

# Rethinking glycaemic control in critical illness – from concept to clinical practice change

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## ABSTRACT

**Objective:** To examine the practical difficulties managing hyperglycaemia in critical illness and present recently developed model-based glycaemic management protocols to provide tight control.

**Background:** Hyperglycaemia is prevalent in critical care. Current published protocols require significant added clinical effort and result in highly variable results. No currently published methods successfully address the practical clinical difficulties and patient variation while also providing safe, tight control.

**Methods:** We develop a unique model-based approach that manages both nutritional inputs and exogenous insulin infusions. Computerised glycaemic control methods and proof-of-concept clinical trial results are presented. The system is simplified to a set of tables and adopted as a clinical practice change. Eight pilot test cases are presented to demonstrate the overall approach.

**Results:** Computerised clinical control trials lowered blood to 4-6.1 mmol/L within 10 hours. Over 90% of pre-set hourly blood glucose targets were achieved within measurement error. Eight pilot tests of a simplified, table-based system covering 1651 patient hours produced an average glucose level of 5.7 +/- 0.9 mmol/L, and 60% of the controlled time was in the 4-6.1 mmol/L band. Just under 90% of measurements were between 4.0- 7.0 mmol/L, with 96% between 4-7.75 mmol/L. There were no hypoglycaemic episodes with a minimum of 3.2 mmol/L, and no additional clinical intervention was required.

**Summary:** The overall approach of modulating insulin and nutrition challenges the current practice of using only insulin to reduce glycaemic levels, which often results in large variability and poor control. The protocol was developed from model-based analysis and proof of concept clinical trials, and then generalised to a simple, clinical practice improvement. The results show extremely tight control within safe glycaemic bands.

## INTRODUCTION

Hyperglycaemia is prevalent in critical care, even with no prior diabetes [1-4]. Increased secretion of counter-regulatory hormones stimulates endogenous glucose production and increases effective insulin resistance [3, 4]. Studies also indicate that high glucose nutritional regimes often result in excess glucose [5-10], exacerbating hyperglycaemia.

Hyperglycaemia worsens outcomes, increasing the risk of severe infection [11], myocardial infarction [1], and critical illnesses such as polyneuropathy and multiple-organ failure [2]. Evidence also exists of significant reductions in other therapies with aggressive glycaemic control [12]. More importantly, van den Berghe et al. [2, 13] and Krinsley et al. [14, 15] showed that tight glucose control to a limit of 6.10-7.75mmol/L respectively reduced ICU patient mortality by up to 30-45% overall or for various subgroups.

Regulating blood glucose levels in critical care using simple model-based protocols and insulin alone has been moderately successful [16-19], while sliding scales and other ad-hoc methods have not always been effective [20-23]. Additionally, some studies find intensive insulin therapy “taxing” [24-26], noting that van den Berghe et al [2, 13] required specialised additional staff. Hence, despite the potential, many intensive care units do not use fixed protocols or necessarily agree on what constitutes acceptable or desirable glycaemic management and performance [25].

Nonlinear, model-based control protocols for insulin-mediated glycaemic control have been developed [17, 27, 28]. These protocols are challenged by the significantly elevated insulin resistance often encountered in broad critical care cohorts. In particular, insulin effect saturates at high concentrations [17, 29, 30], limiting the achievable glycaemic reductions in the presence of significant insulin resistance when using only insulin. However, effective glycaemic control is still possible by also controlling the exogenous nutritional inputs exacerbating the original problem [5-10]. In fact, research that specifically lowered glucose nutrition significantly reduced average blood glucose levels without added insulin [5, 10], where Krishnan et al showed that feeding 33-66% of the ACCP guidelines minimised mortality and hyperglycaemia [10].

Overall, any glycaemic control protocol must reduce elevated blood glucose levels in a controlled, predictable manner, while accounting for inter-patient variability, conflicting therapies and varying physiological condition. Hence, it must be adaptive and/or able to identify changes in patient metabolic status, particularly with respect to insulin sensitivity. It must also be simple enough to be easily implemented and effective enough to be essentially automated to minimise the consumption of clinical time and expertise.

Hence, this paper examines the application of models and control theory to this problem. The goal is to employ these tools to better manage this complex problem for improved outcome. A second, equally important, goal is to use these tools in a way that can be readily transferred to non-engineering trained clinical staff without adding excessive training or task burden. In itself, satisfying these two goals creates a significant and challenging opportunity to integrate engineering and clinical practice to provide improved patient care.

## METHODS

### *A Model of Glucose-Insulin Regulation and Computerised Control*

Tight blood glucose control requires a patient-specific glucose-insulin regulatory system model that captures the fundamental dynamics. Chase et al. [16, 17, 27] used a system model that captured rate of insulin utilisation, insulin losses and saturation dynamics, and is also used in this study. The model equations and basic justification are presented in the Appendix and several references detailing its use are shown there for the interested reader or potential user.

With regard to safe, clinical application, the model has been validated over long periods using retrospective data from 17 patients in a data audit [27, 31, 32]. These patients had an average length of stay of 3.1 days and average APACHE II score of 21.8 representing a broad cross section of the typical ICU cohort. Fitted data and forward glucose predictions had errors of 2-10%, which is at or within the measurement error. The model was also validated over short, highly dynamic periods using data from 146 hyperinsulinaemic, euglycaemic clamp trials obtained from the intervention study of McAuley et al [33]. All glucose and insulin fitting errors were within reported measurement errors. More importantly, the model-based insulin sensitivity parameter,  $S_I$ , correlated strongly with the clamp derived ISI,  $r = 0.985$  [34, 35]. Hence, the model is more than capable of capturing the metabolic status of the highly dynamic ICU patient, and is thus suitable for implementing tight control in critical care.

Seven proof-of-concept case studies spanning 10hrs were run beginning at 0900h. Blood glucose at 0900h is taken as the equilibrium level,  $G_E$ , after which the feed rate is decreased by 20-40% as an initial challenge, depending on current glucose level and feed rate. Blood glucose is measured at 15min intervals using a Glucocard™ Test Strip II until 1000h and analysed. At 1000h insulin sensitivity,  $S_I$ , is evaluated and a blood glucose target set for a 10-15% reduction to a minimum of 5mmol/L. Blood glucose is monitored half-hourly after 1000h and each a new target is set after re-evaluating  $S_I$  from the prior hours data. Each hour, the controller determines the required combination of control inputs (insulin bolus size, insulin infusion rate and feed rate) to achieve the target depending on fitted  $S_I$  and estimated levels of insulin effect saturation. The overall clinical trial procedure is outlined in Figure 1.

Total insulin prescribed is limited to 6U/hr to minimise saturation and the administration of ineffective insulin [17, 29, 30]. Insulin is given predominantly in bolus form for safety. The minimum feed rate is 280kcal/day of glucose or 40% of the average maximum goal feed rate. Using the RESOURCE™ Diabetic feed formulation, at 280kcal/day of glucose, the total caloric intake is still 778kcal/day [36] for a typical patient, exceeding the minimum level below which there is an increased risk of bloodstream infections [37].

### *A Simpler Protocol - SPRINT*

However, the computational resources are not typically available in critical care for computerised control methods. In addition, their complexity limits the easy large-scale implementation required to test overall safety and efficacy. In addition, the

measurement frequency of 30 minutes is currently unsustainable in regular clinical practice, requiring 1-2 hourly measurements. Hence, a simpler paper-based method has been developed to mimic this protocol, as described in [22].

The SPRINT (Specialised Relative Insulin + Nutrition Tables) protocol consists of two wheels dedicated to enteral nutrition optimisation (specifically RESOURCE<sup>®</sup> Diabetic or Glucerna in this case) and insulin bolus administration (Actrapid), and is shown in Figures 2 and 3. Instructions are printed directly on the tables, and a more detailed guide is located at each patient workstation. The current starting criterion is 2 successive blood glucose measurements over 8.0mmol/L. Blood glucose is then measured hourly and used to determine the next hour's intervention. Criteria for 2-hourly measurement and stopping the protocol are given in Figures 4-5.

The "Feed Wheel" instructions in Figure 2 are used to determine the feed rate as a percentage of the patient's clinically determined goal feed. The result is based on the previous hour's feed rate, current blood glucose concentration, and whether blood glucose is rising or falling. The percentage goal feed is converted into an absolute feed rate (in ml/hr) using a patient-specific conversion sticker attached to the table. The "Insulin Wheel" shown in Figure 3 is then used to determine the insulin bolus size based on the previous insulin bolus size, current blood glucose level, and whether blood glucose has decreased more than 1.5mmol/L. The feed and insulin interventions are also recorded on the patient's chart. Hence, the method is effectively fully automated.

Hourly blood glucose measurements are used to ensure tight control. Two-hourly measurements are used when the patient is stable, defined as 3 consecutive measurements in the 4.0-6.0mmol/L band (Figure 4). For two-hourly measurements, the feed rate is maintained constant, and the same insulin bolus is administered again on the hour between measurements. Two-hourly measurements are continued until the patient leaves the 4.0-6.0mmol/L band or when SPRINT is stopped.

SPRINT is stopped when the patient is stable, normoglycaemic, and adequately self regulating. Figure 5 defines this state as 6 or more hours in the 4-6.0mmol/L band, with over 80% of goal feed rate and a maximum of 2U per hour of insulin. Finally, insulin is always administered via bolus for patient safety, thus avoiding infusions being left on at levels inappropriate for evolving patient condition.

## RESULTS

### *Computerised Tight Glucose Control Trial Results*

The patient cohort for 7 proof of concept tests is shown in Table 1. Table 2 shows the resulting target errors and intervention for the course of each trial. The overall mean target error for all trials is 8.9% (0.5mmol/L), absolute range [0, 2.9] mmol/L, and 46% of targets are achieved within  $\pm 5\%$  and 20% are outside the 3-10% measurement error. Mean target error for errors  $>5\%$  is 14.3% (0.79mmol/L). Out of 63 targets, 4 had errors  $>20\%$ , so that 94% of all target measurements are within  $\pm 20\%$  of targets. Overall, 90% of target errors can be explained by reported measurement errors. Larger errors are attributable to sudden changes in patient condition, such as the onset of atrial fibrillation, as described in detail in [38, 39].

## *Clinical Application of the SPRINT Protocol*

SPRINT has been implemented as a clinical practice change in the Department of Intensive Care at Christchurch Hospital and ethics committee approval has been obtained for the audit, analysis and publication of this data. For proof of concept, the first 8 patients tested as an initial pilot are presented. There were no specific exclusion criteria for the patients selected. The average APACHE II score is 24 (range: 11-37), the mean age is 58 (range: 43-80) with 4 male and 4 female, and the mean trial period is 206 hours (range: 32-355).

Figure 6 shows a typical trial period covering 163 hours for a patient with APACHE II score of 21. The average blood glucose is 5.4, which was achieved with an average hourly bolus of 2.3U and an average feed rate of 85% (595 kcal/day of glucose, 1700kcal/day total). Note that 85% of all measurements are in the 4-6.1 mmol/L band and 97% are in the 4-7.75 mmol/L band.

Over all 8 patients, there were 1651 hours of control using 1206 measurements, indicating that 445 measurements or 54% of the time was controlled with 2-hourly measurements, minimising clinical effort. The average blood glucose was 5.7 mmol/L (+/- 0.9 mmol/L standard deviation). More importantly, 69% of measurements were in the 4-6.1 mmol/L band, 89% in the 4-7.0 mmol/L band, and 96% in the 4-7.75 mmol/L band. The lowest measurement was 3.2 mmol/L, which is not extreme, and only 22 (1.8%) of all measurements were less than 4.0 mmol/L. The average insulin used was 2.6 U/hr and the average enteral nutrition rate was 68% of goal feed (1308 total kcal/day). Note that the feed rate is 15% higher than retrospective Christchurch Hospital data for a similar cohort [27, 32]. ICU mortality for this pilot was 1 of 8.

These results show that extremely tight control was implemented using an extremely simple insulin and nutrition protocol. Almost 90% of all measurements were less than 7 mmol/L, which is much tighter than reported in other studies [2, 15, 19, 26, 40]. More importantly, it required no specialised clinical intervention at any time.

Finally, the specific layout of the tables/wheels resulted from extensive consultation with ICU staff and brief one-to-one training. Clinical staff became proficient in minutes and report that the system is very easy to use. The covered wheel concept reduces table complexity and user error. More specifically, an evaluation survey of nursing staff opinion of the SPRINT system was conducted, and the results are summarised in Table 3. Of 27 respondents to 3 questions, 72 of the 76 total responses, or 95%, rated SPRINT as satisfactory or better, with 74% rating it good or very good. There were 5 questions left unanswered on those surveys returned. Thus, SPRINT is simple enough to readily integrate with any typical ICU practice.

## **DISCUSSION**

This approach of modulating nutrition in addition to exogenous insulin is a significant departure from other approaches, which use insulin alone to reduce glycaemic levels [2, 13-19, 21]. Despite concerns, recent studies show that low-calorie nutritional inputs reduce hyperglycaemia [5, 8, 41, 42], and above ~30% of standard goal feed rate do not increase infectious complications [37, 42]. More specifically, Krishnan et

al [10] showed that feeding over 66% of the ACCP recommended rates increased ICU mortality, and suggested that the ACCP caloric targets may thus be set too high.

In addition, hyperglycaemia has also been shown to exacerbate muscle protein catabolism in burn patients [43] indicating that excessive nutrition and hyperglycaemia should be avoided in this instance, as well. However, lower amounts of glucose up to 12.5kcal/kg (1000kcal per day for an 80kg male), did not significantly increase hyperglycaemia or infections complications [42]. Finally, reduced caloric nutritional support has been effective in paediatric cases and for the obese [44-46]. Thus, there is reasonable evidence that temporary, moderate reductions in nutrition will not reduce other clinical outcomes. However, extreme, long-term underfeeding should be avoided [47].

Finally, it is also important to note the effect of patient cohort, and in particular level of illness as measured by APACHE II score, on the results. Overall, the clinical results showed tight control to less than 6.1mmol/L for a cohort with median APACHE II score of 23 (range: 17-31). In comparison, van den Berghe et al [2] achieved similarly tight control with median APACHE II score of 9 (inter-quartile range: 7-13), which represents a much lower level of critical illness. For a more comparable ICU population, Krinsley [14, 15] showed tight control to a higher 7.75mmol/L for a cohort with median APACHE II of 16 (inter-quartile range: 10-23). Both studies used insulin alone. Hence, the added control obtained by modulating nutrition, as well as insulin, to control hyperglycaemia is seen in the ability to achieve tight control to a level similar to that reported in van den Berghe et al [2] for a significantly more critically ill ICU cohort.

## CONCLUSIONS

The clinical case studies conducted during this study demonstrate the potential of the control algorithms presented for tight, set-point regulation of hyperglycaemia across a range of critically ill patients. The model and algorithms developed are capable of capturing a patient's metabolic status, despite inter-patient variability and time varying physiological condition by accounting for all critical, physiologically justified non-linear dynamics. More importantly, they indicate that extremely tight control for significantly ill ICU patients can be achieved through careful application of insulin and nutritional feed rate reductions. The simplified protocols presented outperform other published data in initial pilot studies and can be implemented in any typical ICU. Overall, the research presented is a significant step towards more fully automated adaptive control of hyperglycaemia in critically ill patients, leading to reduced complications and mortality.

To aid dissemination of these results, the SPRINT wheels and related data for implementation are also available by contacting the corresponding authors directly.

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## Appendix: Insulin-Glucose Metabolic System Model

The metabolic system model equations are defined [16, 17, 27, 39]:

$$\dot{G} = -p_G G - S_I (G + G_E) \frac{Q}{1 + \alpha_G Q} + P(t) \quad (1)$$

$$\dot{Q} = -kQ + kI \quad (2)$$

$$\dot{I} = -\frac{nI}{1 + \alpha_I I} + \frac{u_{ex}(t)}{V} \quad (3)$$

$$P(t_i < t < t_{i+1}) = \bar{P}_{i+1} + (P(t_i) - \bar{P}_{i+1})e^{-k_{pd}(t-t_i)} \text{ where } \bar{P}_{i+1} < P(t_i) \quad (4)$$

$$P(t_i < t < t_{i+1}) = \bar{P}_{i+1} + (P(t_i) - \bar{P}_{i+1})e^{-k_{pr}(t-t_i)} \text{ where } \bar{P}_{i+1} > P(t_i) \quad (5)$$

### Glossary:

$G(t)$	plasma glucose concentration above equilibrium [mmol/L]
$I(t)$	plasma insulin concentration [mU/L]
$G_E$	equilibrium plasma glucose concentration [mmol/L]
$Q(t)$	interstitial insulin concentration [mU/L]
$k$	rise rate of interstitial insulin concentration from plasma and decay rate of insulin concentration from interstitium [1/min]
$p_G$	fractional glucose clearance rate [1/min]
$S_I$	insulin sensitivity [L/(mU.min)]
$V$	insulin distribution volume [L]
$n$	decay rate of insulin from plasma [1/min]
$P(t)$	total plasma glucose input [mmol/(L.min)]
$u_{ex}(t)$	total insulin input into plasma (exogenous) [mU/min]
$\alpha_I$	Michaelis-Menten saturation parameter for plasma insulin disappearance [L/mU]
$\alpha_G$	Michaelis-Menten saturation parameter for insulin-dependent glucose clearance [L/mU]
$k_{pr}$	rise rate of rate of plasma glucose input from enterally administered feed rate [1/min]
$k_{pd}$	decay rate of rate of glucose input into plasma from enterally administered feed rate [1/min]
$\bar{P}_i, \bar{P}_{i+1}$	stepwise consecutive enteral glucose feed rates [mmol/L.min]

Generally,  $k$ ,  $n$ ,  $\alpha_G$ ,  $\alpha_I$  and  $V$  can be identified from generic population values [16, 31]. The model does not include endogenous insulin or specific terms for endogenous glucose production (EGP). Any immeasurable, endogenous insulin supply is thus accounted for in the identification of the time-varying endogenous clearance parameter,  $p_G$ . Similarly the level of the patient's stress-induced insulin resistance is captured in the identified insulin sensitivity,  $S_I$ , value and can thus serve as an additional metric for severity of illness [16, 17, 27, 31, 38]. Computational methods used to evaluate this model are described in [16], and include integral-based parameter identification techniques described in [27].

## FIGURES

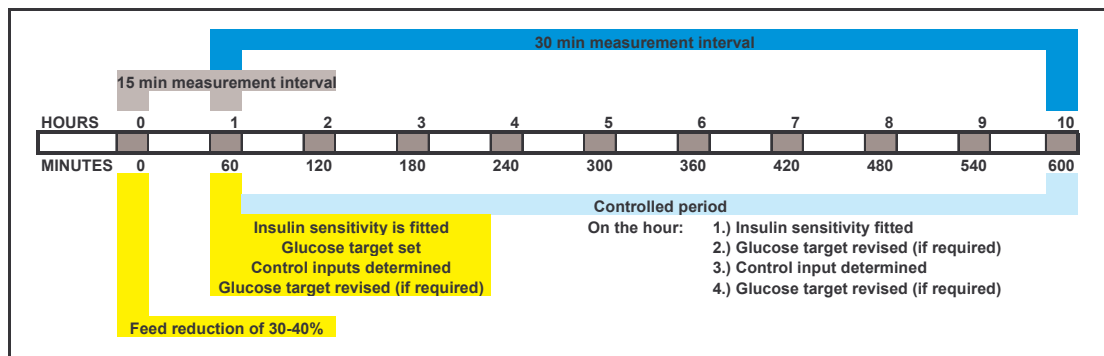


Figure 1: 10-hour clinical trial procedure

# Feed Wheel

## START:

1. Use the feed conversion sticker to find the current percentage feed level.

2. Rotate wheel to patient's current percentage feed level marked in grey.

3. Has the glucose level decreased from the last measurement by more than 1.5 mmol/L?

**YES:** Use side "B" of wheel

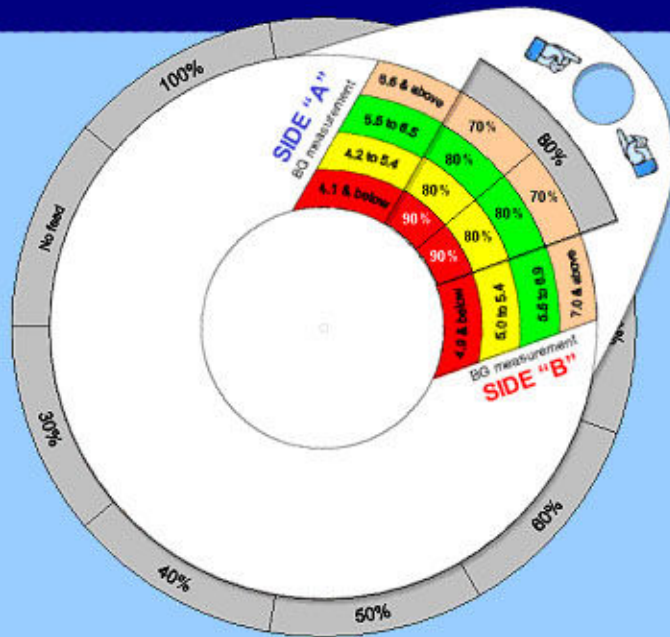
**NO:** Use side "A" of wheel

4. Using the selected side of the wheel from 3, match the current glucose level to the new feed level.

5. Use the feed conversion sticker to find the absolute feed in [mL/hr].

6. Use Insulin Wheel if you have not done so already.

Attach feed conversion sticker here



SPRINT – 11/8/2005

(a)

# Feed Wheel

## START:

1. Use the feed conversion sticker to find the current percentage feed level.

2. Rotate wheel to patient's current percentage feed level marked in grey.

3. Has the glucose level decreased from the last measurement by more than 1.5 mmol/L?

**YES:** Use side "B" of wheel

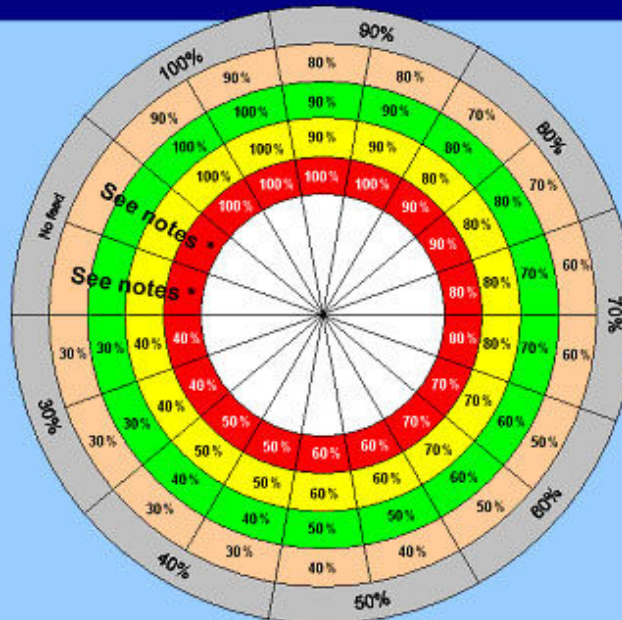
**NO:** Use side "A" of wheel

4. Using the selected side of the wheel from 3, match the current glucose level to the new feed level.

5. Use the feed conversion sticker to find the absolute feed in [mL/hr].

6. Use Insulin Wheel if you have not done so already.

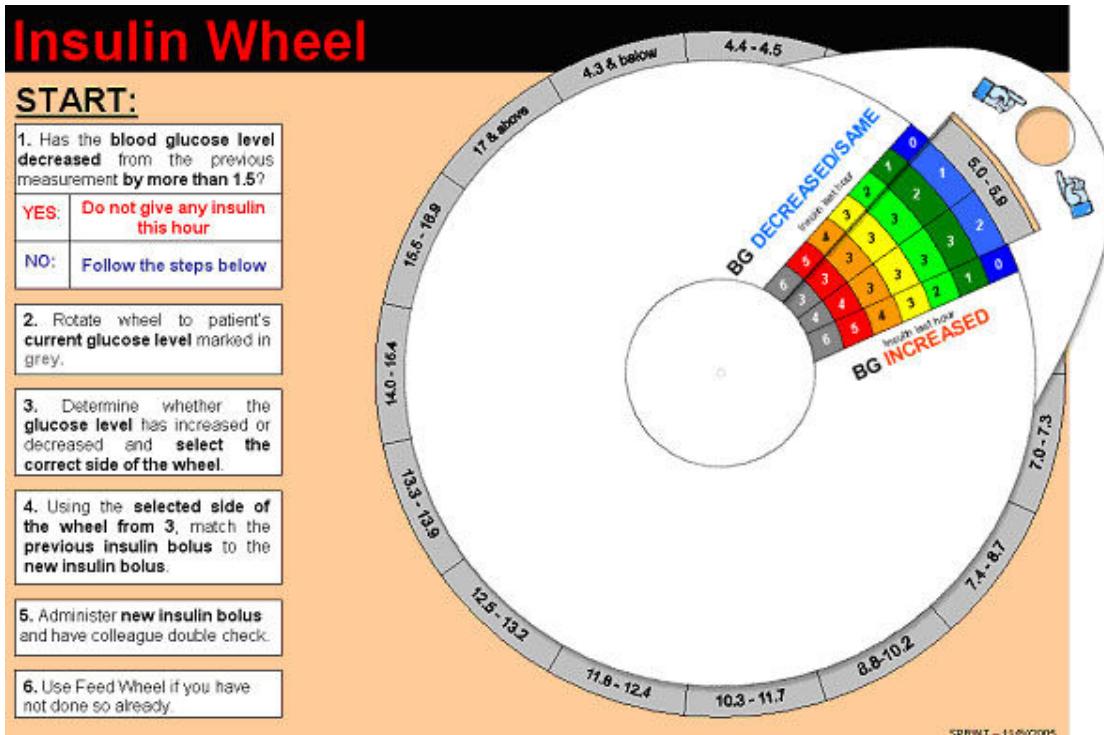
Attach feed conversion sticker here



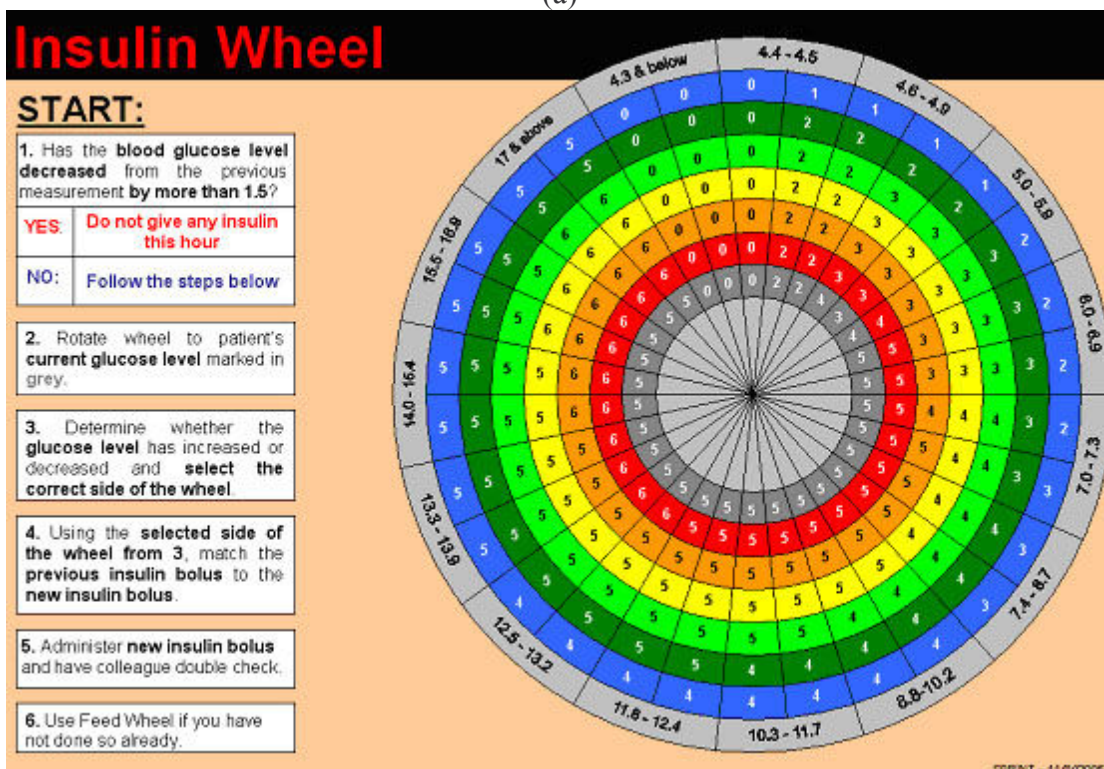
SPRINT – 11/8/2005

(b)

Figure 2: The SPRINT feed wheel with dial (a) and with dial removed (b). Animated and downloadable copies of the wheel are available at [http://www.geocities.com/active\\_insulin\\_control](http://www.geocities.com/active_insulin_control).



(a)



(b)

Figure 3: The SPRINT Insulin wheel with dial (a) and with dial removed (b). Animated and downloadable copies of the wheel are available at [http://www.geocities.com/active\\_insulin\\_control](http://www.geocities.com/active_insulin_control).

## 2-Hour Flow Chart

### When can I measure every 2 hours instead of every 1 hour?

(Reducing the frequency of measurement saves time yet will lose optimum control of the patient; it is in the patient's best interests to measure and act every hour)

#### Follow the Flow Chart:

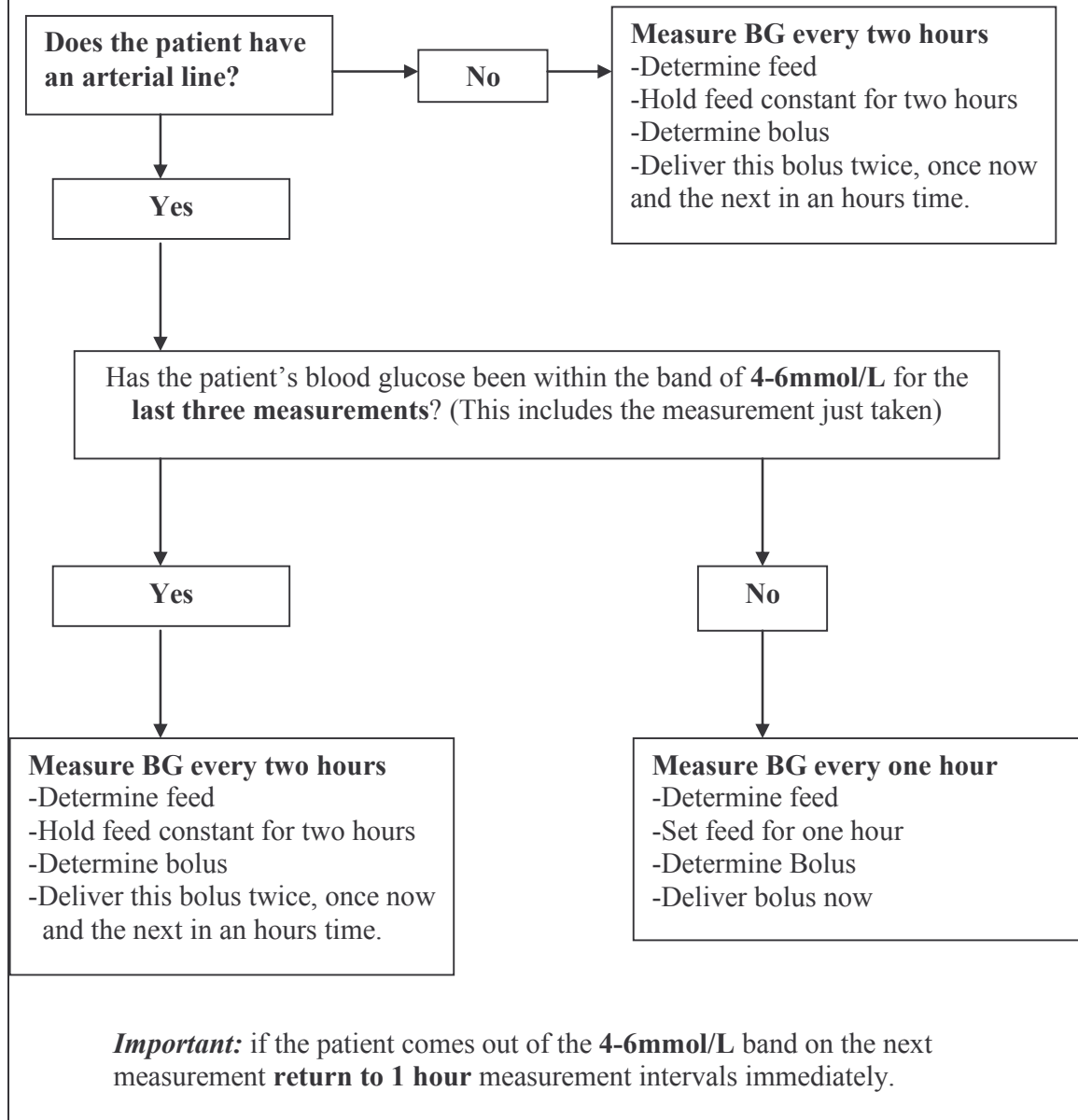


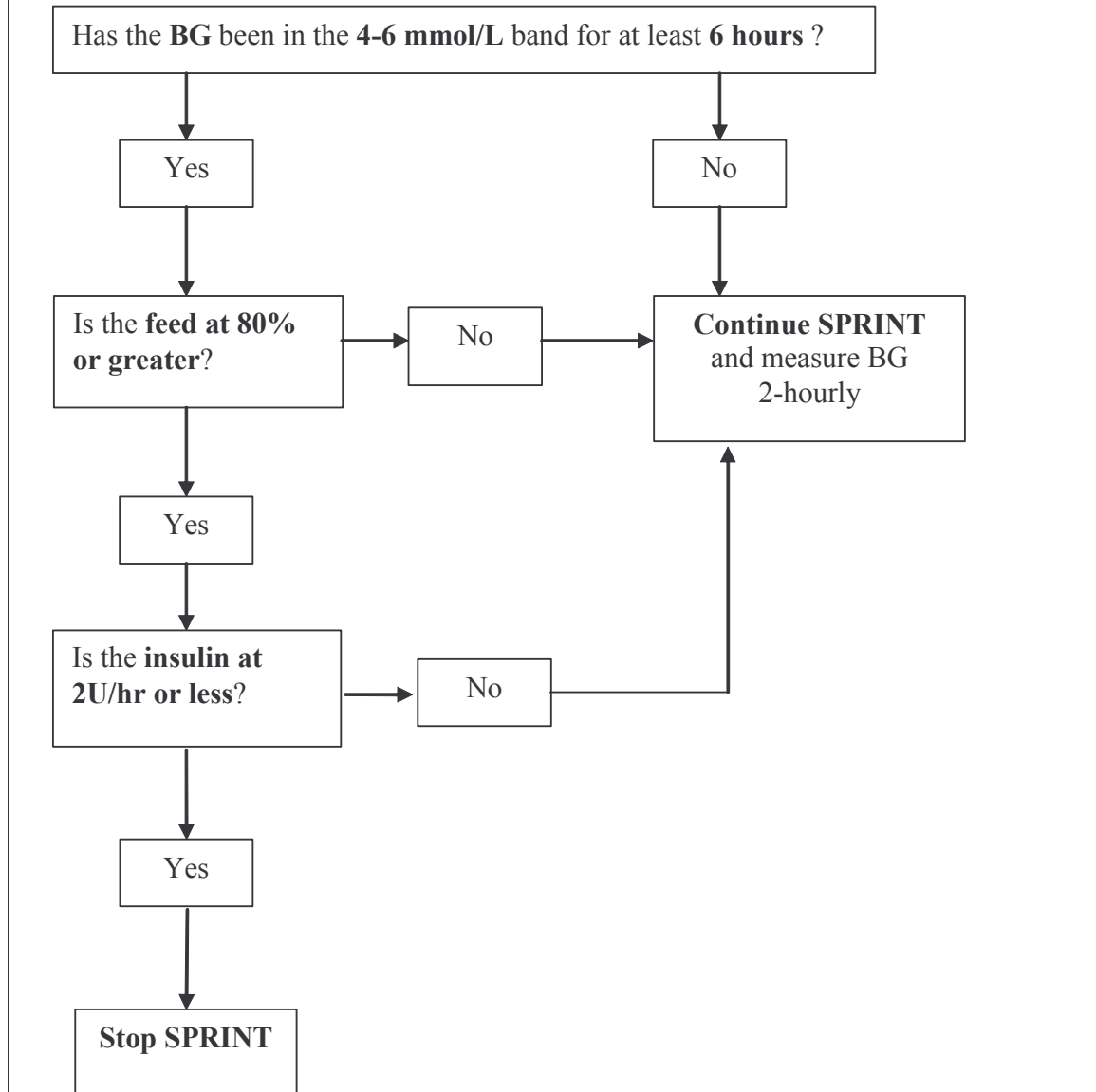
Figure 4: Flow chart specifying guidelines for measuring blood glucose level two-hourly.



## Stop Flow Chart

**When can I stop the SPRINT protocol ?**

**Follow the Flow Chart**



**Figure 5:** Flow chart specifying guidelines for stopping the SPRINT protocol.

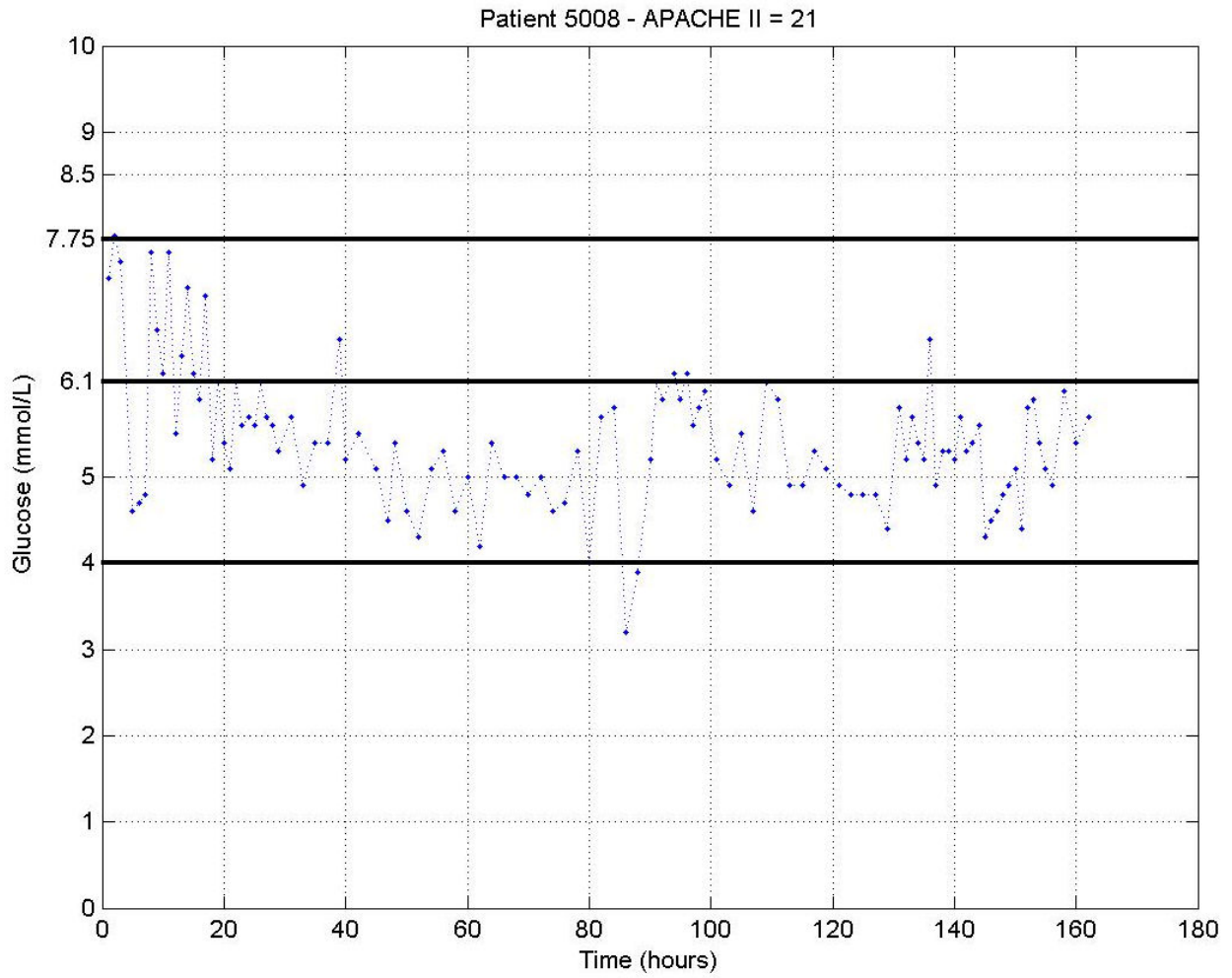


Figure 6: Typical patient response for 163 hour trial using the SPRINT protocol.

## TABLES

**Table 1: Patient cohort data computerised trials**

Patient number	Medical subgroup	APACHE II score	APACHE II ROD (%)	APACHE III	SAPS II	SAPS II ROD (%)	Age	Sex	Mortality	Diabetes
1	Sepsis	17	14.3	40	15	2	56	M	N	Type 2
2	Sepsis	24	49.7	59	35	16.7	64	M	N	
3	Pulmonary	31	73.3	85	45	34.8	60	M	N	
4	Sepsis	26	59.7	91	62	71.9	75	F	N	
5	Sepsis	21	33.2	58	34	15.3	73	M	N	Type 2
6	Other medical	17	14.3	44	44	32.6	57	M	N	
7	General surgical	23	62.3	84	57	61.9	73	F	N	Type 2

**Table 2: Clinical trial results summary for Patients 1-7**

	Hour										
Patient 1	1	2	3	4	5	6	7	8	9	10	Average
Insulin bolus (U)	0	0	0	3	0	3	0	3	0	0	0.9
Insulin infusion (U)	3	3	3	3	1	3	3	3	3	3	2.8
Total insulin (U)	3	3	3	6	1	6	3	6	3	3	3.7
Feed rate (% of 1000kcal/day)	56	42	28	28	28	28	28	28	28	28	32.2
<b>Target glucose value (mmol/L)</b>		<b>12.2</b>	<b>10.2</b>	<b>8.0</b>	<b>6.8</b>	<b>6.6</b>	<b>7.1</b>	<b>5.3</b>	<b>5.0</b>	<b>4.5</b>	
Target error (mmol/L)		1.2	0.3	0.2	-1.0	-1.1	0.9	1.0	0.8	0.9	0.8
Target error (%)		9.8	2.5	2.4	-14.9	-16.1	12.7	18.4	16.0	20.5	12.6
<b>Patient 2</b>											
Insulin bolus (U)	0	0	3	6	6	5.2	6	0	6	6	3.8
Insulin infusion (U)	3	0	0	0	0	0	0	0	0	0	0.3
Total insulin (U)	3	0	3	6	6	5.2	6	0	6	6	4.1
Feed rate (% of 1000kcal/day)	42	67	67	52	28	28	28	28	28	28	39.6
<b>Target glucose value (mmol/L)</b>		<b>7.2</b>	<b>5.3</b>	<b>7.0</b>	<b>7.1</b>	<b>6.0</b>	<b>6.1</b>	<b>6.0</b>	<b>6.5</b>	<b>6.2</b>	
Target error (mmol/L)		1.3	-2.9	-1.4	0.4	-0.7	0.0	-0.9	-0.5	-0.3	0.9
Target error (%)		18.3	-54.1	-20.5	5.1	-11.7	0.0	-15.0	-7.1	-4.0	15.1
<b>Patient 3</b>											
Insulin bolus (U)	0	2.5	0	4	0	4	1.5	0	4	0	1.6
Insulin infusion (U)	3	3	3	2	2	2	2	2	2	2	2.3
Total insulin (U)	3	5.5	3	6	2	6	3.5	2	6	2	3.9
Feed rate (% of 1000kcal/day)	35	35	55	45	60	40	40	40	30	40	42.0
<b>Target glucose value (mmol/L)</b>		<b>5.7</b>	<b>6.4</b>	<b>5.4</b>	<b>6.5</b>	<b>5.0</b>	<b>5.0</b>	<b>5.4</b>	<b>3.9</b>	<b>5.0</b>	
Target error (mmol/L)		0.0	-0.1	0.5	0.4	-0.4	0.1	-0.3	-0.9	-0.6	0.3
Target error (%)		-0.7	-1.4	9.4	6.0	-7.1	2.0	-5.4	-21.8	-11.0	7.2
<b>Patient 4</b>											
Insulin bolus (U)	0	0	0	0	0	0	0	0	1	0	0.1
Insulin infusion (U)	2	2	2	2	2	2	1	1	1	1	1.6
Total insulin (U)	2	2	2	2	2	2	1	1	2	1	1.7
Feed rate (% of 1000kcal/day)	35	50	35	35	40	40	61	61	44	44	44.5
<b>Target glucose value (mmol/L)</b>		<b>5.7</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	<b>5.6</b>	<b>6.7</b>	<b>4.2</b>	<b>5.0</b>	
Target error (mmol/L)		0.0	-0.4	0.1	0.4	1.7	0.2	1.5	-0.4	-0.2	0.5
Target error (%)		0.2	-8.0	2.0	7.0	33.0	4.1	22.0	-9.6	-4.0	10.0
<b>Patient 5</b>											
Insulin bolus (U)	0	1.5	1	0	1	0	1	1.5	0	0.5	0.7
Insulin infusion (U)	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	1.5	1.4
Total insulin (U)	1.5	3	2.5	1.5	1.6	1.5	2.5	3	1.5	2	2.1
Feed rate (% of 1000kcal/day)	35	35	35	35	49	49	49	35	49	49	42.0
<b>Target glucose value (mmol/L)</b>		<b>5.7</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	<b>5.5</b>	<b>5.9</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	
Target error (mmol/L)		0.0	0.1	-0.1	0.0	-0.2	0.3	0.1	0.2	0.3	0.1
Target error (%)		-0.2	1.0	-1.0	0.0	-3.5	4.7	2.8	3.0	5.0	2.4
<b>Patient 6</b>											
Insulin bolus (U)	0	1.1	2	0	0	3	5.5	5.5	5.5	3	2.6
Insulin infusion (U)	2	2	2	0	0	0.5	0.5	0.5	0.5	0.5	0.9
Total insulin (U)	2	3.1	4	0	0	3.5	6	6	6	3.5	3.4
Feed rate (% of 1000kcal/day)	60	60	0	0	0	35	31	31	31	31	27.9
<b>Target glucose value (mmol/L)</b>		<b>6.1</b>	<b>5.2</b>	<b>5.7</b>	<b>6.1</b>	<b>5.7</b>	<b>5.4</b>	<b>5.0</b>	<b>5.4</b>	<b>5.0</b>	
Target error (mmol/L)		-0.4	-0.5	0.1	-0.7	-0.7	-0.4	-0.8	0.1	-0.2	0.4
Target error (%)		-6.2	-9.6	2.3	-10.8	-11.5	-7.5	-15.0	1.3	-4.0	7.6
<b>Patient 7</b>											
Insulin bolus (U)	0	3	0.5	3	3	3	1	0	3	0	1.7
Insulin infusion (U)	3	3	3	3	3	3	3	0.5	0.5	0.5	2.3
Total insulin (U)	3	6	3.5	6	6	6	4	0.5	3.5	0.5	3.9
Feed rate (% of 1000kcal/day)	32	32	32	32	32	32	32	32	32	32	32.0
<b>Target glucose value (mmol/L)</b>		<b>8.2</b>	<b>6.9</b>	<b>5.9</b>	<b>5.8</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	<b>5.0</b>	
Target error (mmol/L)		0.3	-0.3	-0.5	0.5	0.2	1.0	0.3	0.7	-0.1	0.4
Target error (%)		3.2	-4.5	-7.6	9.3	3.0	19.0	6.0	14.0	-1.0	7.5

**Table 3: Summarised results of nurse evaluation survey**

	<b>Very Good</b>	<b>Good</b>	<b>Satisfactory</b>	<b>Poor</b>
<b>Ease of Use</b>	2	13	9	2
<b>Quality</b>	6	14	4	1
<b>Suitability</b>	7	14	3	1
<b>Total</b>	15	41	16	4