Title: INFUSION APPARATUS FOR REGULATING BLOOD SUGAR LEVELS AND METHOD THEREOF

Abstract: An infusion apparatus (1) for regulating blood sugar levels of a patient, the apparatus (1) comprising a controller (2), a sensor system (7) and an infusion system (8). Both the sensor system (7) and the infusion system (8) is at least in data communication with the controller (2). The sensor system (7) comprises a sensor (3) and a sensor interface (4). The sensor system (7) is operable to regularly measure the blood sugar level of a patient and provide a sensor signal to the controller (2) in response to the measured blood sugar level. The controller (2) then calculates the required infusion rate, in response to the received sensor signal, and provides a control signal to the infusion system (8). The infusion system (8) comprises a pump (5) and a pump interface (6) and is operable, in response to the control signal, to deliver medication for regulating blood sugar levels at the calculated infusion rate. This process continuously repeats to form a feedback loop, the loop executing in a manner such that the patient is medicated at predetermined intervals.
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
"Infusion Apparatus for Regulating Blood Sugar Levels and Method"

Therefor

Field of the Invention

The present invention relates to an Infusion Apparatus, particularly, although not exclusively, for regulating the levels of blood sugar levels in humans and a method for doing same.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Background Art

The pancreas of a healthy person secretes insulin, which is important in the regulation of the metabolism of carbohydrates, proteins and fats. Insulin increases the storage of glucose, fatty acids and amino acids. Normally, the pancreas constantly delivers small amounts of insulin into the bloodstream to keep the blood glucose concentration within the normal range. But the balance between insulin delivery and blood glucose concentration is impaired in persons with diabetes, and this results in occasional or persistently high blood glucose values. The human body may also be unable to produce enough insulin during times of stress such as critical illness. The administration of exogenous insulin to control the blood glucose concentration is therefore essential for those critically ill patients to maintain a normal Blood Sugar Level ("BSL") and avoid short and long-term complications.

Glycemic control in critically ill patients in Intensive Care has usually been achieved by a sliding scale method that matched blood glucose level to a set dose of insulin.
In general, the sliding scale method assigns a specific dose of insulin (in units per hour) depending upon the measured BSL within a range. As an example, a sliding scale for intravenous ("IV") insulin infusion, in the Coronary Care Unit ("CCU") of a hospital in Perth, has the following partition:

- soluble insulin is infused at the rate of 1 unit per hour for plasma glucose levels in the range 4-8 mmol/L;

- at a rate of 2 units per hour for plasma glucose levels 8-12 mmol/L; and

- at a rate of 4 units per hour if plasma glucose levels exceed 12 mmol/L.

Blood sugar levels are monitored every 1-2 hours.

It is also considered better to accept moderate hyperglycaemia (that is a BSL of 10-15 mmol/L) than to allow the risk of hypoglycaemia (that is a BSL <5 mmol/L).

However, any prescribed sliding scale may be less effective if the patient's insulin sensitivity/resistance changes with time, and under various conditions. These changes may be due to either an aggravation or amelioration of the patient's medical condition. In such a situation, the nursing staff need to control the patient's BSL based on clinical experience, or other clinical techniques, rather than using scale rules. Technique such as titration method has been employed where blood glucose level was halved, doubled, or logarithmically scaled in an attempt to lower and maintain blood sugar level to within a target range.

Obviously, this can have implications for the patient's care, as how well blood sugar level can be controlled depends on the experience in using these techniques, and experience can be limited. Also, human errors may occur.

**Disclosure of the Invention**

In accordance with a first aspect of the present invention, there is provided an infusion apparatus for regulating blood sugar levels of a patient, the apparatus comprising:
- 3 -

- a controller;

- a sensor system and an infusion system, each at least in data communication with the controller, the sensor system being operable to regularly measure the blood sugar level of a patient and provide a sensor signal to the controller in response to the measured blood sugar level,

wherein the controller calculates the required infusion rate, in response to the received sensor signal, and provides a control signal to the infusion system at predetermined intervals; the infusion system being operable, in response to the control signal, to deliver medication for regulating blood sugar levels at the calculated infusion rate.

Preferably, the infusion rate is determined by the equation:

\[
\text{Infusion rate} = \text{basic rate} + \text{offset}
\]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and the offset is a second value representative of how effective the current infusion dose is in assisting in regulating the patient’s blood sugar level.

More preferably, the offset is initially determined by subtracting the basic rate from the initial predetermined infusion rate, and subsequently incremented when there is a positive change or there is no change in the current basic rate when compared with the previous basic rate.

Preferably, the controller is further operable to determine when the measured blood sugar level is within a desired range.

More preferably, the desired range is a blood sugar level between 6.1 and 10 mmol/L.
More preferably still, the desired range is a blood sugar level between 6.1 and 8 mmol/L.

Preferably, when the patient's blood sugar level is within the desired range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = \begin{cases} 
\frac{1}{2} \times \text{Previous dose}, & \text{where BSL first enters 6-8 mmol/L from above} \\
0, & \text{where BSL } \leq 6 \text{ mmol/L} \\
\text{Previous dose} + 1, & \text{where BSL first enters 8-10 mmol/L from below}
\end{cases}
\]

More preferably, the new offset is calculated by subtracting the basic rate from the infusion dose, except in the situation where the infusion dose is 0, when the new offset is set to -1, and thereafter the offset being subsequently incremented when there is a positive change or there is no change in the current base rate when compared with the previous base rate.

Alternatively, the infusion rate is determined by the equation:

\[
\text{Infusion dose} = \text{Basic dose} + \text{Offset (n)} + \text{Derivative control}
\]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, Offset (n) is a second value representative of how effective the current infusion dose is in assisting in regulating the patient's blood sugar level and Derivative control is a third value representative of the current increasing trend, if any, in infusion doses.

More preferably, Offset (n) is calculated as follows:

\[
\text{Offset}(n) = \begin{cases} 
\text{Prescribed dose by user} - \text{BSL Region}, & t = 0, \text{ and } n = 0 \\
\text{TopUp} + \text{Offset}(n - 1), & t > 0 \text{ and } n > 0
\end{cases}
\]

where:
\[ t = \text{time}; \]

\( n \) is an index to Offset; and

**TopUp** is calculated as follows:

\[
\text{TopUp} = \begin{cases} 
4 \text{ U/hr}, & \text{if } W_{zona} > 4.5 \\
2 \text{ U/hr}, & \text{if } 3.6 \leq W_{zona} \leq 4.5 \\
1 \text{ U/hr}, & \text{if } 2.7 \leq W_{zona} < 3.6 \\
0 \text{ U/hr}, & \text{if } W_{zona} < 2.7 
\end{cases}
\]

5 in which \( W_{zona} \) is calculated as follows:

\[
W_{zona} = \frac{1}{a} \times \sum_{i=1}^{a} n \times x[n]
\]

\( x[n] \) representing a set of basic rates, \( a \) being the basic rate as determined by the most recent blood sugar level measurement.

More preferably, Derivative control is calculated as follows:

\[
\text{Derivative Control} = \begin{cases} 
6 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} \geq 2 \text{ mmol/L} \\
4 \text{ U/hr}, & \text{if } 1 \leq \Delta y_{\text{proj}} < 2 \text{ mmol/L} \\
0 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} < 1 \text{ mmol/L} 
\end{cases}
\]

where:

\[
\Delta y_{\text{proj}} = b_{xy} \cdot \Delta x
\]

and

\[
b_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}
\]
in which:

\[ x_{\text{max}} = \text{maximum time value in the 30 min window} \]
\[ x_{\text{min}} = \text{minimum time value in the 30 min window} \]
\[ y_{\text{max}} = \text{maximum BSL value in the 30 min window} \]
\[ y_{\text{min}} = \text{minimum BSL value in the 30 min window} \]

\[ \bar{x} = \frac{x_{\text{max}} + x_{\text{min}}}{2} \]

\[ \bar{y} = \frac{y_{\text{max}} + y_{\text{min}}}{2} \]

Still more preferably, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

In which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.75, & \text{if } t \text{ BSL cross 1.2} \text{ mmol/L boundary} - t \text{ BSL cross 10} \text{ mmol/L boundary} < 30 \text{ minutes} \\
0.85, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

Alternatively, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

in which \( k \) is calculated as follows
\[ k = \begin{cases} 
0.50, & \text{if } t_{\text{BSL cross } 3 \text{ mmol/L boundary}} - t_{\text{BSL cross } 10 \text{ mmol/L boundary}} < 45 \text{ minutes} \\
0.80, & \text{otherwise} 
\end{cases} \]

and t is time.

More preferably, Offset (n) is calculated as follows:

\[ \text{Offset (n)} = \text{infusion dose} - \text{derivative control} - \text{basic rate} \]

provided that if the value of Offset (n) is negative, Offset (n) is set to \(-1\).

In a further alternative, when the patient's blood sugar level is within the range 8.1 mmol/L to 10.0 mmol/L and after previously measuring a lower blood sugar level, the infusion dose is calculated as follows:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset (n)} \]

Where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset (n)} = \text{Offset (n - 1)} + 1 \]

In a still further alternative, when the patient's blood sugar level is within the range 10.1 mmol/L to 12.0 mmol/L and after previously measuring a lower blood sugar level, the infusion dose is calculated as follows:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset (n)} \]

where:
Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset (n)} = \text{Offset (n - 1)} \]

Preferably, the Offset value, or the value of Offset (n), as appropriate, is determined at regular predetermined intervals.

More preferably, the predetermined intervals are determined by the half-life or duration of action of the medication for regulating blood sugar levels being used.

Still more preferably, the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.125 to 2.

In a yet further preferable embodiment, the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.25 to 1.5.

In a yet further preferable embodiment, predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.5 to 1.

In a yet further preferable embodiment, the predetermined interval is equal to the half-life or duration of action of the medication for regulating blood sugar levels being used.

Still more preferably, the predetermined interval is 1 hour.

Preferably, the controller confirms a change in the range of the basic rate if at least two of the last three blood sugar level measurements fall within the new range.
Preferably, the controller confirms a change in the range of the basic rate in situations where the last three blood sugar levels measurements each fall within a new range, the change in range of the basic rate being equal to the range as determined by the second most recent blood sugar level measurement.

5 Preferably, the sensor system comprises a sensor and a sensor interface and the sensor interface is integral with either the controller or the sensor.

Preferably, the infusion system comprises a pump and a pump interface and the pump interface is integral with either the controller or the pump.

Preferably, at least one of the sensor system or the infusion system is in wireless communication with the controller.

Preferably, the controller comprises a microprocessor and the microprocessor references a static memory location, wherein the static memory location is a memory address positioned on a removable memory, the static memory location being the start location for instructions representing the algorithm used to determine the required infusion rate.

In accordance with a first aspect of the present invention, there is provided a method of regulating blood sugar levels comprising:

- Measuring the blood sugar level of a patient;

- Calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement; and

- Delivering to the patient the medication for regulating blood sugar levels at the required infusion rate determined.

Preferably, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:
Infusion rate = basic rate + offset

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges and the offset is a second value representative of how effective the current infusion dose is in assisting in regulating the patient’s blood sugar level.

More preferably, the offset is determined by subtracting the basic rate from the initial predetermined infusion rate, and subsequently incremented when there is a positive change or there is no change in the current basic rate when compared with the previous basic rate.

Preferably, the method further comprises the step of determining whether the measured blood sugar level is within a desired range.

More preferably, the desired range is a blood sugar level between 6.1 and 10 mmol/L.

Still more preferably, the desired range is a blood sugar level between 6.1 and 8 mmol/L.

Preferably, when the patient’s blood sugar level is within the desired range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = \begin{cases} 
\frac{1}{2} \times \text{Previous dose}, & \text{where BSL first enters 6-8 mmol/L from above} \\
0, & \text{where BSL is 6 mmol/L} \\
\text{Previous dose} + 1, & \text{where BSL first enters 8-10 mmol/L from below}
\end{cases}
\]

More preferably, the new offset is calculated by subtracting the basic rate from the infusion dose, except in the situation where the infusion dose is 0, when the new offset is set to \(-1\), and thereafter the offset being subsequently incremented when there is a positive change or there is no change in the current base rate when compared with the previous base rate.
Preferably, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[ \text{Infusion dose} = \text{Basic dose} + \text{Offset (n)} + \text{Derivative control} \]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, Offset (n) is a second value representative of how effective the current infusion dose is in assisting in regulating the patient’s blood sugar level and Derivative control is a third value representative of the current increasing trend, if any, in infusion doses.

More preferably, Offset (n) is calculated as follows:

\[
\text{Offset}(n) = \begin{cases} 
\text{Prescribed dose by user - BSL Region,} & t = 0, \text{ and } n = 0 \\
\text{TopUp + Offset(n-1),} & t > 0 \text{ and } n > 0 
\end{cases}
\]

where:

\( t = \text{time}; \)

\( n = \text{an index to Offset; and} \)

TopUp is calculated as follows:

\[
\text{TopUp} = \begin{cases} 
4 \text{ U/hr,} & \text{if } W_{zone} > 4.5 \\
2 \text{ U/hr,} & \text{if } 3.6 \leq W_{zone} \leq 4.5 \\
1 \text{ U/hr,} & \text{if } 2.7 \leq W_{zone} < 3.6 \\
0 \text{ U/hr,} & \text{if } W_{zone} < 2.7 
\end{cases}
\]

in which \( W_{zone} \) is calculated as follows:
\[ W_{\text{zone}} = \frac{1}{\sum_{i=1}^{n_i} n_i \times x[n]} \]

\( x[n] \) representing a set of a basic rates, \( a \) being the basic rate as determined by the most recent blood sugar level measurement.

More preferably, Derivative control is calculated as follows:

\[
\text{Derivative Control} = \begin{cases} 
6 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} \geq 2 \text{ mmol/L} \\
4 \text{ U/hr}, & \text{if } 1 \leq \Delta y_{\text{proj}} < 2 \text{ mmol/L} \\
0 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} < 1 \text{ mmol/L}
\end{cases}
\]

where:

\[ \Delta y_{\text{proj}} = b_{xy} \cdot \Delta x \]

and

\[
b_{xy} = \frac{\sum_{i=1}^{q} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{q} (x_i - \bar{x})^2}
\]

in which:

\[ \bar{x} = \frac{x_{\text{max}} + x_{\text{min}}}{2} \]

\[ \bar{y} = \frac{y_{\text{max}} + y_{\text{min}}}{2} \]
Alternatively, when the patient’s blood sugar level is within the desired range and after previously being in a higher range, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.75, & \text{if } t_{\text{BSL cross } 12 \text{ mmol/L boundary}} - t_{\text{BSL cross } 10 \text{ mmol/L boundary}} < 30 \text{ minutes} \\
0.85, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

In a further alternative, when the patient’s blood sugar level is within the desired range and after previously being in a higher range, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.50, & \text{if } t_{\text{BSL cross } 3 \text{ mmol/L boundary}} - t_{\text{BSL cross } 10 \text{ mmol/L boundary}} < 45 \text{ minutes} \\
0.80, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

More preferably, Offset (n) is calculated as follows:

\[
\text{Offset (n)} = \text{infusion dose} - \text{derivative control} - \text{basic rate}
\]

provided that if the value of Offset (n) is negative, Offset (n) is set to -1.
In a yet further alternative, when the patient's blood sugar level is within the range 8.1 mmol/L to 10.0 mmol/L and after previously measuring a lower blood sugar level, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset} (n) \]

where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset} (n) = \text{Offset} (n - 1) + 1 \]

In yet a further alternative, when the patient's blood sugar level is within the range 10.1 mmol/L to 12.0 mmol/L and after previously measuring a lower blood sugar level, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset} (n) \]

where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset} (n) = \text{Offset} (n - 1) \]

Preferably, the method further includes the step of determining the Offset value, or the value of Offset (n), at regular predetermined intervals.
More preferably, the predetermined intervals are determined by the half-life or duration of action of the medication for regulating blood sugar levels being used.

Still more preferably, the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.125 to 2.

In yet a further preferable embodiment, the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.25 to 1.5.

In yet a further preferable embodiment, the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.5 to 1.

In yet a further preferable embodiment, the predetermined interval is equal to the half-life or duration of action of the medication for regulating blood sugar levels being used.

In yet a further preferable embodiment, the predetermined interval is 1 hour.

Preferably, the method further comprises the step of confirming a change in the range of the basic rate if at least two of the last three blood sugar level measurements fall within the new range.

Preferably, the method further comprises the step of confirming a change in the range of the basic rate in situations where the last three blood sugar levels measurements each fall within a new range, the change in range of the basic rate being equal to the range as determined by the second most recent blood sugar level measurement.

The present invention has the advantage that it adapts to patient’s insulin sensitivity & insulin requirements in order to optimise insulin dose delivery. There
is also compensation of the estimated insulin dose based on the past history and physiological status (e.g. hypoglycaemia, exercise etc) of the patient.

The present invention is therefore able to treat Type I & II diabetes mellitus in both an ambulatory or hospitalised condition, both in critical illness and in less severe illness.

**Brief Description of the Drawings**

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram representing a first embodiment of a BSL Regulating and Monitoring Apparatus of the present invention;

Figure 2 is a schematic block diagram representing a second embodiment of a BSL Regulating and Monitoring Apparatus of the present invention;

Figure 3 is a schematic block diagram representing a third embodiment of a BSL Regulating and Monitoring Apparatus of the present invention;

Figure 4 is a graphical representation of the discretization process carried out during a section of the algorithm used by the apparatus of Figures 1 to 3; and

Figure 5 is a schematic illustration of the components of the apparatus of Figure 1

**Best Mode(s) for Carrying Out the Invention**

The apparatus 1 of the present invention comprises a controller 2, an infusion system 8 for dispensing insulin at a predetermined rate into the patient and a sensor system 7 for measuring the BSL of a patient.

The infusion system 8 is coupled to the controller 2. The infusion system 8 comprises a pump 5 and pump interface 6. The sensor system 7 comprises a sensor 3 and a sensor interface 4. The sensor interface 4 provides an interface
between the sensor 3 and the controller 2. The pump interface 6 provides an interface between the pump 5 and the controller 2. This is illustrated schematically in Figure 1.

The sensor 3 comprises any suitable, commercially available, continuous blood glucose monitor. Preferably, the continuous blood glucose monitor is minimally invasive or non-invasive. The sensor 3 should be configured to either:

- take a finite number of measurements in a given period of time (e.g. 12 measurements in one hour); or

- take measurements intermittently, but in a very short time interval (e.g. taking a measurement every 10 seconds and averaging the measurements taken over a 5 minute period).

The sensor interface 4 provides the controller 2 with input signals from the sensor 3 that correspond to the BSL measurement derived from the sensor 3.

Due to the multitude of sensors 3 that may be used, each having a different configuration and method of operation, the sensor interface 4 must be capable of interpreting the data provided by the sensor 3 and communicating that data to the controller 2. In this manner, the same controller 2 can be used regardless of the sensor 3 used.

The combination of sensor interface 4 and controller 2 can be arranged in the following manner:

- in a first embodiment of the invention, the sensor interface 4 is integrated with the controller 2 (see Figure 1); and

- in a second embodiment of the invention, the sensor interface 4 is integrated with the sensor 3 (see Figure 2); and
• In a third embodiment of the invention, the sensor interface 4 is wirelessly coupled to the controller 2 using radio frequency ("RF") telemetry.

In the third embodiment, the sensor interface 4 includes an RF telemetry unit 46 for wireless communication between the sensor interface 4 and the controller 2. The RF telemetry unit 46 may also be used for wireless communication with the sensor 3 (described in more detail below). As the use of RF telemetry is well known it will not be described in any further detail herein, except as is relevant to the present invention.

Regardless of the embodiment used, the sensor interface 4 contains internal circuitry to allow the controller 2 to directly control the operation of the sensor interface 4. The internal circuitry is contained within a suitable housing (not shown).

Figure 5 illustrates how the sensor 3, sensor interface 4, pump 5, pump interface 6 and controller 2 are coupled in the first embodiment of the invention. However, it will be understood by a person skilled in the art, that the general principles can be used whatever the physical arrangement of the components of the apparatus 1.

Sensor interface 4 incorporates a microprocessor 44 to handle communication between the sensor 3 and the sensor interface 4. The microprocessor 44 also controls operation of the sensor interface 4.

In an alternative arrangement, sensor interface 4 shares the same CPU 11 as the controller 2. In this arrangement, the sensor interface 4 must have a separate memory module (not shown), such as a ROM, RAM or EEPROM. The memory module contains the software required to facilitate communication between the sensor 3 and the controller 2. This allows the sensor interface 4 to be replaced by a new sensor interface 4, the new sensor interface 4 now facilitating communication between a new sensor 4, connected to the new sensor interface 4.
4, and the controller 2. One or more physical connections allow the controller 2 to identify the sensor 3/sensor interface 4 combination being used.

As mentioned above, sensor interface 4 is in communication with sensor 3. To enable this communication, sensor interface 4 is equipped with one or more of the following communications means:

- a direct cable connection (DCC) 41, such as an RS232C, straight wire, parallel port or USB connection;

- an infra red ("IR") communications unit 42; and

- a RF telemetry unit 43.

The sensor 3 has corresponding connections to facilitate communication with the sensor interface 4, i.e. DCC 31, IR unit 32 and RF telemetry unit 33. In this manner, the communications means, or combination of communications means, used depends on the type of sensor 3 being used.

In the arrangement where the sensor interface 4 has a microprocessor 44, the communications means of the sensor interface 4 is coupled to the microprocessor 44. The communications means of the sensor interface 4 communicates with the sensor 3 in accordance with a first protocol S0.

Protocol S0 must be sufficient to allow the sensor 3 to at least communicate BSL readings and any errors encountered by the sensor 3 to the sensor interface 4.

Sensor interface 4 also includes a communications unit 45 to convey the data received from the sensor 3, notably BSL readings and error details, to the controller 2. In this regard, the sensor adapter 4 also includes a communications unit 45 to convey sensor signals, such as BSL info and errors, to the controller 2. This communication uses a second protocol S1. The S1 protocol can be any protocol, as long as the sensor interface 4 can "talk in the same language" as the controller 2. The protocol can be hardware or software based or a combination of
both (e.g. in a computer modem, we can have a hardware handshake, in which
handshakes are done through physically raising or dropping the CTS, RTS, etc
lines, or a software handshake, where an Xon/Xoff protocol is used between the
modem and the computer, or even both handshakes are used simultaneously).

5  The controller 2 may also use protocol S1 to obtain information such as how often
the sensor 3 gathers data.

As mentioned above, the infusion system 8 comprises a pump 5 for delivering
insulin to a patient at a rate determined by the controller 2 via an intravenous,
intraperitoneal or subcutaneous route. The pump interface 6 provides an
interface between the pump 5 and the controller 2. The pump 5 can be any
suitable, commercially available, intravenous or subcutaneous pump.

10  As with the sensor system 7, the pump interface 6 can be integrated with the
pump 5 or integrated with the controller 2. The pump interface 6 also functions as
a generic interface between the controller 2 and the variety of pumps 5 mentioned
in the last paragraph that may be used as part of the present invention.

The pump interface 6 facilitates communication between the pump 5 and
controller 2. The means and protocols for communication are analogous to those
used by the sensor interface 4. For example, using the embodiment shown in
Figure 5, the pump interface 6 can include a DCC 61, an IR unit 62, and/or an RF
telemetry unit 63. Whether a DCC 61, IR unit 62 and/or RF telemetry unit 63 is
20  used will depend on the pump used.

The pump interface 6 communicates with the controller 2 in a manner analogous
to the communication between the sensor interface 4 and the controller 2. The
pump interface 6 therefore includes a microprocessor 64 for controlling operation
of the pump interface 6 and pump 5, and for handling communication
therebetween in accordance with a first protocol P1.

25  There is also a communications module 65 for facilitating and controlling
communication between the pump interface 6 and the controller 2.
Communication between pump interface 6 and controller 2 is conducted in accordance with a second protocol P0 (note: protocols S0 and P0 may be identical but controlled by different physical wire connections). The pump interface 6 and the controller 2 may be in wireless communication with one another, in which case both the controller 2 and the pump interface 6 are provided with a RF telemetry unit 63, 66. If the controller 2 is in wireless communication with both the pump interface 6 and the sensor interface 4, RF telemetry units 43, 63 may be combined to form a single RF telemetry unit.

Pump 5 has appropriate connection means 51, 52, 53, in a manner similar to those connections provided on sensor 3, to allow communication between the pump 5 and the pump interface 6.

As an example, the IMED™ pump has a RS232C communication port allowing a pump interface 6 having an RS232C port to connect to the pump 5 via a serial cable. In this situation, the controller 2 can transmit the determined infusion dose of insulin to the pump interface 6, and the pump interface 6 can then package it (according to the pump communication protocol given by the manufacturer of the pump) as a valid command recognised by the pump 5.

The controller 2 comprises a housing 12 which houses all the internal circuitry for the controller 2, including a CPU 11 with associated working memory. The CPU 11 receives signals from the sensor system 7 via the sensor interface 6 (referred to hereafter as "input signals"). The CPU 11 is then operable to provide output signals to the infusion system 8 relating to the control of the pump 5 in response to the input signals.

The housing 12 includes suitable sockets (if required, and not shown) for the connections from the sensor 3 / sensor interface 4 and pump 5 / pump interface 6 (as appropriate). Housing 12 also includes appropriate internal circuitry to ensure coupling of the signals to and from the CPU 11.

Controller 2 may, optionally, include a touch screen 14 or other suitable user interface for data entry & display. For example, an SP10Q003-T from Hitachi
Europe. The touch screen 14 needs to have some means of illumination, such as a backlight, for night viewing. The touch screen 14 can be locked by software, or hardware to prevent accidental button press.

The controller 2 is operable to ensure that insulin is dispensed as an optimal insulin dose by means of an insulin infusion algorithm, which will be described in further detail below. The algorithm can be carried out by the CPU 11, or by means of alternative circuitry provided in the controller 2.

The controller 2 is also operable to:

1. Execute codes as contained in the ROM, RAM, EEPROM or within the CPU (or other memory module) to calculate infusion dose, make decisions to control the pump interface 6 and/or the sensor interface 4, and handle specific error signals from the sensor 3 or pump 5 etc.

2. Relay sensor errors and pump errors to the operator via the touch screen 14.

3. Accept and act in response to commands input by the operator, such as STOP insulin, Manual override, etc.

4. Record BSL, insulin dose, error and other information in memory.

5. Coordinate functionality, such as any graphical user interface or button press to stop the controller 2.

6. Control any additional functions that are not handled by other components, such as a low battery check, etc.

As mentioned above, appropriate communication protocols, S0, P0, for data and command transfer between the sensor interface 4 and CPU 11, and pump interface 6 and CPU 11 should be used.

As also discussed above, communications can happen through IR ports, DCC or RF telemetry. Any of these combinations is possible, but may not necessarily be
appropriate. It may also be possible for some pumps 5 and sensors 3 to communicate directly with the controller 2 without the need for adaptors 4, 6. This means that the controller 2 may have fixed ports (IR – standard IRDA protocol and/or serial RS232C and/or RF telemetry), and the main CPU memory module has the protocol onboard to enable such communication.

If the controller 2 is arranged to communicate directly with the sensor 3 and pump 5 via RF telemetry, the controller 2 may communicate to both components through a single RF telemetry unit. In such a situation, alternative modulation of the RF signal can be used to determine whether the signal being received is from the sensor 3 or the pump 5. A similar modulation system can be used to determine whether the signal being transmitted by the controller 2 is intended for the sensor 3 or the pump 5.

In an alternative arrangement, the adaptors 4, 6 may be configured as cards (similar to PCMCIA cards for example), that are able to slot into the controller 2.

The operation of the controller 2 with regard to the way in which it controls the rate of infusion of insulin to the patient depending upon the measured BSL (as measured by the sensor 3), will now be described.

The calculation of the insulin delivery rate is performed by one or more segments of an algorithm (or by one or more algorithms), where:

- There exists adaptation to a patient's insulin sensitivity & insulin requirements in order to optimise insulin dose delivery,

- There is compensation of the estimated insulin delivery rate based on the past history and physiological status (e.g. hypoglycaemia, exercise etc) of the patient

- The algorithm is based on a sliding scale control approach (but may not be limited to such an approach).
The algorithm(s) can be made changeable by embedding them on separate ROMs, RAMs, EEPROMs or other memory modules 15. In such an arrangement the CPU 11 must point to a specific memory address or addresses, being the memory address or addresses corresponding to the start of each algorithm. This would allow the user to use algorithms more appropriate to the current configuration of the invention. Alternatively, the algorithm(s) may remain static but incorporate redundant code to accommodate the different possible configurations of the invention.

The algorithm described herein provides a dynamic sliding scale that adjusts to the patient’s insulin sensitivity by regularly assessing the effectiveness of the current insulin dose in normalising the patient’s BSL.

In implementing the sliding scale control approach, a continuous range of blood glucose levels is partitioned into discrete ranges – each discrete range being referred to herein as a Region. Control decisions are based on the location of the BSL in the Regions rather than on an instantaneous value – with one exception that will be discussed below. The control decisions are issued every hour. The partitioning is performed in accordance with the following partition table.

Table 1 - Partitioning table for BSL.

<table>
<thead>
<tr>
<th>BSL range</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 6 mmol/L</td>
<td>0</td>
</tr>
<tr>
<td>6.1 – 10 mmol/L</td>
<td>1</td>
</tr>
<tr>
<td>10.1– 15 mmol/L</td>
<td>2</td>
</tr>
<tr>
<td>15.1– 20 mmol/L</td>
<td>3</td>
</tr>
<tr>
<td>&gt; 20 mmol/L</td>
<td>4</td>
</tr>
</tbody>
</table>
To reject noise in the BSL readings from the sensor 3, a valid region-checking algorithm is used to determine that the measured BSL has validly entered into a new Region. This algorithm is dependent on the frequency with which BSL readings from the sensor 3 are provided. For example, with a sensor that provides readings every 5 minutes, any changes to a different BSL Region will only be accepted if at least two of the three most recent consecutive BSL readings lie in that Region. In cases where all three BSL Regions are different, then the middle BSL Region, in terms of arrival order, will be accepted.

This ensures that any change in BSL has stabilised within that particular Region, and is therefore a valid reading. This assessment is done with every received BSL reading. The number of consecutive BSL readings that are required will depend very much on how long it takes for a BSL reading to arrive. For example, where frequent readings are taken, say every 5 minutes, then it is possible to have three consecutive readings to determine that entry into a region is stable, and thus valid. However, some sensors may only give three readings in an hour, and in such a case there would be no region-checking algorithm used at all.

Where there are frequent measurements being made, it is important to ensure that the BSL has really entered a new region, rather than the reading entering a region because of possible noise. Thus, the insulin infusion rate is prescribed by three sections of the algorithm, namely, a proportional control section, an integral control section, and a protection control section.

The proportional control section is based upon a basic sliding scale table as shown below.

\[
\text{Basic dose} = \begin{cases} 
0, & G \leq 6 \\
1, & 6 < G \leq 10 \\
2, & 10 < G \leq 15 \\
3, & 15 < G \leq 20 \\
4, & G > 20 
\end{cases}
\]
Where G is the BSL measured in mmol/L. This arrangement is graphically illustrated in Figure 4. The basic dose is given in units per hour, and, as can be seen above, corresponds to the Regions set out in Table 1 above.

The proportional control section of the algorithm provides responses to changes in BSL by a unit increment or decrement of insulin dose with respect to a detected increase or decrease in the resident BSL Region. It serves to maintain the patient’s BSL to within a certain Region.

The control signals to the pump system are sent from the controller 2 hourly, although other time periods could be used. To localise BSLs within Region 1 (the desired BSL Region), the piece-wise integral control section is implemented.

The integral control section involves the addition of an offset to the Basic Dose as determined by the proportional control section described above. This offset supplements the basic dose via the following relationship:

\[ \text{Infusion dose} = \text{Basic dose} + \text{offset} \]

The offset is determined by assessing, at regular intervals, how effective the current infusion dose is in bringing the patient’s BSL into the desired region.

The assessment interval selected is consistent with the duration of action and half-life of the insulin preparation used. For example, for Humulin R™ or Actrapid™, which have a duration of action of 2-4 hours when infused subcutaneously, assessments would be made every two hours. For subcutaneously-delivered insulin Lispro™, which achieves its maximum effect within 30 minutes, the assessment would be made hourly, although shorter assessment interval may also be considered.

Within any assessment period, the BSL can either:
• enter a Region higher than the Region determined at the time the last infusion rate decision was made;

• enter a Region lower than the Region determined at the time the last infusion rate decision was made;

• or remain within the same Region as that determined at the time the last infusion rate decision was made.

The equation below shows how the offset is determined:

\[
\text{Offset} = \begin{cases} 
\text{Offset} + 1 & \text{Up in region} \\
\text{Offset} + 1 & \text{No change in region} \\
\text{Offset} & \text{Down in region}
\end{cases}
\]

This control is piece-wise because it is activated only when the BSL is in Region 2 or greater, and at the end of every assessment interval so that the new infusion dose is calculated before the coming of the next hour. The offset may be increased more if the BSL enters a higher Region and the Region determined at the time the last infusion decision was made was Region 3 or higher.

When the apparatus 1 is initialised the operator has two choices, namely: 1). To allow the controller 2 to prescribe the first dose; or 2). To prescribe the first dose himself/herself.

In the first option, the controller 2 selects the basic dose only, and sets the offset to 0. In the second option, the initial offset is the operator's prescribed dose minus whatever the Region the measured BSL currently resides in. If the Offset is less than –1, than the Offset is set to -1. (i.e. offset cannot go below –1). For example, say the current measured BSL is 11.5 mmol/L, then the current Region is 2. If the operator selects an initial dose of 3, then the initial Offset is 1. If the operator were to select an insulin dose of 1, then the initial Offset is -1.
As mentioned above, the control signals are repeated hourly for the proportional section. However, not all of these will include the integral control section component (i.e. if the measured BSL is in Region 1 or Region 0). The actual timing of the proportional control component can be done in a number of ways.

For example, it can be done every hour on the hour (i.e. 2pm, 3pm etc.) so that if the infusion begins at 12.30pm, the next hourly assessment will occur at 1.00pm. Alternatively, the timing of the assessment interval could be reset from when any additional change in dose is made, for example, due to the protection scheme section, discussed below. This control scales-up insulin dose dynamically to lower a patient’s BSL to the desired Region. As such, it adjusts to the patient’s insulin sensitivity.

The protection scheme is implemented only when the measured BSL is inside the desired Region. It is rule-based, and overrides the proportional and integral control sections discussed above. Unlike the other two sections that make decisions at a predetermined rate, such as every two hours, this section is activated immediately on recognition of entrance into the desired Region and in one case activated immediately on knowing that the instantaneous BSL value is lower than the low-end boundary of the desired region. That is when the Region Checking Algorithm reports the current BSL Region, and protection scheme sees that the current Region has entered the desired Region, then action is taken immediately without waiting for the arrival of the hour, instead of the usual practice of the dose being decided on the hour.

In this section, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = \begin{cases} 
\frac{1}{2} \times \text{Previous dose}, & \text{where BSL first enters 6-8 mmol/L from above} \\
0, & \text{where BSL} \leq 6 \text{ mmol/L} \\
\text{Previous dose} + 1, & \text{where BSL first enters 8-10 mmol/L from below}
\end{cases}
\]

Thus, when the patient’s BSL first enters the 6-8 mmol/L range, the previous infusion dose is halved and truncated to the nearest integer, i.e.
Infusion dose = $\frac{1}{2} \times $Previous dose. A new offset is calculated according to equation:

$$\text{New Offset} = \text{infusion dose} - \text{current region}$$

When the patient’s BSL first enters the 8-10 mmol/L range from below, the infusion dose is incremented by one unit to keep blood glucose level within the 6-8 mmol/L. A new offset is again calculated according to equation:

$$\text{New Offset} = \text{infusion dose} - \text{current region}.$$

The exception is when the patient’s BSL is less than 6 mmol/L. In this case, it is determined by the instantaneous value of the patient’s BSL (rather than by region recognition). The insulin infusion is cut-off until the patient’s BSL is again $> 8$ mmol/L (as recognised by region).

The cut-off when the measured BSL falls below 6 mmol/L needs to be immediate to prevent hypoglycaemia. However, the decision line of 8 mmol/L is not as critical, and, therefore the apparatus 1 measures at least two consecutive readings in Region 2 before starting infusion of insulin. In this situation, the new offset is set to $-1$.

In this manner, the controller 2 is operable to receive input signals from the sensor system 7 at constant intervals, the input signals representing the patient’s BSLs, and react to these input signals in accordance with the algorithm(s) set out above, to determine the rate that insulin should be infused into the patient and thereafter control the operation of the infusion system 8 to ensure that the pump 5 dispenses insulin at the determined rate.

The apparatus 1 can be provided as a wearable portable battery-powered three-in-one device i.e. comprising the sensor system 7, controller 2 and insulin infusion system 8 as a single unit, or as two or more wearable portable battery-powered devices comprising the sensor system 7, controller 2, and insulin infusion system 8 in any combination.
The controller 2 can also provide an allowance on manual overrides of insulin infusion as deemed required by the operator. When the operator wants manual control, he/she can manually program the insulin dose into the controller 2 to give infusion over a period of time chosen by him/her, or the operator can select boluses of insulin dose by pressing a button, or some other appropriate mechanism.

The operator 2 may transfer control back to the apparatus 1 at any time. When this occurs, the operator has the choice of choosing the first dose of insulin to administer to the patient or let the apparatus 1 prescribe the first dose as described above. From that point on the algorithm(s) mentioned above are restarted and control the continuous administration of insulin to the patient.

Touch screen 14 is also used to display any alerts the controller 2 has relayed. The alert may be in the form of a blinking light or other attention-catching signal. Alternatively, the alert may be an audible alarm emitted by speakers incorporated into the touch screen 14. Further, the controller 2 can also provide an audible and/or visual alarm when conditions require attention – for example, when BSLs reach a critical point, or for example, if any of the components of the apparatus are faulty. If the controller 2 is not arranged to convey problems with the pump 5 or sensor 3, then the pump interface 4 and sensor interface 6 must be arranged to handle the reporting of such problems to the operator (eg. through an audible or visual alert).

Allowances can also be made for a “pre-meal” insulin dose, where the operator can manually give boluses of insulin, and the controller 2 will be operable to automatically make adjustments accordingly.

In a further embodiment, the algorithm used to determine the amount of insulin to be delivered to the patient has been revised. As part of the revised algorithm, the Regions set out in Table 1 have also been revised as follows:
Table 2 – Revised Partitioning and Zone Table for BSL

<table>
<thead>
<tr>
<th>BSL range</th>
<th>Region</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 6 mmol/L</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6.1 – 8 mmol/L</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8.1 – 10 mmol/L</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10.1 – 12 mmol/L</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>12.1 – 15 mmol/L</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>15.1 – 20 mmol/L</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>&gt;20 mmol/L</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

The addition and relevance of the Zones column will be discussed in more detail below.

In the revised algorithm(s), the intention is to adjust the region checking algorithm to provide more weight to more recent BSL readings when determining the Region the patient’s BSL readings presently fall into. This is attained through the introduction of a further variable, TopUp, such that the infusion dose is now calculated as follows:

\[
\text{Infusion dose} = \text{Basic dose} + \text{Offset(n)} + \text{Derivative control}
\]

Where:

- Basic dose is the Region as determined by Table 2.
Offset(n) is calculated as follows:

\[
\text{Offset}(n) = \begin{cases} 
\text{Prescribed dose by user - BSL Region}, & t = 0, \text{ and } n = 0 \\
\text{TopUp} + \text{Offset}(n-1), & t > 0 \text{ and } n > 0
\end{cases}
\]

where:

- \( t \) = time as mentioned above.
- \( n \) is an index to Offset and is not real-time-related.

Offset(n) = TopUp + Offset(n-1) reads:

Newly determined Offset = Topup + most recently available offset in memory.

- Offset(n) refers to the newly determined offset and Offset(n-1) refers to the previous offset that was used in generating the dose currently received by the patient.

- Offset(n) is used to prescribed the dose that the patient WILL received, not the dose that he/she is currently receiving.

TopUp is calculated as follows:

\[
\text{TopUp} = \begin{cases} 
4 \text{ U/hr}, & \text{if } W_{\text{zone}} > 4.5 \\
2 \text{ U/hr}, & \text{if } 3.6 \leq W_{\text{zone}} \leq 4.5 \\
1 \text{ U/hr}, & \text{if } 2.7 \leq W_{\text{zone}} < 3.6 \\
0 \text{ U/hr}, & \text{if } W_{\text{zone}} < 2.7
\end{cases}
\]

where:

\[
W_{\text{zone}} = \frac{1}{24} \times \sum_{n=1}^{24} n \times x(n)
\]
and we let $x[24]$ contains the most recent BSL zone information, $x[23]$ contains the BSL zones 5-minutes ago, etc.

and $x[n]$ is the array of previous BSL readings taken over the determined time period (in this mathematical equation the series of 24 5-minute BSL readings taken over a 2 hour period). If any member of the array $x[n]$ has invalid entries, such as missing values because the sensor was not connected properly over, say, the last 15 minutes, then those entries will be skipped, and the corresponding count, $n$, is skipped as well.

Once a TopUp of $>0 \text{ U/hr}$ is obtained, then integral control will not be active until two hours have passed since the TopUp was last calculated (i.e. TopUp calculation will be locked for two hours, starting from the hour where a non-zero TopUp was obtained and included in the “infusion dose” delivered to patient)

- Derivative Control is calculated as follows:

$$
\text{Derivative Control} = \begin{cases} 
6 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} \geq 2 \text{ mmol/L} \\
4 \text{ U/hr}, & \text{if } 1 \leq \Delta y_{\text{proj}} < 2 \text{ mmol/L} \\
0 \text{ U/hr}, & \text{if } \Delta y_{\text{proj}} < 1 \text{ mmol/L}
\end{cases}
$$

The algorithm, as described above, is referenced to a 2 hour period where BSL readings are taken on a 5 minute interval basis.

In this manner, the TopUp variable is indicative of the integral control component of the algorithm(s). It should also be noted that a $W_{\text{Zone}}$ of 3.6 is equivalent to a $W_{\text{Zone}}$ residing within 90% of zone 3, while a $W_{\text{Zone}}$ of 4.5 is equivalent to a $W_{\text{Zone}}$ residing within 90% of zone 4.

The Derivative control variable is designed to boost the insulin level when a BSL increase has been detected. The Derivative control variable is only activated once the magnitude of the projected increase in BSLs exceeds a threshold value and when BSL is above 10 mmol/L, although it can also be activated for BSL
above 6 mmol/L. The projected increase in BSLs, \( \Delta y_{\text{proj}} \), is calculated using a least square regression method. In particular, this is calculated by fitting a regression line to the 6 most recent BSL readings, and calculating a projected BSL in accordance with the regression line, i.e.

\[
\begin{align*}
 x_{\text{max}} &= \text{maximum time value in the 30 min window} \\
 x_{\text{min}} &= \text{minimum time value in the 30 min window} \\
 y_{\text{max}} &= \text{maximum BSL value in the 30 min window} \\
 y_{\text{min}} &= \text{minimum BSL value in the 30 min window}
\end{align*}
\]

By defining,

\[
\bar{x} = \frac{x_{\text{max}} + x_{\text{min}}}{2} \quad \text{and} \quad \bar{y} = \frac{y_{\text{max}} + y_{\text{min}}}{2}
\]

Then the slope of a least square regression line fitted to the dataset will be

\[
b_{xy} = \frac{\sum_{i=1}^{6} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{6} (x_i - \bar{x})^2}
\]

By maintaining \( \Delta x = x_{\text{max}} - x_{\text{min}} \), a projected change in BSL, \( \Delta y_{\text{proj}} \), can be found by

\[
\Delta y_{\text{proj}} = b_{xy} \cdot \Delta x
\]

After the bolus of insulin has been delivered for a period of 30 minutes it is followed by a hiatus of 30 minutes. The hiatus interval of 30 minutes is chosen because IV injected insulin has a maximum effect within 15-30 minutes. Thus, it is deemed desirable to wait for the infused insulin to run its full course before making the next decision based on the reaction.
In this embodiment, the region checking scheme and protection scheme are also modified.

The region checking scheme will recognize a change in region when at least two out of the three consecutive BSL readings lay in the same region. If all three consecutive BSL readings are of different regions, the middle BSL reading is assumed. An exception arises when the BSL falls in to the range of 6-8 mmol/L and also when the BSL rises into the range 8-10 mmol/L. In these cases, it is the BSL value (rather than the region) that is used by the controller to make the infusion decision. An identical scheme is adapted for checking changes in Zones.

The protection scheme, as implemented in this embodiment, is split depending on the current BSL trend. For example, if there exists a downward BSL trend, i.e. if the current BSL trend where to continue the patient’s BSL level would eventually reside in Region 0, the protection scheme operates as follows:

where BSL level entering Zone 2 (i.e. BSL range of 8.1 mmol/L to 10.0 mmol/L)

\[ k = \begin{cases} 0.75, & \text{if } t_{\text{BSL cross 12 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 30 \text{ minutes} \\ 0.85, & \text{otherwise} \end{cases} \]

Infusion dose = \( k \times (\text{present dose} - \text{derivative control}) + \text{derivative control} \)

Offset(n) = (infusion dose - derivative control - BSL Region)^+

where BSL level entering Zone 1 (i.e. BSL range of 6.1 mmol/L to 8.0 mmol/L)

\[ k = \begin{cases} 0.50, & \text{if } t_{\text{BSL cross 8 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 45 \text{ minutes} \\ 0.80, & \text{otherwise} \end{cases} \]

Infusion dose = \( k \times (\text{present dose} - \text{derivative control}) + \text{derivative control} \)

Offset(n) = (infusion dose - derivative control - BSL Region)^+
Where "present dose" refers to the dose currently received by patient, and the "Infusion dose" is the dose that will be delivered to the patient. Because "present dose" was calculated previously and it included derivative control component, therefore in the calculation of "infusion dose" here, the derivative control is taken off "present dose" before "present dose" is scaled by k. "Infusion dose" is then given to patient with derivative control added in.

The protection scheme updates the variable Offset(n) by the equation as defined, and (.)^+ means that if the term inside the bracket turns out to be negative-valued, then the operation (.)^+ will return a value of -1. Again, derivative control component is taken off in the calculation of Offset(n).

Derivative control can be terminated the instance BSL zones fall below zone 3 (i.e. going into zone 0, 1 and 2) regardless of whether 30 mins of bolus hasn't yet finished or not.

where BSL level entering BSL range <= 6.0 mmol/L, checked by instantaneous BSL value, and not through the usual Region-checking.

\[
\text{Infusion dose} = 0; \text{ and Offset(n)} = 0
\]

However, if there exists an upward BSL trend, i.e. if the current BSL trend where to continue the patient's BSL level would eventually reside in Region 2 or higher, the protection scheme operates as follows:

where BSL level entering Zone 2 (i.e. BSL range of 8.1 mmol/L to 10.0 mmol/L)

\[
\text{Offset (n)} = \text{Offset (n - 1)} + 1
\]
\[
\text{New dose} = \text{Basic dose} + \text{Offset (n)}
\]

where BSL level entering Zone 3 (i.e. BSL range of 10.1 mmol/L to 12.0 mmol/L)

\[
\text{Offset(n)} = \text{Offset(n-1), i.e. no change.}
\]

\[
\text{New dose} = \text{Basic dose} + \text{Offset (n)}
\]
In each of the above formulas used in the protection scheme $t_{BSL \text{ cross } x \text{ mmol/L boundary}}$ represents the time BSL crosses the $x \text{ mmol/L boundary}$ and $n$ represents the index of Offset, which may or may not be real-time related.

In yet another embodiment, assessment is done based on BSL region change, rather than time.

It will be understood that various modifications are possible within the scope of the present invention. For example, combinations of fixed couplings and wireless telemetry couplings between the controller 2, sensor 3 and pump 5 can be used. Further, the algorithm is not limited to the description as provided herein and derivative control may be added and/or other changes may be made to cater for different clinical situations and/or using different insulin preparations. As more findings surface, modifications to the algorithm may be done to better approximate human insulin dynamics and optimise glycaemic control. In addition, any suitable region-checking algorithm consistent with removing noise and/or improving BSL readings can be used.
The Claims defining the Invention are as Follows:

1. An infusion apparatus for regulating blood sugar levels of a patient, the apparatus comprising:
   
   • a controller;

   • a sensor system and an infusion system, each at least in data communication with the controller, the sensor system being operable to regularly measure the blood sugar level of a patient and provide a sensor signal to the controller in response to the measured blood sugar level,

   wherein the controller calculates the required infusion rate, in response to the received sensor signal, and provides a control signal to the infusion system at predetermined intervals; the infusion system being operable, in response to the control signal, to deliver medication for regulating blood sugar levels at the calculated infusion rate.

2. An infusion apparatus for regulating blood sugar levels according to claim 1, wherein the infusion rate is determined by the equation:

   \[
   \text{Infusion rate} = \text{basic rate} + \text{offset}
   \]

   Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and the offset is a second value representative of how effective the current infusion dose is in assisting in regulating the patient's blood sugar level.

3. An infusion apparatus for regulating blood sugar levels according to claim 2, wherein the offset is initially determined by subtracting the basic rate from the initial predetermined infusion rate, and subsequently incremented
when there is a positive change or there is no change in the current basic rate when compared with the previous basic rate.

4. An infusion apparatus for regulating blood sugar levels according to any of the preceding claims, wherein the controller is further operable to determine when the measured blood sugar level is within a desired range.

5. An infusion apparatus for regulating blood sugar levels according to claim 4, wherein the desired range is a blood sugar level between 6.1 and 10 mmol/L.

6. An infusion apparatus for regulating blood sugar levels according to claim 4 or claim 5, wherein the desired range is a blood sugar level between 6.1 and 8 mmol/L.

7. An infusion apparatus for regulating blood sugar levels according to any one of claims 4 to 6, as dependent on claim 2, wherein, when the patient’s blood sugar level is within the desired range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = \begin{cases} 
\frac{1}{2} \times \text{Previous dose}, & \text{where BSL first enters 6 - 8 mmol/L from above} \\
0, & \text{where BSL } \leq 6 \text{ mmol/L} \\
\text{Previous dose} - 1, & \text{where BSL first enters 8 - 10 mmol/L from below}
\end{cases}
\]

8. An infusion apparatus for regulating blood sugar levels according to claim 7, wherein the new offset is calculated by subtracting the basic rate from the infusion dose, except in the situation where the infusion dose is 0, when the new offset is set to -1, and thereafter the offset being subsequently incremented when there is a positive change or there is no change in the current base rate when compared with the previous base rate.
9. An infusion apparatus for regulating blood sugar levels according to any one of claim 1 and claims 4 to 6 as dependent on claim 1, wherein the infusion rate is determined by the equation:

\[
\text{Infusion dose} = \text{Basic dose} + \text{Offset (n)} + \text{Derivative control}
\]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, Offset \((n)\) is a second value representative of how effective the current infusion dose is in assisting in regulating the patient’s blood sugar level and Derivative control is a third value representative of the current increasing trend, if any, in infusion doses.

10. An infusion apparatus for regulating blood sugar levels according to claim 9, wherein Offset \((n)\) is calculated as follows:

\[
\text{Offset}(n) = \begin{cases} 
\text{Prescribed dose by user - BSL Region,} & t = 0, \text{and } n = 0 \\
\text{TopUp} + \text{Offset}(n-1), & t > 0 \text{ and } n > 0 
\end{cases}
\]

where:

\(t\) = time;

\(n\) is an index to Offset; and

TopUp is calculated as follows:

\[
\text{TopUp} = \begin{cases} 
4 \text{ U/hr,} & \text{if } W_{\text{Zone}} > 4.5 \\
2 \text{ U/hr,} & \text{if } 3.6 \leq W_{\text{Zone}} \leq 4.5 \\
1 \text{ U/hr,} & \text{if } 2.7 \leq W_{\text{Zone}} < 3.6 \\
0 \text{ U/hr,} & \text{if } W_{\text{Zone}} < 2.7 
\end{cases}
\]

in which \(W_{\text{Zone}}\) is calculated as follows:
\[ W_{zone} = \frac{1}{a} \sum_{i=1}^{a} n \times x[n] \]

\( x[n] \) representing a set of a basic rates, \( x[a] \) being the basic rate as determined by the most recent blood sugar level measurement.

11. An infusion apparatus for regulating blood sugar levels according to either claim 9 or claim 10, wherein Derivative control is calculated as follows:

\[
\text{Derivative Control} = \begin{cases} 
6 \text{ U/hr}, & \text{if } \Delta y_{proj} \geq 2 \text{ mmol/L} \\
4 \text{ U/hr}, & \text{if } 1 \leq \Delta y_{proj} < 2 \text{ mmol/L} \\
0 \text{ U/hr}, & \text{if } \Delta y_{proj} < 1 \text{ mmol/L}
\end{cases}
\]

where:

\[ \Delta y_{proj} = b_{xy} \cdot \Delta x \]

and

\[
b_{xy} = \frac{\sum_{i=1}^{a} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{a} (x_i - \bar{x})^2}
\]

in which:
- \( a \) = number of readings taken
- \( x_{max} \) = maximum time value in the 30 min window
- \( x_{min} \) = minimum time value in the 30 min window
- \( y_{max} \) = maximum BSL value in the 30 min window
- \( y_{min} \) = minimum BSL value in the 30 min window

\[
\bar{x} = \frac{x_{max} + x_{min}}{2}
\]

\[
\bar{y} = \frac{y_{max} + y_{min}}{2}
\]
12. An infusion apparatus for regulating blood sugar levels according to any one of claims 9 to 11, as dependent on claim 5, wherein, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.75, & \text{if } t_{\text{BSL cross 12 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 30 \text{ minutes} \\
0.85, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

13. An infusion apparatus for regulating blood sugar levels according to any one of claims 9 to 11, as dependent on claim 6, wherein, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control}
\]

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.50, & \text{if } t_{\text{BSL cross 8 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 45 \text{ minutes} \\
0.80, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

14. An infusion apparatus for regulating blood sugar levels according to either claim 13 or claim 14, wherein Offset (n) is calculated as follows:

\[
\text{Offset (n)} = \text{infusion dose} - \text{derivative control} - \text{basic rate}
\]
provided that if the value of Offset (n) is negative, Offset (n) is set to −1.

15. An infusion apparatus for regulating blood sugar levels according to any one of claims 9 to 11, as dependent on claim 5, wherein, when the patient's blood sugar level is within the range 8.1 mmol/L to 10.0 mmol/L and after previously measuring a lower blood sugar level, the infusion dose is calculated as follows:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset (n)} \]

Where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset (n)} = \text{Offset (n − 1)} + 1 \]

16. An infusion apparatus for regulating blood sugar levels according to any one of claims 9 to 11, as dependent on claim 4, wherein, when the patient's blood sugar level is within the range 10.1 mmol/L to 12.0 mmol/L and after previously measuring a lower blood sugar level, the infusion dose is calculated as follows:

\[ \text{Infusion dose} = \text{Basic rate} + \text{Offset (n)} \]

Where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[ \text{Offset (n)} = \text{Offset (n − 1)} \]
17. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the Offset value, or the value of Offset (n), as appropriate, is determined at regular predetermined intervals.

18. An infusion apparatus for regulating blood sugar levels according to claim 17, wherein the predetermined intervals are determined by the half-life or duration of action of the medication for regulating blood sugar levels being used.

19. An infusion apparatus for regulating blood sugar levels according to claim 17 or claim 18, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.125 to 2.

20. An infusion apparatus for regulating blood sugar levels according to claims 17 to 19, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.25 to 1.5.

21. An infusion apparatus for regulating blood sugar levels according to claims 17 to 20, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.5 to 1.

22. An infusion apparatus for regulating blood sugar levels according to claims 17 to 21, wherein the predetermined interval is equal to the half-life or duration of action of the medication for regulating blood sugar levels being used.

23. An infusion apparatus for regulating blood sugar levels according to claim 17, wherein the predetermined interval is 1 hour.

24. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the controller confirms a change in
the range of the basic rate if at least two of the last three blood sugar level measurements fall within the new range.

25. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the controller confirms a change in the range of the basic rate in situations where the last three blood sugar levels measurements each fall within a new range, the change in range of the basic rate being equal to the range as determined by the second most recent blood sugar level measurement.

26. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the sensor system comprises a sensor and a sensor interface and the sensor interface is integral with either the controller or the sensor.

27. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the infusion system comprises a pump and a pump interface and the pump interface is integral with either the controller or the pump.

28. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein at least one of the sensor system or the infusion system is in wireless communication with the controller.

29. An infusion apparatus for regulating blood sugar levels according to any one of the preceding claims, wherein the controller comprises a microprocessor and the microprocessor references a static memory location, wherein the static memory location is a memory address positioned on a removable memory, the static memory location being the start location for instructions representing the algorithm used to determine the required infusion rate.

30. A method of regulating blood sugar levels comprising:
• Measuring the blood sugar level of a patient;

• Calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement; and

• Delivering to the patient the medication for regulating blood sugar levels at the required infusion date determined.

31. A method of regulating blood sugar levels according to claim 30, wherein the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion rate} = \text{basic rate} + \text{offset}
\]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges and the offset is a second value representative of how effective the current infusion dose is in assisting in regulating the patient’s blood sugar level.

32. A method of regulating blood sugar levels according to claim 31 wherein the offset is determined by subtracting the basic rate from the initial predetermined infusion rate, and subsequently incremented when there is a positive change or there is no change in the current basic rate when compared with the previous basic rate.

33. A method of regulating blood sugar levels according to any one of claims 30 to 32, further comprising the step of determining whether the measured blood sugar level is within a desired range.

34. A method of regulating blood sugar levels according to claim 33 wherein the desired range is a blood sugar level between 6.1 and 10 mmol/L.
35. A method of regulating blood sugar levels according to claim 33 or claim 34, wherein the desired range is a blood sugar level between 6.1 and 8 mmol/L.

36. A method of regulating blood sugar levels according to any one of claims 33 to 35, as dependent on claim 31, wherein, when the patient's blood sugar level is within the desired range, the infusion dose is calculated as follows:

\[
\text{Infusion dose} = \begin{cases} 
\frac{1}{2} \times \text{Previous dose}, & \text{where BSL first enters 6 - 8 mmol/L from above} \\
0, & \text{where BSL } \leq 6 \text{ mmol/L} \\
\text{Previous dose} + 1, & \text{where BSL first enters 8 - 10 mmol/L from below}
\end{cases}
\]

37. A method of regulating blood sugar levels according to claim 36, wherein the new offset is calculated by subtracting the basic rate from the infusion dose, except in the situation where the infusion dose is 0, when the new offset is set to -1, and thereafter the offset being subsequently incremented when there is a positive change or there is no change in the current base rate when compared with the previous base rate.

38. A method of regulating blood sugar levels according to any one of claim 30 or claims 33 to 35 as dependent on claim 30, wherein the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion dose} = \text{Basic dose} + \text{Offset (n)} + \text{Derivative control}
\]

Where the basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, Offset (n) is a second value representative of how effective the current infusion dose is in assisting in regulating the patient's blood sugar level and
Derivative control is a third value representative of the current increasing trend, if any, in infusion doses.

39. A method of regulating blood sugar levels according to claim 38, wherein Offset (n) is calculated as follows:

\[
\text{Offset}(n) = \begin{cases} 
\text{Prescribed dose by user - BSL Region}, & t = 0, \text{ and } n = 0 \\
\text{TopUp + Offset(n - 1)}, & t > 0 \text{ and } n > 0 
\end{cases}
\]

where:

- t = time;

- n is an index to Offset; and

TopUp is calculated as follows:

\[
\text{TopUp} = \begin{cases} 
4 \text{ U/hr}, & \text{if } W_{\text{Zone}} > 4.5 \\
2 \text{ U/hr}, & \text{if } 3.6 \leq W_{\text{Zone}} \leq 4.5 \\
1 \text{ U/hr}, & \text{if } 2.7 \leq W_{\text{Zone}} < 3.6 \\
0 \text{ U/hr}, & \text{if } W_{\text{Zone}} < 2.7 
\end{cases}
\]

in which \( W_{\text{Zone}} \) is calculated as follows:

\[
W_{\text{Zone}} = \frac{1}{\Delta t} \times \sum_{n=1}^{a} n \times x[n]
\]

\( x[n] \) representing a set of a basic rates, \( x[a] \) being the basic rate as determined by the most recent blood sugar level measurement.

40. A method of regulating blood sugar levels according to either claim 38 or claim 39, wherein Derivative control is calculated as follows:
Derivative Control = \begin{align*}
6 \text{ U/hr, if } \Delta y_{\text{proj}} \geq 2 \text{ mmol/L} \\
4 \text{ U/hr, if } 1 \leq \Delta y_{\text{proj}} < 2 \text{ mmol/L} \\
0 \text{ U/hr, if } \Delta y_{\text{proj}} < 1 \text{ mmol/L}
\end{align*}

where:

\[ \Delta y_{\text{proj}} = b_{xy} \cdot \Delta x \]

and

\[ b_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \]

in which:

- \( a \) = number of readings
- \( x_{\text{max}} \) = maximum time value in the 30 min window
- \( x_{\text{min}} \) = minimum time value in the 30 min window
- \( y_{\text{max}} \) = maximum BSL value in the 30 min window
- \( y_{\text{min}} \) = minimum BSL value in the 30 min window

\[ \bar{x} = \frac{x_{\text{max}} + x_{\text{min}}}{2} \]

\[ \bar{y} = \frac{y_{\text{max}} + y_{\text{min}}}{2} \]

4.1 A method of regulating blood sugar levels according to any one of claims 38 to 40, as dependent on claim 34, wherein, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:
Infusion dose = \( k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control} \)

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.75, & \text{if } t_{\text{BSL cross 12 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 30 \text{ minutes} \\
0.85, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

42. A method of regulating blood sugar levels according to any one of claims 38 to 40, as dependent on claim 35, wherein, when the patient's blood sugar level is within the desired range and after previously being in a higher range, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

Infusion dose = \( k \cdot (\text{Immediately previous Infusion dose} - \text{Derivative control}) + \text{Derivative control} \)

in which \( k \) is calculated as follows

\[
k = \begin{cases} 
0.50, & \text{if } t_{\text{BSL cross 12 mmol/L boundary}} - t_{\text{BSL cross 10 mmol/L boundary}} < 45 \text{ minutes} \\
0.80, & \text{otherwise}
\end{cases}
\]

and \( t \) is time.

43. An infusion apparatus for regulating blood sugar levels according to either claim 41 or claim 42, wherein Offset (n) is calculated as follows:

Offset (n) = infusion dose – derivative control – basic rate

provided that if the value of Offset (n) is negative, Offset (n) is set to \(-1\).
44. An infusion apparatus for regulating blood sugar levels according to any one of claims 38 to 40, as dependent on claim 34, wherein, when the patient's blood sugar level is within the range 8.1 mmol/L to 10.0 mmol/L and after previously measuring a lower blood sugar level, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion dose} = \text{Basic rate} + \text{Offset} (n)
\]

Where:

10 Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to determine which range a current measured blood sugar level resides in, and

\[
\text{Offset} (n) = \text{Offset} (n - 1) + 1
\]

45. A method of regulating blood sugar levels according to any one of claims 38 to 40, as dependent on claim 35, wherein, when the patient's blood sugar level is within the range 10.1 mmol/L to 12.0 mmol/L and after previously measuring a lower blood sugar level, the step of calculating the required infusion rate of medication for regulating blood sugar levels based on the blood sugar level measurement is determined according to the equation:

\[
\text{Infusion dose} = \text{Basic rate} + \text{Offset} (n)
\]

Where:

Basic rate is one of a plurality of first values representative of a plurality of adjacent blood sugar level ranges, the controller being operable to
determine which range a current measured blood sugar level resides in, and

$$\text{Offset (n)} = \text{Offset (n-1)}$$

46. A method of regulating blood sugar levels according to any one of claims 30 to 45, wherein the method further includes the step of determining the Offset value, or the value of Offset (n), at regular predetermined intervals.

47. A method of regulating blood sugar levels according to claim 46, wherein the predetermined intervals are determined by the half-life or duration of action of the medication for regulating blood sugar levels being used.

48. A method of regulating blood sugar levels according to claim 46 or claim 47, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.125 to 2.

49. A method of regulating blood sugar levels according to claims 46 to 48, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.25 to 1.5.

50. A method of regulating blood sugar levels according to claims 46 to 49, wherein the predetermined interval is determined by multiplying the half-life or duration of action of the medication for regulating blood sugar levels being used by from 0.5 to 1.

51. A method of regulating blood sugar levels according to claims 46 to 50, wherein the predetermined interval is equal to the half-life or duration of action of the medication for regulating blood sugar levels being used.

52. A method of regulating blood sugar levels according to claim 46, wherein the predetermined interval is 1 hour.
53. A method of regulating blood sugar levels according to any one claims 30 to 52, wherein the method further comprises the step of confirming a change in the range of the basic rate if at least two of the last three blood sugar level measurements fall within the new range.

54. A method of regulating blood sugar levels according to any one of claims 30 to 53, wherein the method further comprises the step of confirming a change in the range of the basic rate in situations where the last three blood sugar levels measurements each fall within a new range, the change in range of the basic rate being equal to the range as determined by the second most recent blood sugar level measurement.

55. An infusion apparatus for regulating blood sugar levels substantially as described herein with reference to the drawings.

56. A method of regulating blood sugar levels substantially as described herein with reference to the drawings.
Figure 4

Basic Sliding Scale

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INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: A61M 5/172, A61B 5/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
REFER TO THE ELECTRONIC DATABASE CONSULTED BELOW
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
DWPI + key words (blood, diabet+, glycaem+, infusion, rate etc)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<td>US 4151845 A (CLEMENS) 1 May 1979 See entire document</td>
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<td>CA 1040271 A (THE HOSPITAL FOR SICK CHILDREN) 10 October 1978 See entire document</td>
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Further documents are listed in the continuation of Box C

See patent family annex

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
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  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search
30 September 2002

Date of mailing of the international search report
31 Oct 2002

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Authorized officer

Mr. SWAYAM CHINTAMANI
Telephone No: (02) 6283 2202
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Form PCT/ISA/210 (continuation of Box C) (July 1998)
This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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END OF ANNEX