Improved Blood Glucose Forecasting Models using Changes in Insulin Sensitivity in Intensive Care Patients

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Background & Objectives

Glycaemic control (GC) to improve outcomes in intensive care patients has been proven difficult to achieve safely, yielding significant glycaemic variability and hypoglycaemia.

STAR is a model-based GC protocol using a **stochastic model** to forecast distributions of likely future changes in **insulin sensitivity (SI)**, based on its current value. This is used to determine **likely future blood glucose** (BG) levels for a given intervention, enabling optimal dosing (**Figure 1**).

This study investigates a novel 3D model capable to predict likely future distribution of SI using **both current SI and its prior variability (%ΔSI)**.

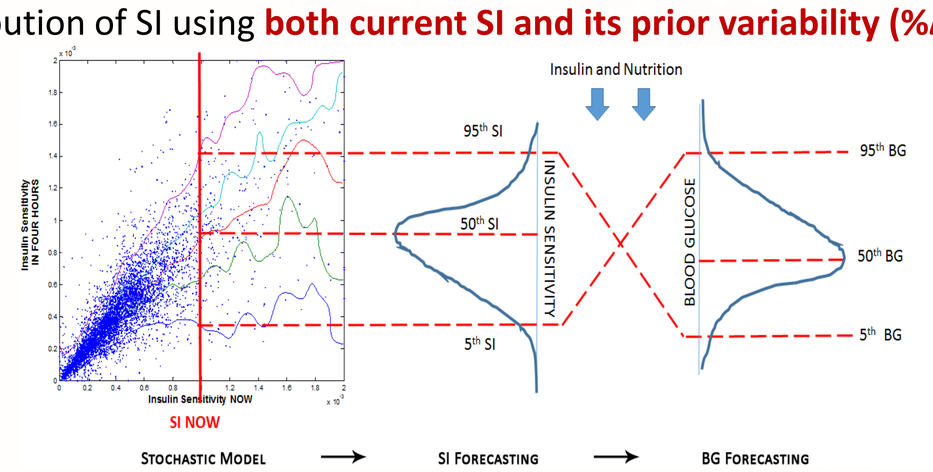

Figure 1 – Future insulin sensitivity (SI) is forecast from current SI. The distribution of future SI is used to predict likely BG outcomes for a given insulin-nutrition treatment intervention.

Methods

Metabolic data from 3 clinical ICU cohorts totalling 819 episodes and 68629 hours of treatment under STAR and SPRINT protocols are used in this study (**Table 1**).

Table 1 – Summary of patient demographics for three cohorts. Results are given as median [IQR] where relevant.

	SPRINT Christchurch	STAR Christchurch	STAR Gyula
# episodes	442	330	47
# hours	39838	22523	6268
% male	62.7	65.5	61.7
Age (years)	63 [48, 73]	65 [55, 72]	66 [58, 71]
APACHE II	19.0 [15.0,24.5]	21.0 [16.0,25.0]	32.0 [28.0,36.0]
LOS - ICU (days)	6.2 [2.7,13.0]	5.7 [2.5,13.4]	14.0 [8.0,20.5]

Insulin sensitivity (SI) is hourly identified from clinical BG and insulin data. SI variability (%ΔSI) is defined as the hour-to-hour percentage change in SI:

$$\%\Delta SI_{\,i} = 100 \times \frac{SI_{i+1} - SI_i}{SI_i}$$

Data triplets ($\%\Delta SI_n$, SI_n, SI_{n+1}) are created and grouped together in bins of size %ΔSI = 10% and SI_n = 0.5e-4.

The 5th, 50th, and 95th percentile of SI_{n+1} are determined for each bin where data density is high enough (>100 triplets).

The new model is compared to the previous stochastic model by

- Comparing their 90% CI prediction range and the percentage change in their prediction widths
- Assessing their predictive power, computing median [IQR] per-patient percentage prediction of SI within the 5th-95th and 25th-75th percentile ranges of model predictions.

Results

Results show the previous model is over-conservative for ≈77% of the data, mainly where %ΔSI is within an absolute 25% change (**Figure 2**).

The percentage change in the 90% CI width in this region is reduced by ≈25-40%. Conversely, non-conservative regions are also identified, with 90% CI width increased up to ≈ 80% (**Figure 3**).

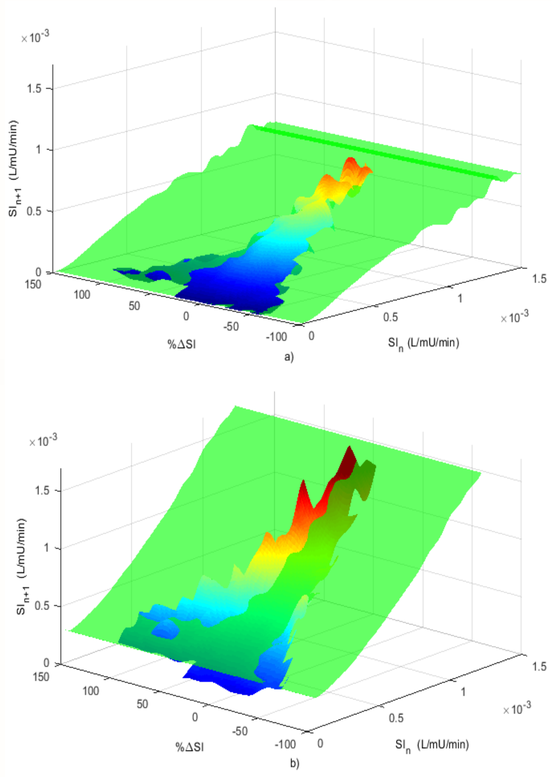

Figure 2 – Comparison between the 3D model (colour) and the original 2D model (green) for the 5th (a) and 95th (b) percentiles.

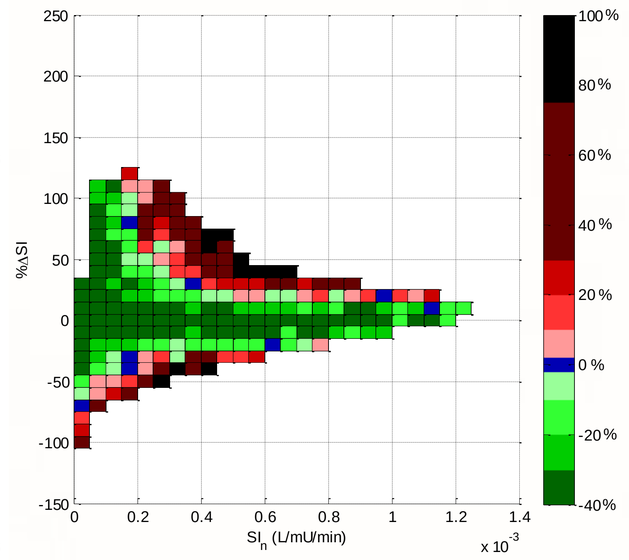

Figure 3 – Percentage change in the width of the 5th-95th percentile range when the new 3D model is compared to the previous 2D model. Green and red areas suggest over and under conservative behaviour respectively within the 2D model.

As shown in **Table 2** and **Figure 4**, the predictive power is similar for both model (60.3% [47.8%, 71.5%] vs. 51.2 [42.9%, 59.2%] within 25th-75th and 93.6% [85.7%, 97.3%] vs. 90.7% [84.4%, 94.6%] within 5th-95th range).

Table 2 – Per-patient predictive power comparison between previous and new stochastic model. Results are given as median [IQR].

	2D Model	3D model
Median % prediction within 25th-75th range	63.1% [62.8%, 63.4%]	51.8% [51.5%, 52.1%]
Median % prediction within 5th-95th range	92.6% [92.5%, 92.7%]	89.7% [89.6%, 90.0%]
Median % reduction 90% CI width	30.8% [30.5%, 31.1%]	

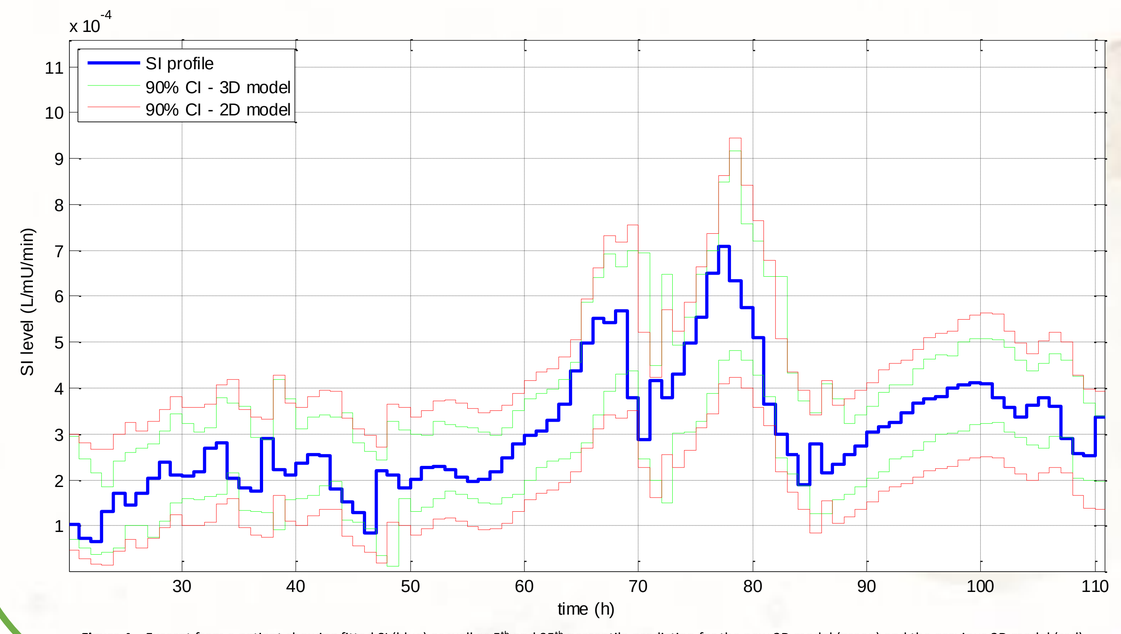

Figure 4 – Excerpt from a patient showing fitted SI (blue) as well as 5th and 95th percentile prediction for the new 3D model (green) and the previous 2D model (red). The new model predictive range is generally narrower than the old model.

Conclusions

The new 3D model achieved **similar predictive power** as the previous model, **while reducing the 5-95th percentile prediction range** for more than 77% of the data. If the over-conservative regions allows **more aggressive dosing for stable patient**, under-conservative regions identify **potential risks from over-aggressive treatment** for more variable patients.

These outcomes improve both **performance** and **safety**, and thus **patient outcomes**.

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