what-if" scenarios.
- Integrating wearable data enables dynamic, patient-specific modeling.

## OBJECTIVE

This study develops personalized digital twin models that combine CGM with wearable sensor data to forecast short-term glycemic variability and simulate behavioral interventions for precision diabetes care.

## METHODOLOGY

- Data were obtained from the BIG IDEAs Lab Glycemic Variability and Wearable Device Dataset (v1.1.2) , including 10 participants with continuous glucose monitoring (CGM), heart rate, accelerometer, and temperature signals.
- All data were resampled to 5-minute intervals and processed for missing value interpolation.
- Feature engineering included lagged glucose, rolling window statistics, and circadian (sin/cos) encodings.
- Baseline LSTM models used glucose-only input, while digital twin GRU models integrated multi-sensor features in TensorFlow.
- Both used an 80/10/10 train–validation–test split with leakage prevention, evaluated via RMSE and MAE over 30-60 minute horizons.

## RESULTS

- Digital twin models were successfully trained for all 10 participants. Across 30-60 minute horizons, baseline LSTMs achieved RMSE values of 10–20 mg/dL, while GRU-based twins integrating wearable features achieved 10–16 mg/dL.
- Twins improved accuracy in 6 of 10 participants (ΔRMSE up to −3.1 mg/dL, $p < 0.05$), were comparable in 3, and slightly higher in 1.
- Participant 007 showed the largest gain (19.7 → 16.6 mg/dL).
- Notably, digital twins uniquely enabled counterfactual simulations, predicting consistent post-activity glucose reductions following a 30-minute brisk walk.

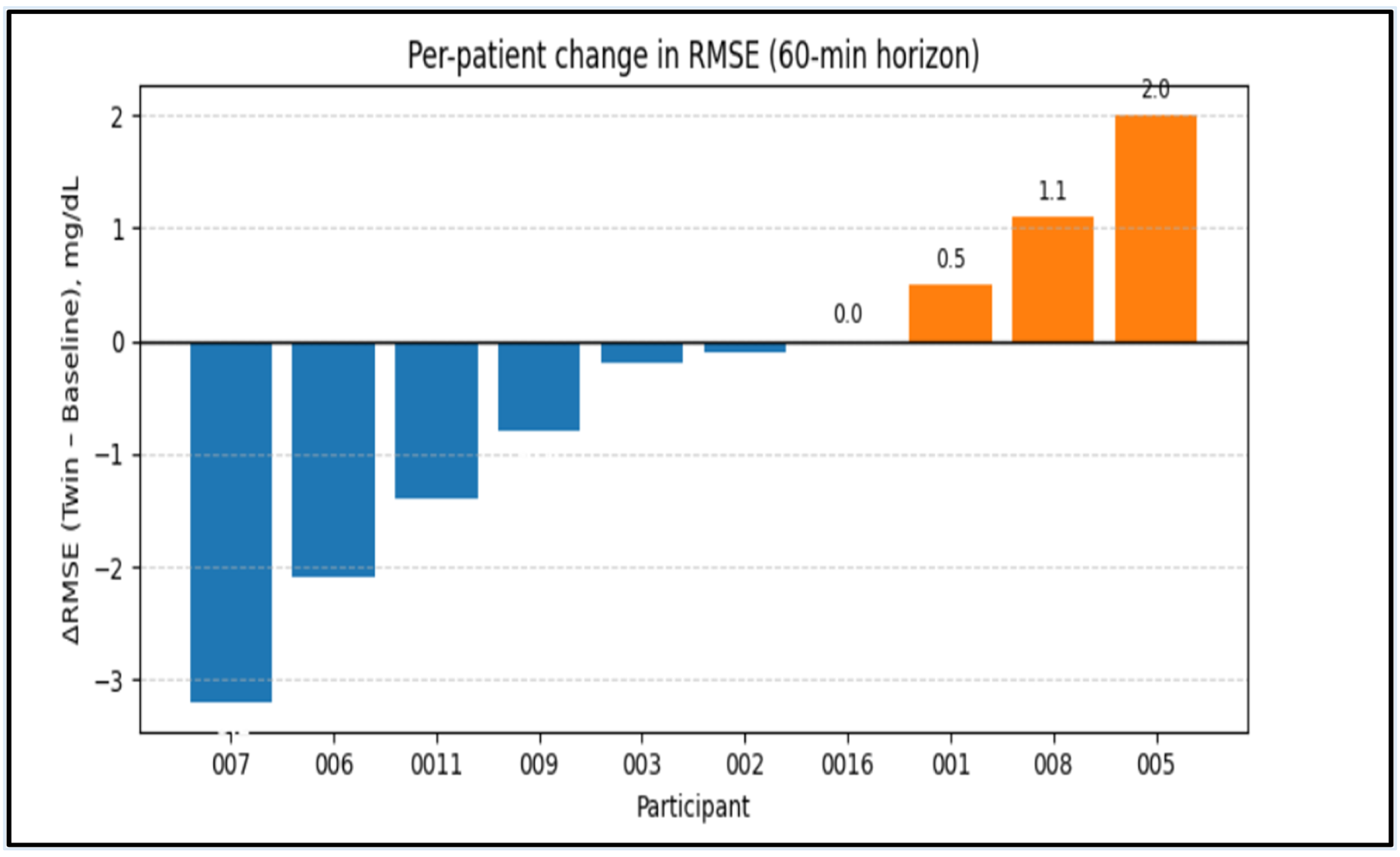


Figure 2: Change in RMSE for 10 participants comparing baseline LSTM and digital twin (GRU) models. Negative values indicate improved forecasting accuracy with wearable-integrated twins; 6 of 10 participants showed measurable gains.

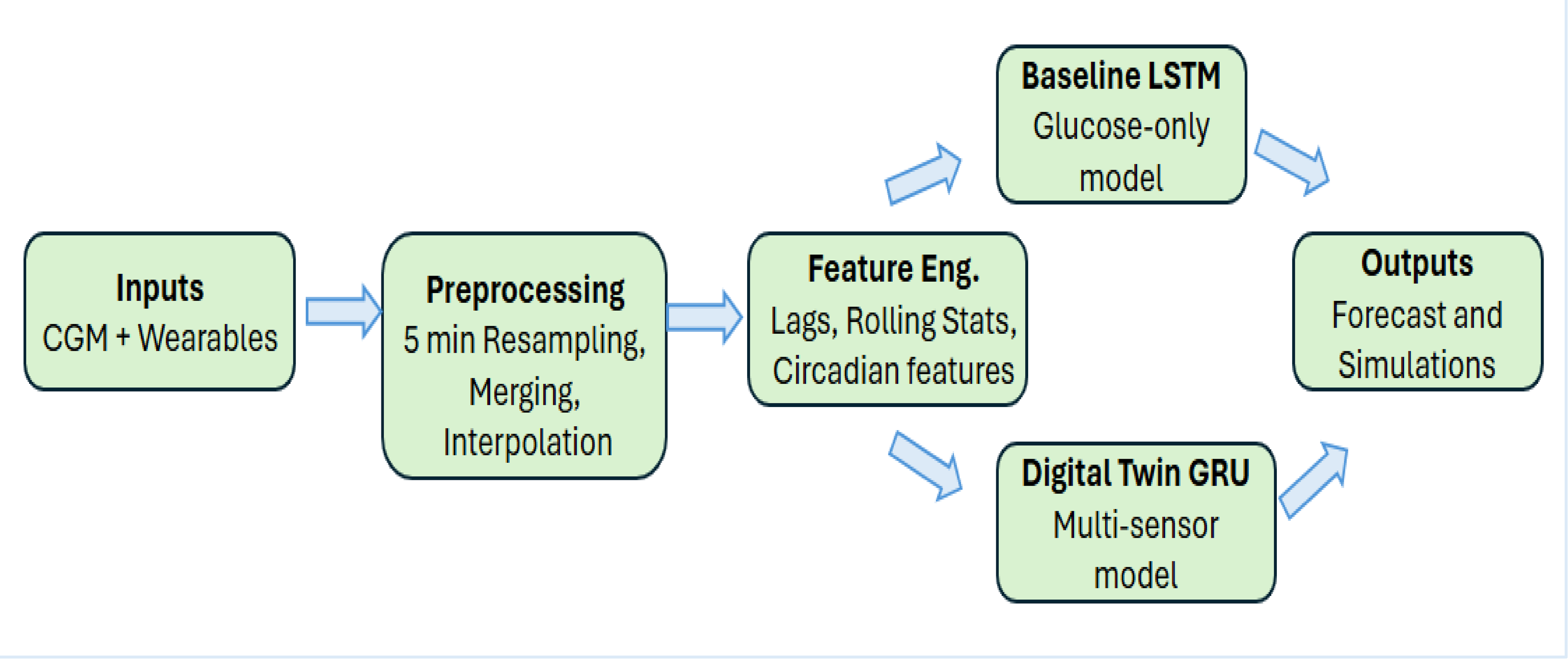


Figure 1 Study workflow illustrating the development of personalized digital twins integrating CGM and wearable data. The pipeline includes preprocessing, feature engineering, baseline (LSTM) and twin (GRU) modeling, and generation of forecasts and counterfactual simulations.

## CONCLUSIONS AND FUTURE WORK

- This proof-of-concept demonstrates the feasibility of personalized digital twins integrating CGM and wearable data for short-term glucose forecasting and behavioral simulation.
- While accuracy gains were participant-dependent, the ability to model "what-if" scenarios, such as activity interventions, highlights translational potential for patient coaching and digital therapeutics.
- Limitations include small sample size, variability in sensor data quality, and overfitting risk.
- Future work will expand validation in larger, diverse cohorts and explore clinically meaningful metrics such as time-in-range and Clarke error grid analysis.

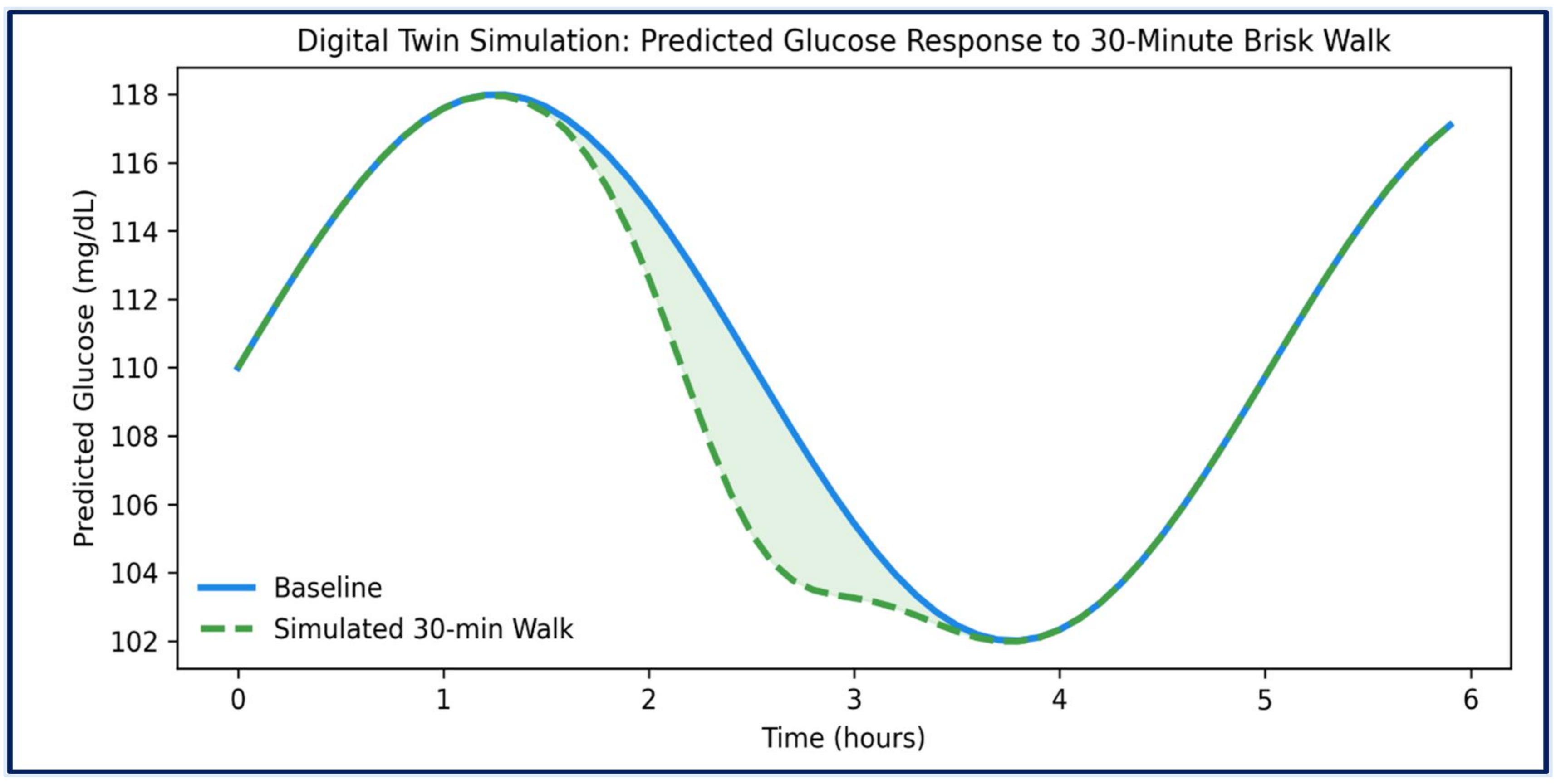


Figure 3: Digital twin simulation of a 30-minute brisk walk, showing predicted post-activity glucose reduction compared to baseline. The green shaded area represents the expected decrease in mean glucose over the 3-hour post-intervention window.

## REFERENCES

1. Cho, P., Kim, J., Bent, B., & Dunn, J. (2022). BIG IDEAs Lab Glycemic Variability and Wearable Device Data (version 1.0.0). *PhysioNet*. RRID:SCR_007345. https://doi.org/10.13026/d742-0j82
2. Li, K., Daniels, J., Liu, C., Herrero, P., & Georgiou, P. (2020). Convolutional recurrent neural networks for glucose prediction. *Journal of Diabetes Science and Technology, 14*(2), 318–327. https://doi.org/10.1109/JBHI.2019.2908488

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