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(54) SYSTEM AND METHOD CONSIDERING THE EFFECT OF PHYSICAL ACTIVITY ON THE GLUCOREGULATORY SYSTEM

SYSTEM UND VERFAHREN UNTER BERÜCKSICHTIGUNG DER WIRKUNG EINER PHYSIKALISCHEN AKTIVITÄT AUF DAS GLUKOSEREGULATORISCHE SYSTEM

SYSTÈME ET PROCÉDÉ EXAMINANT L'EFFET DE L'ACTIVITÉ PHYSIQUE SUR LE SYSTÈME GLUCO-RÉGULATEUR

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Description

BACKGROUND

[0001] The present disclosure generally relates to a model of the glucoregulatory system and, in particular, to a model quantifying the effect of physical activity on the glucoregulatory system.

[0002] The regulation of blood glucose in diabetics is a perpetual concern. High blood glucose levels, commonly referred to as hyperglycemia, can for example lead to organ damage and/or ketoacidosis, which is a life-threatening condition that needs immediate medical treatment. On the other hand, low blood glucose levels, commonly referred to as hypoglycemia, can lead to unconsciousness or even death. To avoid these conditions, many researchers have tried to understand and develop a model of the glucoregulatory system so that appropriate remedial action can be taken, such as injecting an appropriate insulin dose or ingesting the appropriate foods. The modeling of the glucose regulatory system has been widely studied in the literature over the past 30 years, and continues to be an active research field. One of the key objectives of such models, apart from improving the understanding of the glucoregulatory system, is to allow the prediction of blood glucose concentration, which opens the way for model-based recommendation or control of insulin injection for patients with type 1 diabetes mellitus.

[0003] A difficulty that arises is that these models should not only consider the interaction between glucose and insulin, but also include the effects of the carbohydrate intake and physical activity, as they represent two typical factors that change blood glucose concentration. In particular, if the effect of physical activity is neglected, the risk of hypoglycemia during exercise is dramatically increased. While the effect of carbohydrate intake has been widely investigated, only a few exercise models, which rely on the metabolic changes induced by physical activity, have been developed. However, these models are complex and involve a number of model parameters that are too large for proper parameter identification. For example, others have used more complex models to describe the effect of exercise, but are not able to identify the parameters, because the modeled effects are difficult to detect in clinical data. To evaluate the state of physical activity a patient is in, others use devices like heart rate monitors or need to measure the percentage of VO_2 max. VO_2 max (also maximal oxygen consumption, maximal oxygen uptake, peak oxygen uptake or aerobic capacity) is the maximum capacity of an individual's body to transport and use oxygen during incremental exercise, which reflects the physical fitness of the individual. The name is derived from V - volume per time, O_2 - oxygen, max - maximum.

[0004] This makes it necessary for the patient to wear a measurement device, which causes inconvenience and additional costs. Others model the exercise-induced drop in blood glucose concentration as proportional to either the heart rate or the percentage of VO_2 max. This means that a higher level of activity, i.e. a higher intensity of exercise leads to a steeper drop. However, it has been shown intense exercise has unique effects on both insulin release and its roles in glucoregulation diabetes that this is not the case if anaerobic exercise is performed. Moreover, these identifications of parameters for controlling blood glucose levels are made even more difficult when a meal is eaten close to exercise.

[0005] Document US 2009/006129 A1 describes a diagnosis, therapy and prognosis system (DTPS) and method thereof to help either the healthcare provider or the patient in diagnosing, treating and interpreting data are disclosed. The apparatus provides data collection based on protocols, and mechanism for testing data integrity and accuracy. The data is then driven through an analysis engine to characterize in a quantitative sense the metabolic state of the patient's body. The characterization is then used in diagnosing the patient, determining therapy, evaluating algorithm strategies and offering prognosis of potential use case scenarios.

[0006] In document EP 1 873 667 A2, computerized determination of the characteristic daily profile of an individual glucose metabolism using a mathematical model is disclosed.

[0007] Roy and Parker (A. Roy and R.S. Parker, Dynamic Modelling of Exercise Effects on Plasma Glucose and Insulin Levels, Journal of Diabetes Science and Technology, vol. 1, no. 3, pages 338 - 347, 2007, XP002660806) describe a model of exercise effects on plasma glucose-insulin dynamics.

[0008] Gulve (E. A. Gulve, Exercise and Glycemic Control in Diabetes: Benefits, Challenges, and Adjustments to Pharmacotherapy, Physical Therapy, vol. 88, no. 11, pages 1297-1321, 2008, XP055407640) discusses the effects of exercise on glycemic control.

[0009] Thus, there is a need for improvement in this field.

SUMMARY

[0010] The technique and model described herein address the issues mentioned above, as well as other issues, by facilitating a better understanding of the effect of physical activity on blood glucose concentrations in type 1 diabetics as well as in others.

[0011] Previous models were based on the somewhat intuitive assumption that any change in blood glucose concentration depended on the intensity of the exercise. For instance, the higher intensity exercises or physical activities would be expected to more quickly reduce blood glucose levels as compared to lower intensity exercises or physical activities. As a result, previous models required quantifiable measurements of exercise intensity, such as heart rate or blood oxygen levels. The resulting extra monitoring devices and added complexity made commercial implementation or use of such models extremely difficult.

[0012] It was however unexpectedly discovered that, at least in certain exercise intensity ranges, the exercise intensity had no significant effect on the change or drop in blood glucose levels due to exercise. As a result, the number of parameters needed to predict the effects of exercise on blood glucose levels in this exercise model are dramatically reduced to two parameters that are readily determined, exercise sensitivity (K_{ex}) and an inverse time constant for the exercise effect (a_{ex}). Exercise sensitivity (K_{ex}) is the amplitude of the drop in blood glucose levels during exercise for an individual, and the inverse time constant for exercise effect (a_{ex}) defines how quickly the exercise effect appears and disappears in the individual. Simple blood glucose readings during a clinical exercise test can be used to determine these parameters for an individual. Once these parameters are determined, all that is required to model the effect of exercise is single binary input called the exercise input (U_{ex}). The exercise input (U_{ex}) has a value of zero (0) when no exercise is being performed and a value of one (1) during exercise. In this sense the exercise input is the only non-constant i.e. time varying and measured parameter of the model. In a more general sense, this model is independent of aerobic exercise intensity and does not require the complexity of collecting additional information during exercise, such as heart rate and venous oxygen levels. By not depending on these measures of exercise intensity, no additional measurement devices are required, which in turn results in lower costs and more patient comfort. In other words, this minimal approach allows modeling of blood glucose levels during or before an intended exercise using only one variable i.e. the blood glucose measurements. Since fewer variables have to be considered, measured and proofed the model is also more reliable.

[0013] With this minimalistic model approach, predictions on future blood glucose changes during exercise can be readily achieved. This minimalistic physical activity or exercise model can be incorporated into other existing models of the glucoregulatory system, such those based on insulin dosages and carbohydrate intake, thereby facilitating more complete prediction capabilities. This more complete approach of incorporating a practical exercise model for example can enhance the operation of automated pancreases, optimize insulin injection therapies, improve bolus calculations, and enhance educational tools for patients. Moreover, this modeling approach can be readily incorporated into other models that consider other factors such as the effects of meals and insulin.

[0014] Further forms, objects, features, aspects, benefits, advantages, and embodiments of the present invention will become apparent from a detailed description and drawings provided herewith.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

FIG. 1 shows a block diagram of the parameters used in one example of a model on how exercise affects blood glucose levels.

FIG. 2 shows a graph 200 that shows heart rate and blood glucose concentration during exercise at approximately 75% of the maximum heart rate for an individual patient.

FIG. 3 shows a graph 300 that shows a linear regression slope of the drop in glucose concentration resulting from exercise.

FIG. 4 shows a box-plot graph comparing the slopes at 65% and 75% exercise intensities.

FIG. 5 shows a box-plot graph comparing the slopes between different patients.

FIG. 6 shows a graph with an upper section that shows the exercise glucose effectiveness value ($S_{g,ex}$) and a lower section that shows the corresponding exercise input (U_{ex}).

FIG. 7 shows a graph with an upper section that shows the glucose concentration measurements along with a fit line generated by the exercise model and a lower section showing the corresponding exercise input (U_{ex}).

FIG. 8 shows a block diagram of an example of a blood glucose monitoring system that utilizes the exercise model.

FIG. 9 shows a flow diagram of a technique for monitoring blood glucose levels in a patient during exercise utilizing the exercise model.

FIG. 10 shows an example of an optimized insulin infusion profile.

FIG. 11 shows a simulation of a blood glucose profile obtained with the optimized insulin infusion profile of FIG. 10.

DETAILED DESCRIPTION

[0016] In the following detailed description of the embodiments, it is to be understood that other embodiments may be utilized and that logical, mechanical, and electrical changes may be made without departing from the spirit and scope of the present disclosure.

[0017] For the convenience of the reader, it should be initially noted that the drawing in which an element is first introduced is typically indicated by the left-most digit(s) in the corresponding reference number. For example, a component identified with a one-hundred series reference number (e.g., 100, 101, 102, 103, etc.) will usually be first discussed with reference to FIG. 1, a component with a two-hundred series reference number (e.g., 200, 201, 202, 203, etc.) will usually be first discussed with reference to FIG. 2, and so on.

[0018] As discussed before, many models have been developed to consider the interaction between glucose and insulin along with the effects of the carbohydrate intake. However, very few models consider the effect of exercise. For example, in the Adaptive Bolus Pattern (ABP) context, an identifiable model based on the Bergman minimal model has been developed. It is designed to consider meals, but it does not consider exercise. Since every meal is different, each meal is considered as separate input. The model equations for only one meal input are the following:

$$\frac{dU_{g,gut}}{dt} = \dot{U}_{g,gut} \qquad \text{Equation 1}$$

$$\frac{d\dot{U}_{g,gut}}{dt} = -2a\dot{U}_{g,gut} - a^2U_{g,gut} + K_g a^2 U_{CHO} \qquad \text{Equation 2}$$

$$\frac{dQ}{dt} = -XQ - S_{g,zero}Q + U_{endo} + U_{g,gut}\frac{g \to mmol}{M} \qquad \text{Equation 3}$$

$$\frac{dX}{dt} = -a_x X + a_x X_1 \qquad \text{Equation 4}$$

$$\frac{dX_1}{dt} = -a_x X_1 + K_x a_x \frac{U_{i,sq}}{M} \qquad \text{Equation 5}$$

where:

Q = glucose amount in the accessible compartment [mmol/kg]
X = insulin action [min^{-1}]
X_1 = first compartment insulin action [min^{-1}]
$U_{g,gut}$ = carbohydrate intake rate [g/min]

$$\dot{U}_{g,gut}$$

= carbohydrate intake rate time derivative [g/min/min]
U_{CHO} = rate of ingested carbohydrates in [g/min]
Ui, sq = insulin infusion rate in [mU/min] and the parameters are the following:
M = Body weight [kg]
V_{ga} = Volume of the accessible compartment per body mass [1/kg]
K_g = Bioavailability for fast meals [-]
a_g = Inverse of time constant for meal absorption [min^{-1}]
K_x = Insulin sensitivity [kg/mU]
$S_{g,zero}$ = Glucose effectiveness at zero insulin [min^{-1}]
a_x = Inverse of the time constant of the insulin absorption/action [min^{-1}]
U_{endo} = Insulin independent endogenous production [mmol/kg/min]
$g \to mmol$ is a constant conversion factor that transforms grams of carbohydrates to mmol. Its value is 5.551 [mmol/g].

[0019] This particular model can reproduce the behavior of the glucose/insulin system with the necessary precision for the ABP application when it is perturbed by a meal. However, changes due to exercise are not modeled in this example. Other previous models, which considered the effect of exercise, were based on the somewhat intuitive assumption that any change in blood glucose concentration depended on the intensity of the exercise, but this approach required a complex set of parameters that were difficult to collect in any practical sense.

[0020] The inventors have developed a model that uses a minimalistic approach in determining the effect of exercise on blood glucose levels. That is, the parameters for determining the effect of exercise on blood glucose levels has been reduced to two parameters based on the unexpected discovery that the changes over time in the blood glucose concentration do not generally vary depending on the intensity of the physical activity or exercise, at least within certain ranges.

[0021] FIG. 1 schematically represents the relationship of the parameters used in this model. FIG. 1 generally shows a block diagram 100 of the various parameters that affect blood glucose levels. Most of these parameters have already been mentioned with respect to the ABP model described above, especially with respect to Equation 3. As shown, blood glucose amounts 102 (Q) are increased via endogenous glucose production 104 (U_{endo}) and glucose uptake through meals 106 (Ug,gut). The blood glucose amount 102 (Q) is related to the blood glucose concentration G via the formula:

$$G \text{ in } [\text{mmol/l}] = Q/V_{GA}, \text{ where } V_{GA} \text{ is the accessible volume per body mass in } [\text{l/kg}].$$

where V_{GA} is the accessible volume per body mass in [l/kg].

[0022] As should be appreciated, endogenous glucose production 104 (U_{endo}) can occur when the liver and/or muscles break down stored glycogen (glycogenolysis) and release glucose into the bloodstream. Glucose uptake through meals 106 (Ug,gut) occurs when an individual's body creates glucose as a result from ingesting food (or drink). According to Equation 3 of the previously mentioned ABP model, blood glucose amount 102 (Q) can drop because of two reasons. First, there is an insulin action 108 (X) induced drop, and second, there is a drop dependent on the glucose effectiveness at zero insulin 110 ($S_{g,zero}$). It should be recognized that insulin stores nutrients right after a meal by reducing, among other things, the concentrations of glucose in the bloodstream. For instance, insulin stimulates the liver and muscle cells to store glucose in the form of glycogen. This increased uptake of glucose from the bloodstream created by the insulin action 108 (X) reduces the blood glucose amount 102 (Q). The glucose effectiveness at zero insulin 110 ($S_{g,zero}$) parameter represents the insulin independent uptake of glucose from the bloodstream (i.e., no insulin causes the uptake of glucose).

[0023] It has been previously found that the drop in blood glucose amount 102 (Q) in diabetic patients is due to increased glucose uptake, while endogenous glucose production 104 (U_{endo}) stays the same. This in turn generally means that glucose effectiveness at zero insulin 110 ($S_{g,zero}$) increases during exercise but the endogenous glucose production 104 (U_{endo}) stays constant. Based on this understanding, the inventors developed an exercise model that introduces a new parameter, termed exercise glucose effectiveness 112 ($S_{g,ex}$). As shown in FIG. 1, exercise glucose effectiveness 112 ($S_{g,ex}$) is another source for reducing the blood glucose amount 102 (Q). Like insulin action 108 (X) and glucose effectiveness at zero insulin 110 ($S_{g,zero}$) parameters in Equation 3, the exercise glucose effectiveness 112 ($S_{g,ex}$) parameter is proportional to blood glucose amount 102 (Q), as is indicated by box 114 in FIG. 1. In this exercise model, Equation 3 is modified to incorporate the exercise glucose effectiveness 112 ($S_{g,ex}$) parameter. In Equation 6 below, exercise glucose effectiveness 112 ($S_{g,ex}$) parameter has been introduced into Equation 3 in the following manner:

$$\frac{dQ}{dt} = -XQ - (S_{g,zero} + S_{g,ex})Q + U_{endo} + U_{g,gut}\,\frac{g \rightarrow mmol}{M} \qquad \text{Equation 6}$$

where:

$S_{g,ex}$ = Exercise glucose effectiveness [min^{-1}]

[0024] In developing the model, clinical studies were performed to locate variables that caused a change in the exercise glucose effectiveness 112 ($S_{g,ex}$) factor. In one example, a clinical study was performed on 12 patients. They were admitted to the hospital on the first day and measurements were started. On the second day an ergometer workout was performed at 16h00 (i.e., 4:00 p.m.) at an intensity of 65% of the maximum heart rate for 30 minutes. Insulin management was performed as usual by the patients. On the third day another workout was scheduled at the same time (i.e., 4:00 p.m.) and with the same duration (i.e., 30 minutes), but the exercise was performed with an intensity of 75% of the maximum heart rate. In this instance, insulin management was again adapted by the patient, and meals were not standardized but were in most cases recorded as well.

[0025] Exercise can be roughly divided into two physiological modes: aerobic exercise, often referred to as moderate intensity exercise; and anaerobic exercise, often referred to as high intensity exercise. These define two regions of intensity of the exercise. For Example, the region of intensity on which aerobic exercise occurs can be defined as in the range of 50%-85% of maximal aerobic capacity (VO_2 max) or as in the range of 50%-85% of Heart Rate Reserve or as 60% to 90% of maximal Heart Rate. The Maximum Heart Rate can be calculated by the rule of thumb as

$$\text{Maximum Heart Rate} = 220 - \text{age}.$$

The Heart Rate Reserve can be calculated as :

$$\text{Heart Rate Reserve} = \text{Maximum Heart Rate} - \text{Resting Heart Rate},$$

wherein the Resting Heart Rate is the Heart Rate at resting i.e. without performing any exercise.

[0026] With the clinical study described above, the exercise intensities were between 65% and 75%, which falls in the aerobic category. As will be explained below, it has been deduced from the clinical studies that exercise intensity does not play a relevant role in this range. On the other hand, if anaerobic exercise is performed, the human body's reaction is completely different compared to aerobic exercise. In the case of anaerobic exercise, blood glucose concentrations tend to increase, contrary to the moderate or aerobic exercise in which blood glucose levels tend to become lower. For the clinical studies in developing this exercise model, the exercise durations were about 30 and 45 minutes. After exercising for about 90 minutes, the physiological process changes because the hepatic glycogen stocks are depleted. However, it is rather unusual for an average person to exercise for more than 90 minutes. Consequently, the exercise model below will generally focus aerobic exercise or activities having a duration of no more than 90 minutes.

[0027] The resulting data was used to find out what parameters the drop in blood glucose concentration depends. Several hypotheses were tested, first empirically; then statistically. FIG. 2 shows one example of a graph 200 that illustrates a drop in blood glucose concentration as a result of exercise at the intensity of 75% of the maximum heart rate for an individual patient. As can be seen in FIG. 2, the drop in blood glucose concentration starts and ends with a small delay, and the drop appears to be linear during the exercise. FIG. 3 shows a graph 300 that illustrates the linear nature of the drop in glucose concentration resulting from exercise, and more particularly, it shows the slope of the linear drop. Using linear regression, a straight line was fitted through the glucose measurement points. As mentioned before, there was a delay between when the exercise started and when the glucose concentration started to drop. Due to this warm up or delay phase, the slope for the glucose concentration drop in this example was calculated based on glucose measurements collected 10 minutes after the exercise started. The slope was also calculated based on a 40 minute period, because the effect of the exercise tends to last longer than the exercise itself.

[0028] Several factors were tested to determine if they affected the slope of the linear glucose drop due to aerobic exercise. For example, as mentioned before, it was previously thought that the drop in blood glucose concentration depended on the intensity of physical activity. However, it was unexpectedly discovered that the intensity of aerobic physical activity did not affect the slope of the drop in glucose concentration resulting from physical activity. For instance, FIG. 4 shows a box-plot graph 400 comparing the slope means at 65% and 75% intensity. As can be seen, the box-plot graph 400 shows that the slope means are nearly identical for both intensities. This in turn suggests that at least for this range of exercise intensity, the drop in blood glucose concentration is independent of the exercise intensity. A normality test was passed that indicated this data can be considered as normally distributed. In addition, statistical tests showed that the slope means at the two exercise intensities were statistically the same or indistinguishable.

[0029] Patient variability was another factor analyzed to see if affected the slope of the glucose concentration decrease. It was found that the slope strongly depends on the individual patient. Previous studies have shown that the behavior concerning meals is different for every patient. This leads to the assumption that the behavior concerning physical activity is as well. Considering that the intensity of the exercise has no influence, it was assumed to have two equivalent measurements for each patient. Box-plot graph 500 in FIG. 5 shows that variability of the various slopes between patients, which confirms the hypothesis. An analysis of variance (ANOVA) test shows that slopes are statistically significantly different for every patient with a p-value of 0.0115 (a value below 0.05 is considered significant). This dependence on the patient implies that the model parameters need to be estimated for every individual.

[0030] Several other factors were tested for their influence on the slope, but none of them gave any statistically conclusive results. The factors considered include gender, age, body mass index (BMI), insulin level and blood glucose level. To keep the model simple, only the significant influences were retained, which were patient variability and the presence of exercise.

[0031] The exercise model was designed based on these observations. From these observations, it was determined that the number of parameters needed to predict the effects of exercise on blood glucose levels were dramatically reduced. This simplicity in the model allows the effects of exercise to be accounted for in real world situations. Once the individual's parameters are determined (i.e., the slope in the drop of glucose concentration resulting from exercise and the delay of the exercise effect), the individual merely has to make a binary, exercise input (U_{ex}) of either 0 or 1, depending on whether the patient is at rest or exercising in order to account for the effect of rest or exercise. This elegant model is a direct consequence of the above-discussed finding that the blood glucose drop within certain activity levels is independent of the exercise intensity.

[0032] Again as was alluded to above in the discussion of FIG. 1 and Equation 6, the effect of this exercise input is modeled as an increase in glucose effectiveness at zero insulin or insulin independent glucose uptake 110 ($S_{g,zero}$), depending on the insulin-glucose model used. Again, the exercise glucose effectiveness 112 ($S_{g,ex}$) is another source for reducing the blood glucose amount 102 (Q), and like the glucose effectiveness at zero insulin 110 ($S_{g,zero}$) parameters in Equation 3, the exercise glucose effectiveness 112 ($S_{g,ex}$) parameter is proportional to blood glucose amount 102 (Q). As noted before, Equation 3 was modified to incorporate the exercise glucose effectiveness 112 ($S_{g,ex}$) factor by modeling as an exercise-induced increase in glucose effectiveness at zero insulin 110 ($S_{g,zero}$). The exercise glucose effectiveness 112 ($S_{g,ex}$) factor should be zero when no effect of exercise is present and take a positive value in the opposite case. The exercise input (U_{ex}) takes this into account. In addition, the effect of exercise in reducing blood glucose concentrations (Q) is not instantaneous and therefore a time constant for exercise glucose effectiveness 112 ($S_{g,ex}$) parameter is accounted for in this model as well. Consequently, the change in exercise glucose effectiveness 112 ($S_{g,ex}$) and delay can be accounted for in the following equation:

$$\frac{dS_{g,ex}}{dt} = -a_{ex}S_{g,ex} + K_{ex}a_{ex}U_{ex} \qquad \text{Equation 7}$$

where:

$S_{g,ex}$ = Exercise glucose effectiveness [min^{-1}]
a_{ex} = Inverse of time constant for exercise effect [min^{-1}]
K_{ex} = Exercise sensitivity [min^{-1}]
U_{ex} = Exercise input [-]

[0033] Exercise sensitivity (K_{ex}) defines the amplitude of the drop in blood glucose levels during exercise for an individual, and the inverse time constant for exercise effect (a_{ex}) defines how quickly the exercise effect appears and disappears in the individual. Simple blood glucose readings during a clinical or home based exercise test can be used to determine these parameters for an individual. Once these parameters are determined, all that is required to model the effect of exercise is the single binary, exercise input (U_{ex}). Again, the exercise input (U_{ex}) has a value of zero (0) when no exercise is being performed and a value of one (1) during exercise. This resulting model is independent of aerobic exercise intensity and does not require the complexity of collecting additional information during exercise, such as heart rate, blood pressure or venous oxygen levels. By not depending on these measures of exercise intensity, no additional measurement devices are required, which in turn results in lower costs and more patient comfort. In this sense the exercise input is the only non-constant and measured parameter for the model to consider the aerobic exercise on blood glucose levels for an individual. The exercise input can be monitored with an exercise monitoring device. For example the exercise monitoring device can be realized in that the patient can simply set the exercise input (U_{ex}) by, for example, pressing a button or other input on a glucose meter or other device. However, the exercise monitoring device can also be realized so that this exercise input (U_{ex}) can also be automatically set through a medical device capable of detecting changes in physical activity, such as through pedometers, heart rate monitors, etc. With the heart rate monitor example, if the heart rate is lower than a given limit, the patient is at rest, and the exercise input (U_{ex}) is set to zero (0). On the other hand when the heart rate is higher, the patient is considered physically active, and the exercise input (U_{ex}) is set to one (1).

[0034] FIG. 6 shows a graph 600 that provides an example of the behavior for this exercise model. In this illustrated example, the exercise intensity for the patient was 65% of their maximum heart rate. As can be seen, the upper section 602 of the graph 600 shows the value of the exercise glucose effectiveness ($S_{g,ex}$) factor over time, and the lower section 604 shows the corresponding exercise input (U_{ex}).

[0035] This exercise model was tested by identifying the model parameter using clinical data. The exercise model showed good fitting capabilities for almost all patients. Graph 700 in FIG. 7 shows an example of how the exercise model fits to actual blood glucose readings. In this example, the exercise intensity for the patient was 65% of their maximum heart rate. The graph 700 has an upper section 702 that shows the glucose concentration measurements along with a fit line generated by the exercise model, and a lower section 704 shows the corresponding exercise input (U_{ex}). As can be seen, after the exercise begins, which is signified by the exercise input (U_{ex}) being equal to one in the lower section 704 of the graph 700, the fit line slopes in a generally linear fashion in the upper section 702, thereby corresponding to the drop in blood glucose concentration due to exercise. It should be appreciated from the graph 700 that the model shows good capabilities in modeling blood glucose concentration reductions due to exercise.

[0036] This model can be used in all products and methods that rely on a dynamical model of the blood glucose concentration. As it completes existing models, its range of use is extended. For example, this exercise model can be used in an automated pancreas (AP). In fact most of the recent closed-loop algorithms for automated pancreases rely on model predictions. Completing these predictions is essential if such an algorithm is to be commercially implemented. The exercise model described herein helps to provide this complete algorithm. In another example, the model can for insulin injection optimization. Optimizing the insulin injection profile for insulin pumps allows the patient to have better glycemic control. This model can also be used in model-based bolus calculators. While giving bolus recommendations, a planned exercise session could be considered, thus reducing the risk of hypoglycemia. It can also be used for educational tools. Showing patients what the effect of exercise on their blood glucose levels is, might be a motivation to exercise more while being aware of the underlying risks and thus the quality of life may be increased. It is further envisioned that this model can be used in conjunction with an exercise indicator to give the patient advice on care that he or she has to take (i.e., eat carbohydrates, adjust his insulin medication) before starting an aerobic exercise. It should be recognized that this model can be used in other situations as well.

[0037] An example of this model being used in an automated pancreas system will now be described initially with reference to FIG. 8. FIG. 8 includes a block diagram of a blood glucose monitoring system 800 that utilizes the above described exercise model. In this system 800, an automated pancreas system 802 monitors and controls blood glucose levels of a diabetic patient 804. The automated pancreas system 802 includes a continuous glucose monitor (CGM) 806, an exercise monitor 808, an insulin pump 810, and a glucose meter 812. The continuous glucose monitor 806 continuously monitors blood glucose readings from the patient 804, and the continuous glucose monitor 806 transmits the blood glucose readings to the meter 812 for analysis. While the illustrated automated pancreas system 802 uses a continuous glucose monitor, it should be recognized that discrete type (e.g., finger stick type) glucose monitors can be used as well as other types of glucose monitors. An exercise monitor 808 is used to determine whether or not the patient 804 is performing aerobic exercise. The exercise monitor 808 can for example include a heart rate monitor that monitors the patient's heart rate to detect aerobic activity once the heart rate exceeds a threshold level. Of course, other devices can be used to detect aerobic activity. For this exercise model, the exercise monitor 808 only needs to transmit a binary signal indicating whether the patient is performing an aerobic activity or not (i.e., 0 or 1 for the exercise input U_{ex}). However, for other purposes, the exercise monitor 808 can transmit additional physiological data to the meter 812. For instance, the exercise monitor 808 can transmit a cardiogram of the patient 804 so that a physician can monitor the overall health of the patient 804. In another example, the exercise monitor 808 transmits the raw exercise data to the meter 812, and the meter 812 determines whether the patient 804 is performing aerobic exercise. In other variations, the exercise monitor 808 can be eliminated such that the diabetic patient 804 (or someone else) manually indicates whether or not exercise is being performed via the meter 812. Based on instructions from the meter 812, the insulin pump 810 delivers the appropriate insulin amount to the patient.

[0038] In the FIG. 8 system 800, the meter 812 processes an algorithm that incorporates the exercise model in conjunction with other glucose control models, such as the previously described ABP model, so as to control the insulin delivery to the patient 804 via the insulin pump 810. The meter 812 includes components commonly found in glucose meters and other types of monitoring devices, like one or more processors, memory, displays, speakers, input devices, and output devices. The processor of the meter 812 using the above discussed model is able to predict future blood glucose levels, and if needed, take corrective actions such as increasing insulin dosages and/or alerting the patient 804 when potential problematic blood glucose levels are predicted to occur (e.g., hypoglycemia). The meter 812 in other examples can be replaced by other computing devices, such as a personal computer, medical device, and/or smart phone, to name just a few. In the illustrated embodiment, the various components of the automated pancreas system are illustrated as separate components, but it should be recognized that one or more of these components can be integrated together to form a single unit.

[0039] FIG. 9 shows a flow diagram 900 of a technique for monitoring blood glucose levels in a patient during exercise utilizing the above discussed exercise model. For explanation purposes the technique in the flow diagram 900 will be described with reference to the monitoring system 800 shown in FIG. 8, but it should be recognized that it can be utilized with other systems. As can be seen, the flow diagram 900 includes several sections, including a prior to exercise input section 902, a prior to exercise analysis section 904, an exercise section 906, a retrospective analysis section 908, and an advice section 910.

[0040] In the prior to exercise input section 902, patient data 912, past or historical data 914, and current blood glucose data 916 are entered into the meter 812. Patient data for example can include vital statistics, carbohydrates consumed, etc. Past data can includes factors for calculating the exercise glucose effectiveness 112 ($S_{g,ex}$). To utilize the exercise model, the exercise sensitivity (K_{ex}) and inverse time constant (a_{eX}) of Equation 7 are determined for the individual patient 804 so that the exercise glucose effectiveness 112 ($S_{g,ex}$) factor (Equation 6) can be modeled. These factors can be determined by performing an aerobic exercise test in which blood glucose values are periodically read, such as via the continuous glucose monitor 806, in the manner as described before for the clinical studies. These factors are then determined by the meter 812 or a computer via linear regression or other techniques. While these initial parameters can be determined in a doctor's office, considering only blood glucose data is required, these initial set-up tests can performed at home or elsewhere. In this case, the meter 812 can include a script that guides the patient 804 through the initial testing process for in initializing the exercise model. For example, the meter 812 can instruct the patient to ingest (or not) a specific carbohydrate amount before exercise, and then run on their treadmill for 30 minutes so that the patient's heart rate is within the aerobic exercise heart rate range. During the exercise, the meter 812 can monitor the glucose levels via the continuous glucose monitor 806 (or other type of glucose monitor) and the patient's vital statistics via the exercise monitor 808 to ensure the test is being properly performed.

[0041] After the set-up test is performed, the meter 812 determines the exercise effectiveness ($S_{g,ex}$) factors in the manner as described above with reference to FIGS. 3 to 7. The resulting exercise model can be incorporated into other models, like the ABP model discussed above, that incorporate other factors such as carbohydrate consumption and insulin dosage. Equation 6 is just one example of this combined model approach, but it is envisioned that the exercise model can be incorporated into other models. Before the aerobic exercise or other physical activity, the meter 812 in stage 918 (prior to exercise analysis section 904) generates a prediction based on the calculated model along with other data collection in section 902, like the blood glucose data 916. If a potential dangerous condition is predicted, like hypoglycemia, the meter 812 provides a warning in stage 920, such as by displaying a message warning the user of the potential dangerous condition via an interface device. In addition, if needed, the meter 812 in stage 922 provides recommendations for taking corrective action, such as recommending a particular meal so as to avoid hypoglycemia. In another example, the infusion profile of the insulin pump 810 is adjusted so as to avoid any problematic glucose levels. The interface device can be a display, a diode or diode array, a loudspeaker or another device capable of transport a message to a person involved.

[0042] In an example not shown in the figures the input section 902 comprises in addition or alternatively to the detect exercise stage 926 an exercise input. To perform this exercise input the system comprises an input device which is connected to the exercise monitor 808, so that the patient can itself program the automated pancreas system 802 i.e. the system for an intended exercise. Hence the automated pancreas system 802 can adjust the insulin delivery based on the predicted blood glucose levels on account on an intended exercise. The input device can be a button, a touch sensitive display or any other device capable to process a input form a person involved.

[0043] In the exercise section 906, the exercise monitor 808 in stage 924 monitors the patient's activity, such as their heart rate and/or acceleration, so that the meter 812 is able to automatically detect initiation of the exercise in stage 926. Again, it should be appreciated that the user can manually signify the start of an exercise by pressing a button on the meter 812 and/or interfacing with the meter 812 in some other way. The continuous glucose monitor 806 provides glucose measurements to the meter in stage 928, and based on those measurements as well as other data, predicts future blood glucose levels in stage 930 using the above described exercise model in a manner similar to the one previously described with reference to stage 918. If the meter 812 predicts a potential problem, such as hypoglycemia, the meter provides a warning in stage 920 along with a recommended corrective course of action in stage 922. For instance, the insulin infusion profile of the insulin pump 810 can be adjusted. After the exercise, the meter 812 can perform retrospective analysis in stage 932 so as to validate the model and re-estimate the parameters.

[0044] As mentioned before, the exercise model can help to optimize insulin injection or infusion profiles. Optimizing the insulin injection profile for insulin pumps as well as in other situations allows patients to have better blood glucose control. FIG. 10 shows an example of an insulin infusion profile 1000 that was optimized based at least in part on the above-discussed exercise model. FIG. 11 shows a simulation 1100 of the blood glucose profile obtained with the optimized insulin profile of FIG. 10 as compared to a constant insulin profile. As shown, the blood glucose concentration drops with both profiles during exercise. However, the optimized insulin profile of FIG. 7 avoids a hypoglycemic event, whereas the constant insulin infusion profile drops below the hypoglycemic limit.

[0045] It should be appreciated that the term "exercise" as used herein is meant to encompass a broad range of physical activities, and it is not limited to exercises performed in a gym or clinical setting. Not only does the exercise include traditional exercises, such as running, swimming, walking, biking, rowing, calisthenics, and the like, but it also can include other forms of physical activities that raise the heart rate, such as climbing, digging, gardening, building, and/or work activities, to name just a few examples.

[0046] Having described the present disclosure in detail and by reference to specific embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the disclosure defined in the appended claims.

Claims

1. A system for considering the effect of aerobic exercise on blood glucose levels for a diabetic, comprising:

   - a computing device for generating a prediction of future blood glucose levels for a diabetic at least based on an exercise model how an aerobic exercise affects blood glucose levels of the diabetic, wherein the exercise model

  - is based on parameters that are independent of intensity of the aerobic exercise, the aerobic exercise having an exercise intensity between 65% and 75% and a duration of no more than 90 minutes, and
  - incorporates an exercise sensitivity value that represents change in the blood glucose level over time during exercise without considering intensity of the exercise;

- an exercise monitoring device which is

  - configured to detect the occurrence of the aerobic exercise, and
  - connected to the computing device to send an input signal to the computing device whether the aerobic exercise is being performed by the diabetic or not; and

- means for taking an action at least based on the prediction from the exercise model, wherein the means for taking the action includes an automated pancreas.

2. The system according to claim 1, comprising an interface device structured such that said taking the action with the means includes alerting the diabetic of a dangerous blood glucose level condition via the interface device.

3. A method of considering the effect of aerobic exercise on blood glucose levels for a diabetic, comprising:

- generating with a computing device a prediction of future blood glucose levels for a diabetic at least based on an exercise model how an aerobic exercise affects blood glucose levels, wherein the exercise model

  - is based on parameters that arc independent of intensity of the acrobic exercise, the aerobic exercise having an exercise intensity between 65% and 75% and a duration of no more than 90 minutes, and
  - incorporates an exercise sensitivity value that represents change in the blood glucose level over time during exercise without considering intensity of the exercise;

- detecting the occurrence of the aerobic exercise by an exercise monitoring device connected to the computing device;
- sending, by the exercise monitoring device, an input signal to the computing device whether the aerobic exercise is being performed by the diabetic or not; and
- taking an action with means including an automated pancreas at least based on the prediction from the exercise model.

4. The method according to claim 3, wherein the exercise model accounts for a change in the blood glucose level based on an amplitude of the change in the blood glucose level during exercise for the diabetic and how quickly the exercise effect appears and disappears in the diabetic along with an exercise input that considers whether or not an exercise is being performed without considering the intensity of the exercise.

5. The method according to any of the claims 3 or 4, wherein the exercise model is based on the following equation:

$$\frac{dS_{g,ex}}{dt} = -a_{ex} S_{g,ex} + K_{ex} a_{ex} U_{ex}$$

where

$S_{g,ex}$ = Exercise glucose effectiveness;
a_{ex} = Inverse of time constant for exercise effect;
K_{ex} = Exercise sensitivity; and
U_{ex} = Exercise input.

6. The method according to any of the claims 4 or 5, wherein the exercise model is based on the following equation:

$$\frac{dQ}{dt} = -XQ - (S_{g,zero} + S_{g,ex})Q + U_{endo} + U_{g,gut} \frac{g \rightarrow mmol}{M}$$

where:

Q = glucose amount in the accessible compartment;
X = insulin action;
$S_{g,zero}$ = Glucose effectiveness at zero insulin;
$S_{g,ex}$ = Exercise glucose effectiveness;
U_{endo} = Insulin independent endogenous production;
$U_{g,gut}$ = carbohydrate intake rate; and
$g \rightarrow mmol$ is a constant conversion factor that transforms grams of carbohydrates to mmol;
M = body weight.

7. The method according to any of the claims 3 to 6. wherein the exercise input is a binary type input that signifies whether or not the aerobic exercise is occurring.

8. The method according to any of the claims 3 to 6, wherein said receiving the exercise input includes receiving a manual input from the diabetic.

9. The method according to any of the claims 3 to 8, wherein said taking the action with the means includes alerting the diabetic of a dangerous blood glucose level condition.

10. The method according to any of the claims 3 to 9, wherein said taking the action with the means includes changing an insulin injection profile for the automated pancreas.

Patentansprüche

1. System zum Berücksichtigen der Wirkung von aerobem Training auf Blutglukosespiegel für einen Diabetiker, umfassend:

- eine Computervorrichtung zum Erzeugen einer Voraussage künftiger Blutglukosespiegel für einen Diabetiker, die zumindest auf einem Trainingsmodell basiert, wie ein aerobes Training sich auf Blutglukosespiegel des Diabetikers auswirkt, wobei das Trainingsmodell
  - auf Parametern beruht, die unabhängig von der Intensität des aeroben Trainings sind, wobei das aerobe Training eine Trainingsintensität zwischen 65 % und 75 % und eine Dauer von nicht länger als 90 Minuten aufweist, und
  - einen Trainingsempfindlichkeitswert integriert, der eine Änderung im Blutglukosespiegel über die Zeitspanne während des Trainings ohne Berücksichtigen der Intensität des Trainings darstellt;
- eine Trainingsüberwachungsvorrichtung, die
  - konfiguriert ist, das Stattfinden des aeroben Trainings zu erfassen, und
  - an die Computervorrichtung angeschlossen ist, um ein Eingabesignal an die Computervorrichtung zu schicken, ob das aerobe Training durch den Diabetiker ausgeführt wird oder nicht; und
- Mittel zum Ergreifen einer Maßnahme zumindest auf der Basis der Voraussage vom Trainingsmodell, wobei das Mittel zum Ergreifen der Maßnahme eine automatisierte Bauchspeicheldrüse umfasst.

2. System nach Anspruch 1, umfassend eine Schnittstelleneinrichtung, die derart strukturiert ist, dass das Ergreifen der Maßnahme mit dem Mittel das Warnen des Diabetikers bezüglich eines gefährlichen Blutglukosespiegelzustands über die Schnittstelleneinrichtung umfasst.

3. Verfahren zum Berücksichtigen der Wirkung von aerobem Training auf die Blutglukosespiegel für einen Diabetiker, umfassend:

- Erzeugen, mit einer Computervorrichtung, einer Voraussage künftiger Blutglukosespiegel für einen Diabetiker, die zumindest auf einem Trainingsmodell basiert, wie ein aerobes Training sich auf Blutglukosespiegel auswirkt, wobei das Trainingsmodell

- auf Parametern beruht, die unabhängig von der Intensität des aeroben Trainings sind, wobei das aerobe eine Trainingsintensität zwischen 65 % und 75 % und eine Dauer von nicht länger als 90 Minuten aufweist, und
- einen Trainingsempfindlichkeitswert integriert, der eine Änderung im Blutglukosespiegel über die Zeitspanne während des Trainings ohne Berücksichtigen der Intensität des Trainings darstellt;

- Erfassen des Stattfindens des aeroben Trainings durch eine Trainingsüberwachungsvorrichtung, die an die Computervorrichtung angeschlossen ist;
- Sende, mittels der Trainingsüberwachungsvorrichtung, eines Eingabesignals an die Computervorrichtung, ob das aerobe Training durch den Diabetiker ausgeführt wird oder nicht; und
- Ergreifen einer Maßnahme durch Mittel einschließlich einer automatisierten Bauchspeicheldrüse zumindest auf der Basis der Voraussage aus dem Trainingsmodell.

4. Verfahren nach Anspruch 3, wobei das Trainingsmodell eine Änderung im Blutglukosespiegel auf der Basis einer Amplitude der Änderung im Blutglukosespiegel während des Trainings für den Diabetiker und wie schnell die Trainingsauswirkung im Diabetiker auftritt und verschwindet, zusammen mit einer Trainingseingabe, die berücksichtigt, ob ein Training ausgeführt wird oder nicht, ohne die Intensität des Trainings zu berücksichtigen, nachweist.

5. Verfahren nach einem der Ansprüche 3 oder 4, wobei das Trainingsmodell auf der folgenden Gleichung beruht:

$$\frac{dS_{g,ex}}{dt} = -a_{ex} S_{g,ex} + K_{ex} a_{ex} U_{ex}$$

wobei

$S_{g.ex}$ = Trainingsglukosewirksamkeit;
a_{ex} = Kehrwert der Zeitkonstante für die Trainingswirkung;
K_{ex} = Trainingsempfindlichkeit; und
U_{ex} = Trainingseingabe.

6. Verfahren nach einem der Ansprüche 4 oder 5, wobei das Trainingsmodell auf der folgenden Gleichung beruht:

$$\frac{dQ}{dt} = -XQ - (S_{g,zero} + S_{g,ex})Q + U_{endo} + U_{g.gut} \frac{g \rightarrow mmol}{M}$$

wobei:

Q = Glukosemenge im zugänglichen Kompartiment;
X = Insulinwirkung
$S_{g.null}$ = Glukosewirksamkeit bei null Insulin;
$S_{g.ex}$ = Trainingsglukosewirksamkeit;
U_{endo} = insulinunabhängige endogene Erzeugung;
$U_{g.gm}$ = Kohlehydrataufnahmerate; und
g → mMol ist ein Konstantenumwandlungsfaktor, der Gramm Kohlenhydrate in mMol umwandelt;
M = Körpergewicht.

7. Verfahren nach einem der Ansprüche 3 bis 6, wobei die Trainingseingabe eine Eingabe vom binären Typ ist, die angibt, ob das aerobe Training stattfindet oder nicht.

8. Verfahren nach einem der Ansprüche 3 bis 6, wobei das Empfangen der Trainingseingabe das Empfangen einer manuellen Eingabe von dem Diabetiker umfasst.

9. Verfahren nach einem der Ansprüche 3 bis 8, wobei das Ergreifen der Maßnahme mit dem Mittel das Warnen des Diabetikers bezüglich eines gefährlichen Blutglukosespiegelzustands umfasst.

10. Verfahren nach einem der Ansprüche 3 bis 9, wobei das Ergreifen der Maßnahme mit dem Mittel das Ändern eines Insulininjektionsprofils für die automatisierte Bauchspeicheldrüse umfasst.

Revendications

1. Système pour prendre en considération l'effet de l'exercice aérobique sur les niveaux de glycémie pour un diabétique, comprenant :

- un dispositif informatique pour générer une prédiction de futurs niveaux de glycémie pour un diabétique au moins sur la base d'un modèle d'exercice et de la manière dont un exercice aérobique affecte les niveaux de glycémie du diabétique, dans lequel le modèle d'exercice
  - est basé sur des paramètres qui sont indépendants de l'intensité de l'exercice aérobique, l'exercice aérobique ayant une intensité d'exercice comprise entre 65 % et 75 % et une durée pas supérieure à 90 minutes, et
  - incorpore une valeur de sensibilité d'exercice qui représente une modification des niveaux de glycémie dans le temps durant l'exercice sans prendre en considération l'intensité de l'exercice ;
- un dispositif de surveillance d'exercice qui est
  - configuré pour détecter la survenue de l'exercice aérobique, et
  - relié au dispositif de calcul pour envoyer au dispositif un signal d'entrée indiquant si l'exercice d'aérobique est réalisé ou non par le patient diabétique ; et
- un moyen d'intervention au moins basé sur la prédiction à partir du modèle d'exercice, dans lequel le moyen d'intervention inclut un pancréas automatique.

2. Système selon la revendication 1, comprenant un dispositif d'interface structuré de telle sorte que ladite intervention avec le moyen inclut l'avertissement du diabétique d'une condition de niveau de glycémie dangereuse via le dispositif d'interface.

3. Procédé de prise en considération de l'effet de l'exercice aérobique sur les niveaux de glycémie pour un diabétique, comprenant :

- la génération avec un dispositif informatique d'une prédiction de niveaux de glycémie futurs pour un diabétique au moins sur la base d'un modèle d'exercice et de la manière dont l'exercice aérobique affecte les niveaux de glycémie, dans lequel le modèle d'exercice
  - est basé sur des paramètres qui sont indépendants de l'intensité de l'exercice aérobique, l'exercice aérobique ayant une intensité d'exercice comprise entre 65 % et 75 % et une durée pas supérieure à 90 minutes, et
  - incorpore une valeur de sensibilité d'exercice qui représente une modification des niveaux de glycémie dans le temps durant l'exercice sans prendre en considération l'intensité de l'exercice ;
- la détection de la survenue de l'exercice aérobique par un dispositif de surveillance d'exercice relié au dispositif informatique ;
- l'envoi, au dispositif informatique par le dispositif de surveillance d'exercice, d'un signal d'entrée indiquant si l'exercice aérobique est réalisé ou non par le diabétique ; et
- l'intervention avec un moyen incluant un pancréas automatique au moins sur la base de la prédiction à partir du modèle d'exercice.

4. Procédé selon la revendication 3, dans lequel le modèle d'exercice représente une modification du niveau de glycémie sur la base d'une amplitude de la modification du niveau de glycémie durant l'exercice pour le diabétique et de la rapidité d'apparition et de disparition de l'effet de l'exercice chez le diabétique conjointement à une entrée d'exercice qui prend en considération la réalisation ou non d'un exercice sans prendre en considération l'intensité de l'exercice.

5. Procédé selon l'une quelconque des revendications 3 ou 4, dans lequel le modèle d'exercice se base sur l'équation suivante :

$$\frac{dS_{g,ex}}{dt} = -a_{ex}S_{g,ex} + K_{ex}a_{ex}U_{ex}$$

dans laquelle

$S_{g.ex}$ = efficacité du glucose pendant l'exercice ;
a_{ex} = inverse de la constante de temps pour l'effet de l'exercice ;
K_{ex} = sensibilité de l'exercice ; et
U_{ex} = entrée d'exercice.

6. Procédé selon l'une quelconque des revendications 4 ou 5, dans lequel le modèle d'exercice se base sur l'équation suivante :

$$\frac{dQ}{dt} = -XQ - (S_{g,zero} + S_{g,ex})Q + U_{endo} + U_{g,gut}\frac{g \rightarrow mmol}{M}$$

dans laquelle :

Q = quantité de glucose dans le compartiment accessible ;
X = action de l'insuline ;
$S_{g.zero}$ = efficacité du glucose à zéro insuline ;
$S_{g.ex}$= efficacité du glucose pendant l'exercice ;
U_{endo} = production endogène indépendante d'insuline ;
$U_{g.gut}$ = vitesse d'absorption des glucides ; et
g → mmol est un facteur de conversion constant qui transforme les grammes de glucides en mmol ;
M = poids corporel.

7. Procédé selon l'une quelconque des revendications 3 à 6, dans lequel l'entrée d'exercice est une entrée de type binaire qui indique si l'exercice aérobique a lieu ou non.

8. Procédé selon l'une quelconque des revendications 3 à 6, dans lequel ladite réception de l'entrée d'exercice inclut la réception d'une entrée manuelle du diabétique.

9. Procédé selon l'une quelconque des revendications 3 à 8, dans lequel ladite intervention avec le moyen inclut l'avertissement du diabétique d'une condition de niveau de glycémie dangereuse.

10. Procédé selon l'une quelconque des revendications 3 à 9, dans lequel ladite intervention avec le moyen inclut la modification d'un profil d'injection d'insuline pour le pancréas automatique.

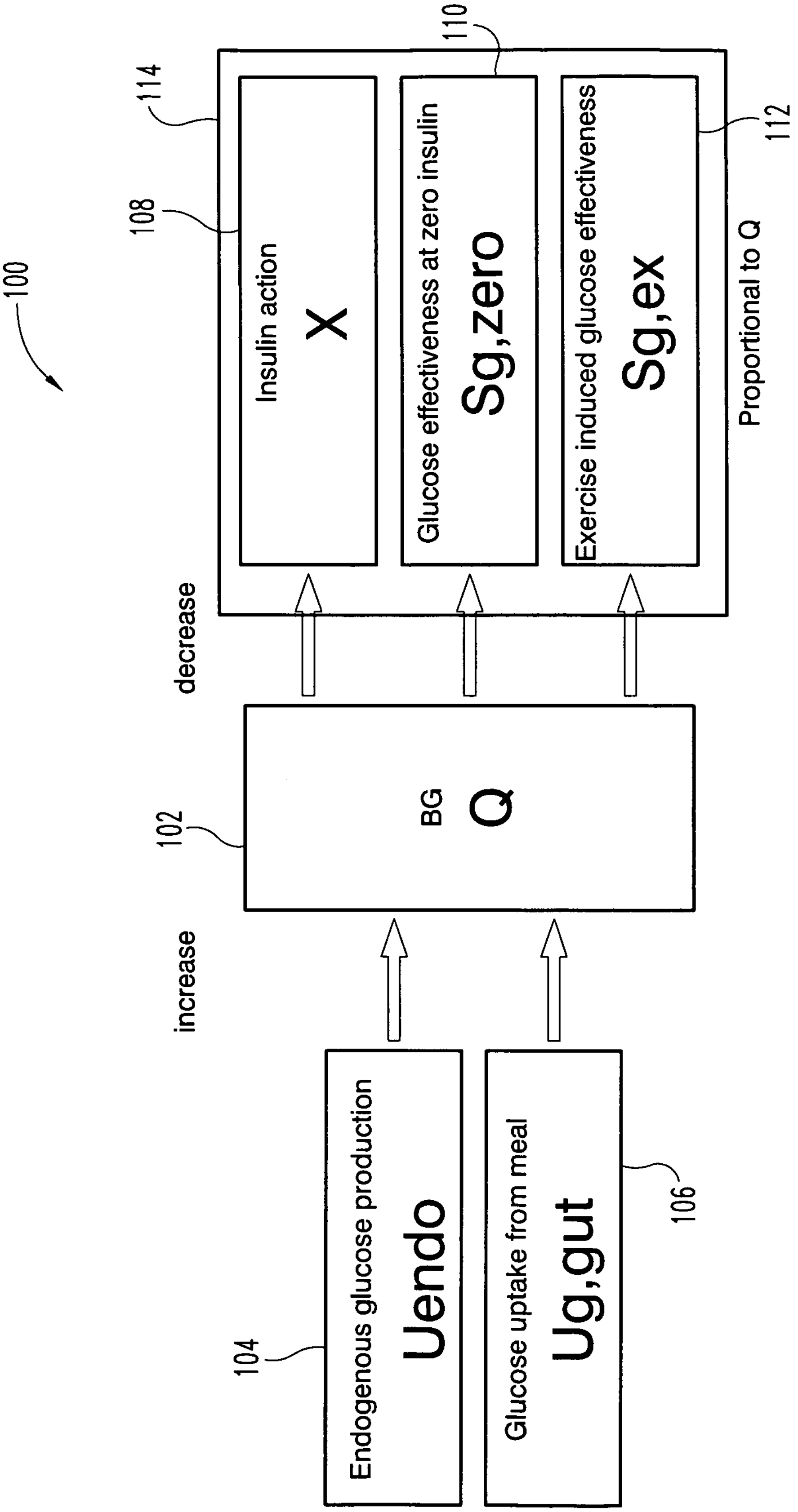
100
104
Endogenous glucose production
Uendo
106
Glucose uptake from meal
Ug,gut
increase
102
BG
Q
decrease
114
108
Insulin action
X
110
Glucose effectiveness at zero insulin
Sg,zero
112
Exercise induced glucose effectiveness
Sg,ex
Proportional to Q

Fig. 1

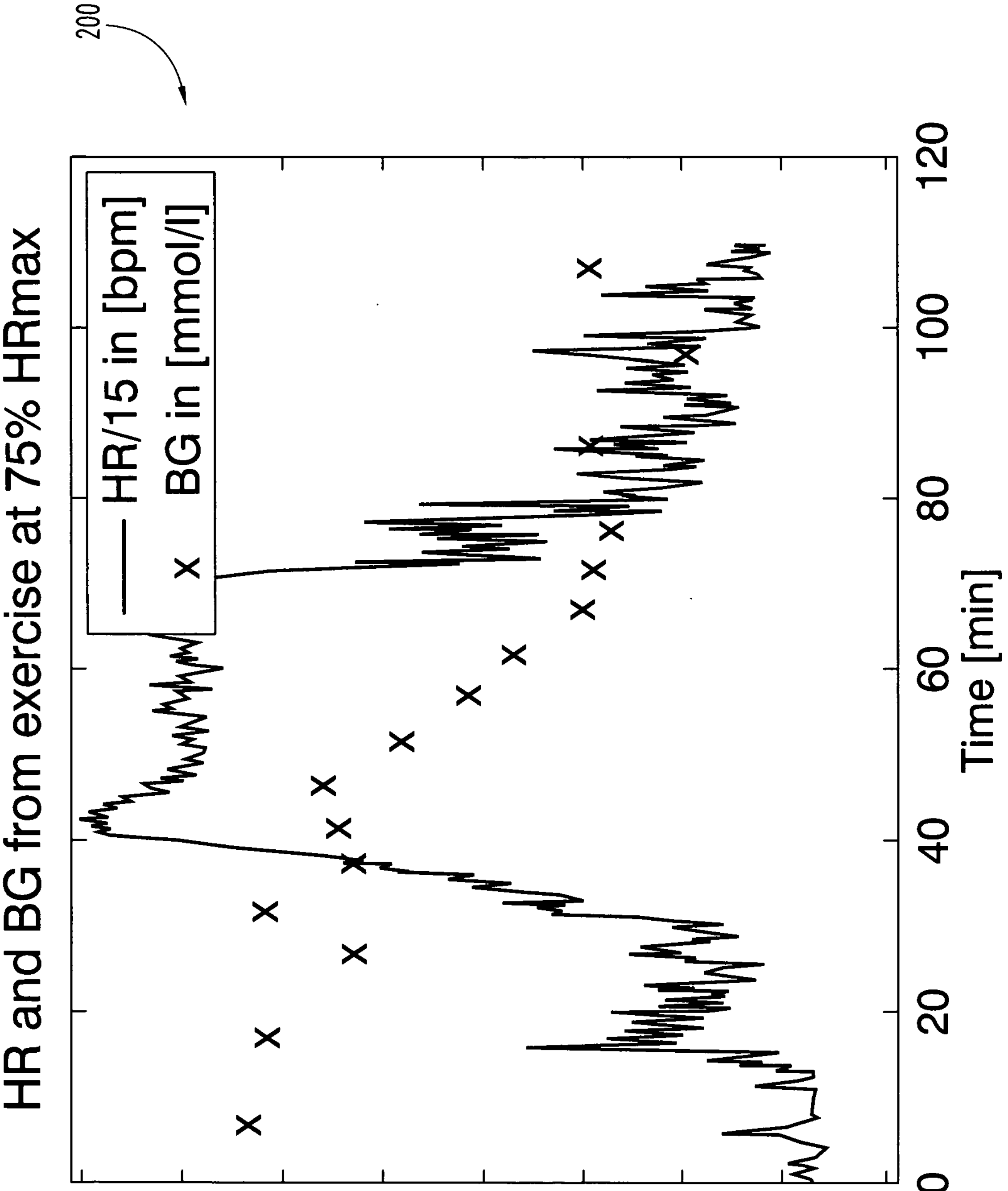
200
HR and BG from exercise at 75% HRmax
HR/15 in [bpm]
BG in [mmol/l]
10
9
8
7
6
5
4
3
2
0
20
40
60
80
100
120
Time [min]

Fig. 2

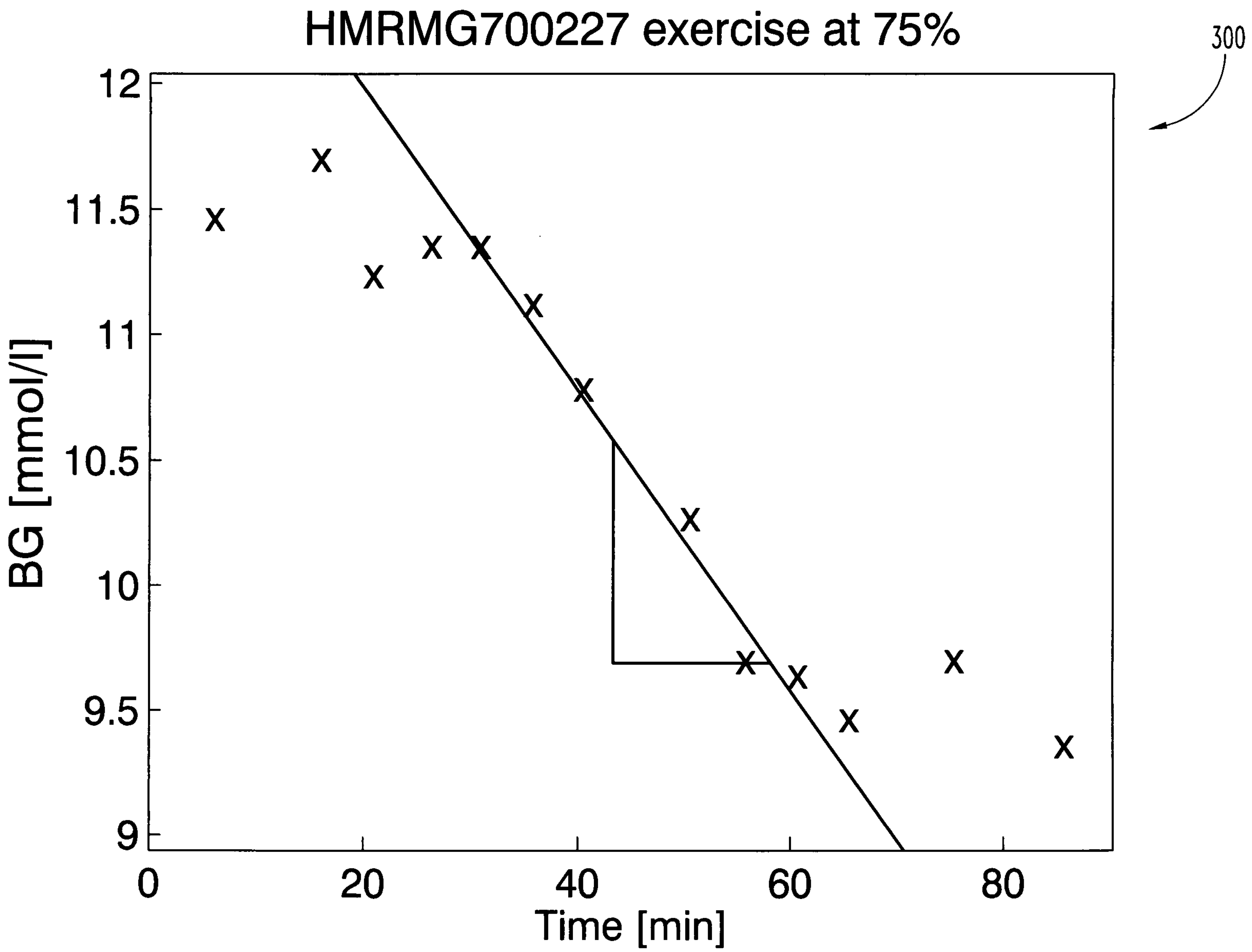
HMRMG700227 exercise at 75%
300
BG [mmol/l]
12
11.5
11
10.5
10
9.5
9
0
20
40
60
80
Time [min]

Fig. 3

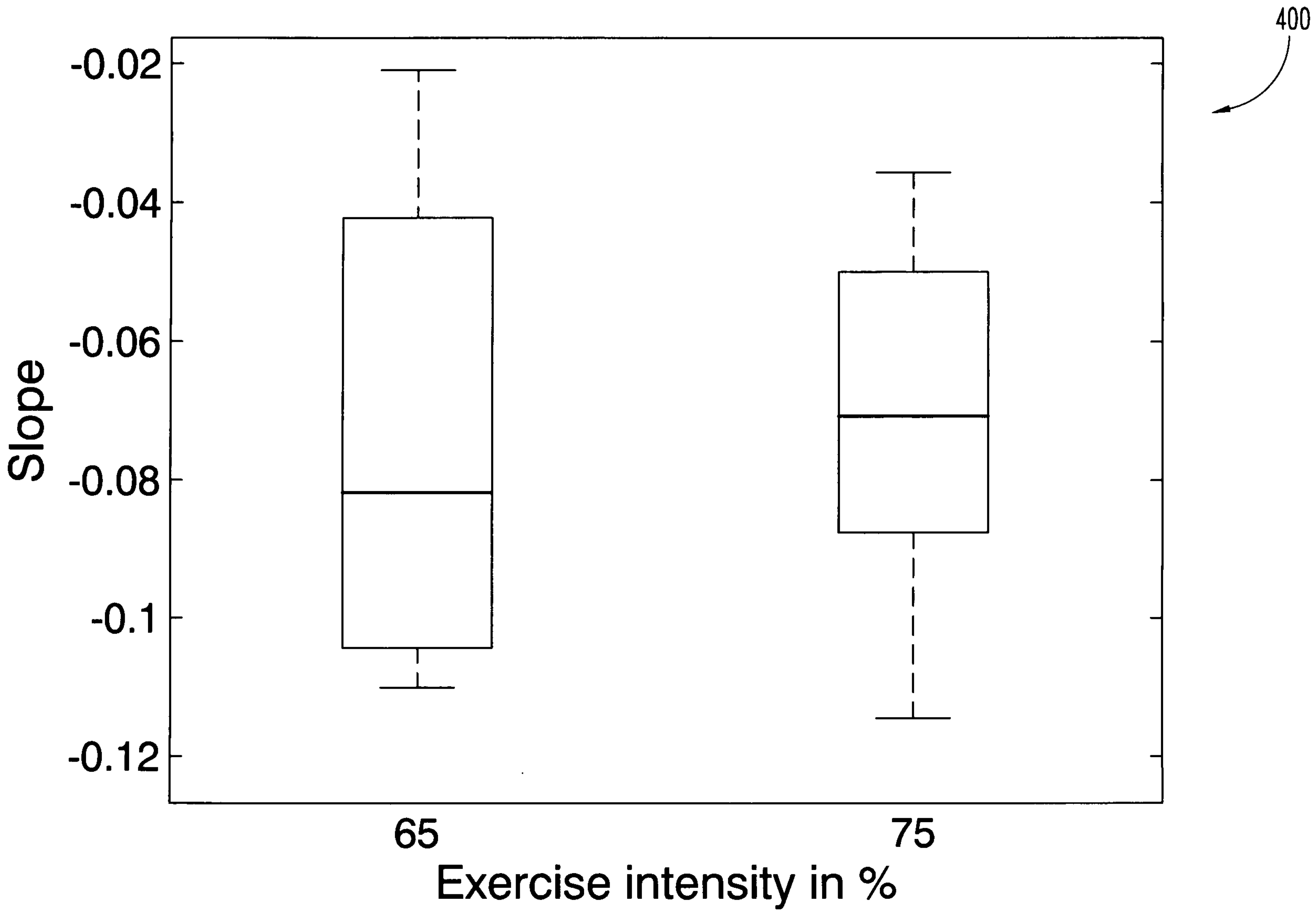

Fig. 4

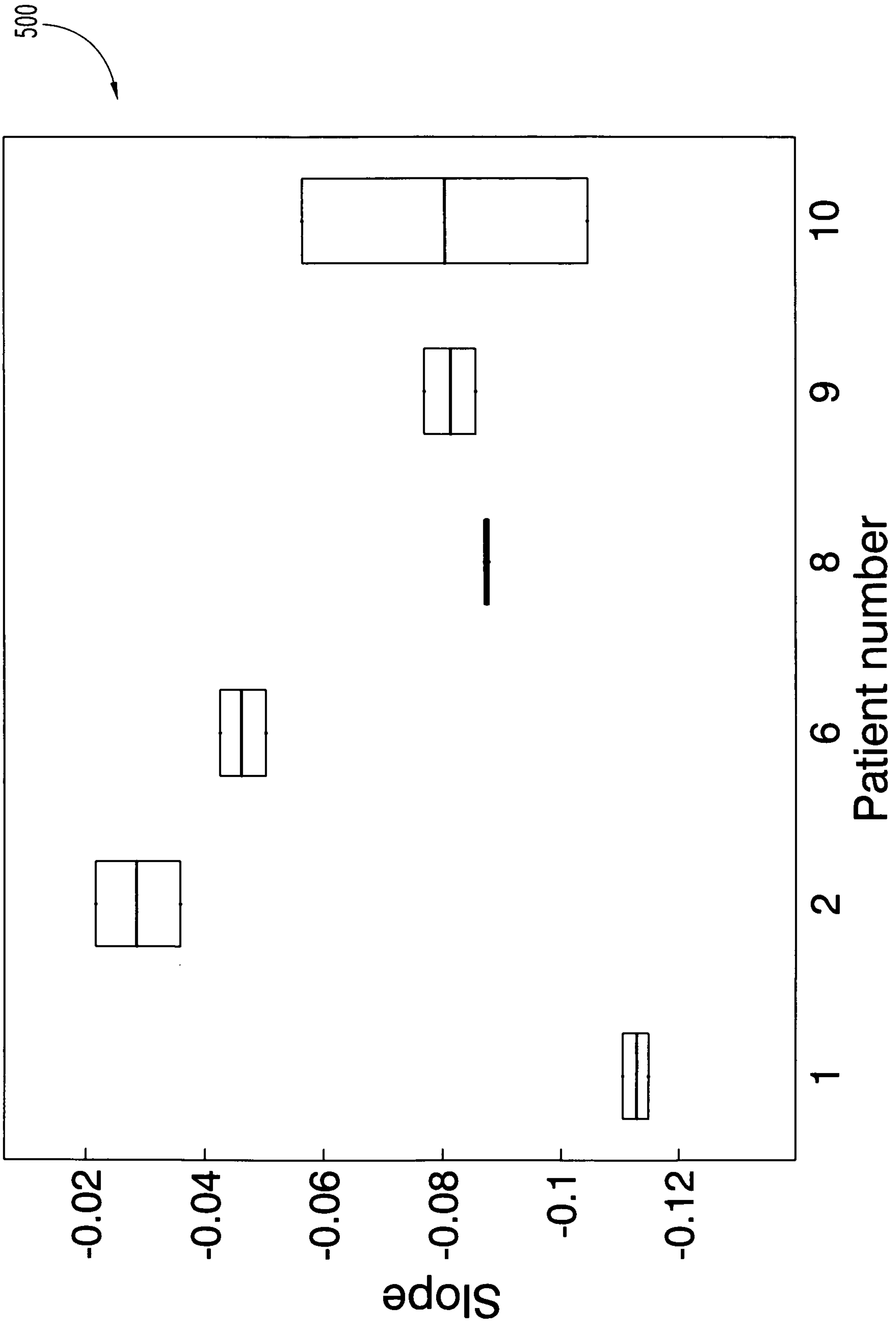

Fig. 5

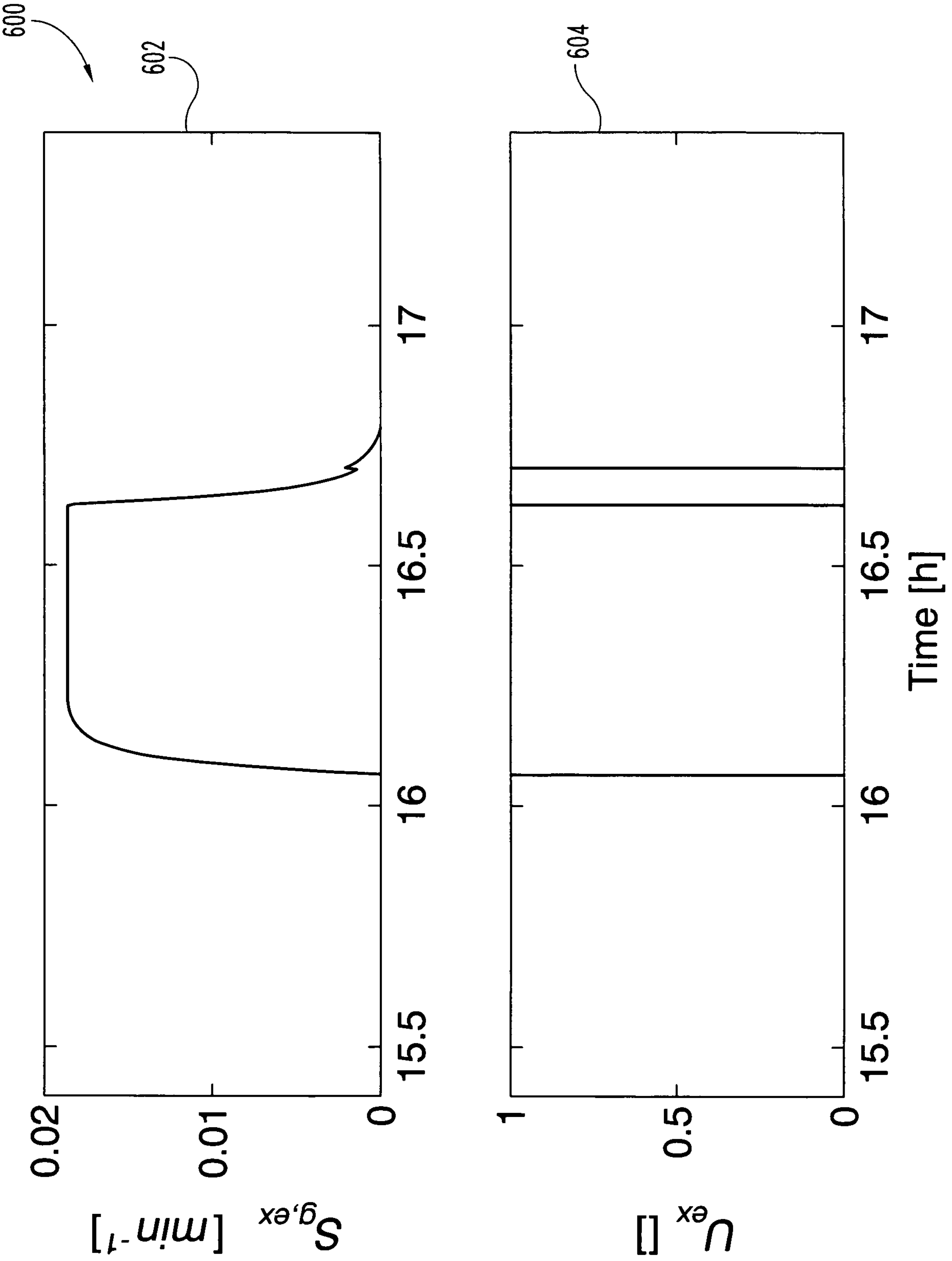

Fig. 6

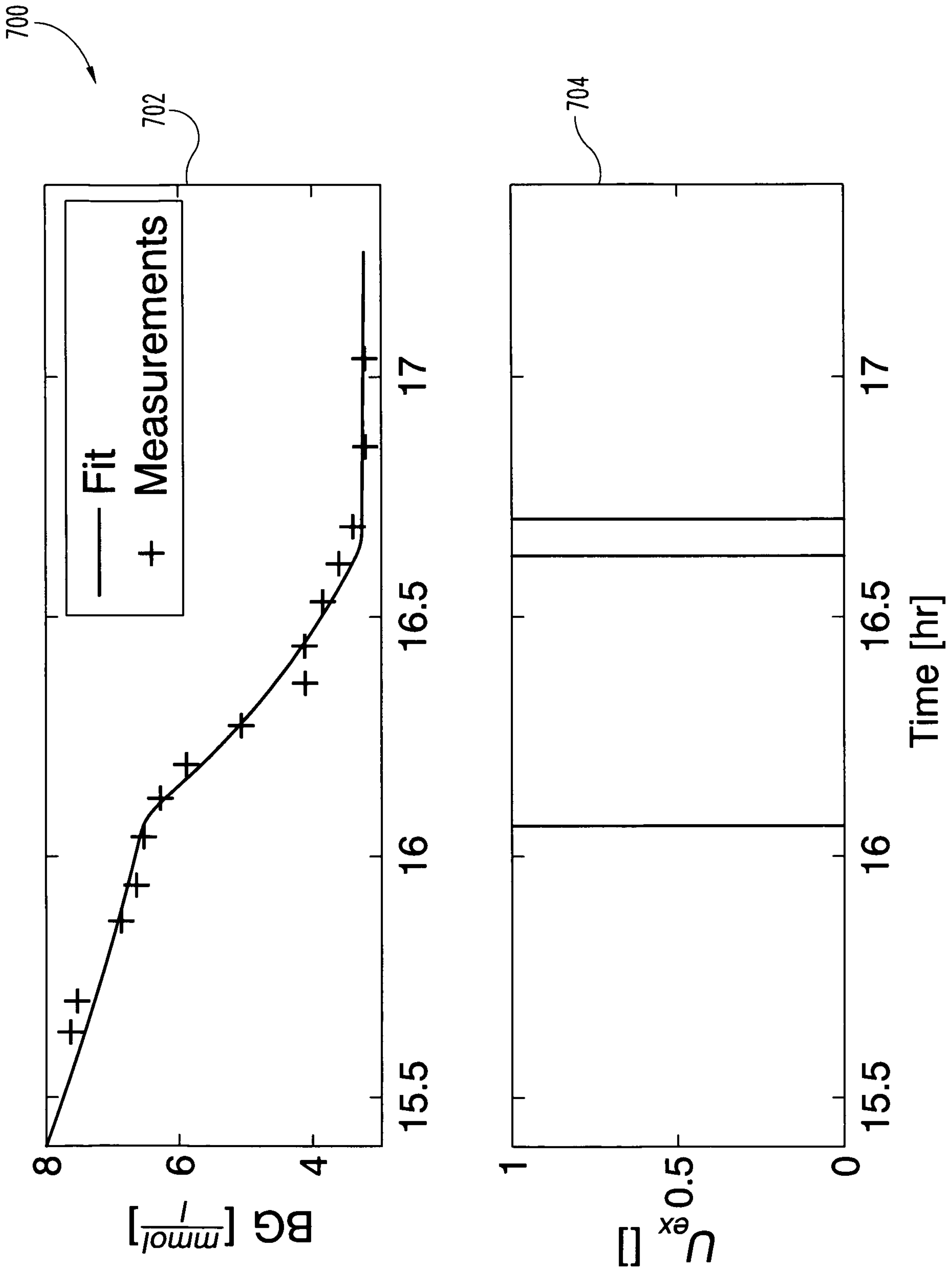
700
702
704
Fit
Measurements
BG [mmol/l]
8
6
4
15.5
16
16.5
17
U_{ex} []
1
0.5
0
15.5
16
16.5
17
Time [hr]

Fig. 7

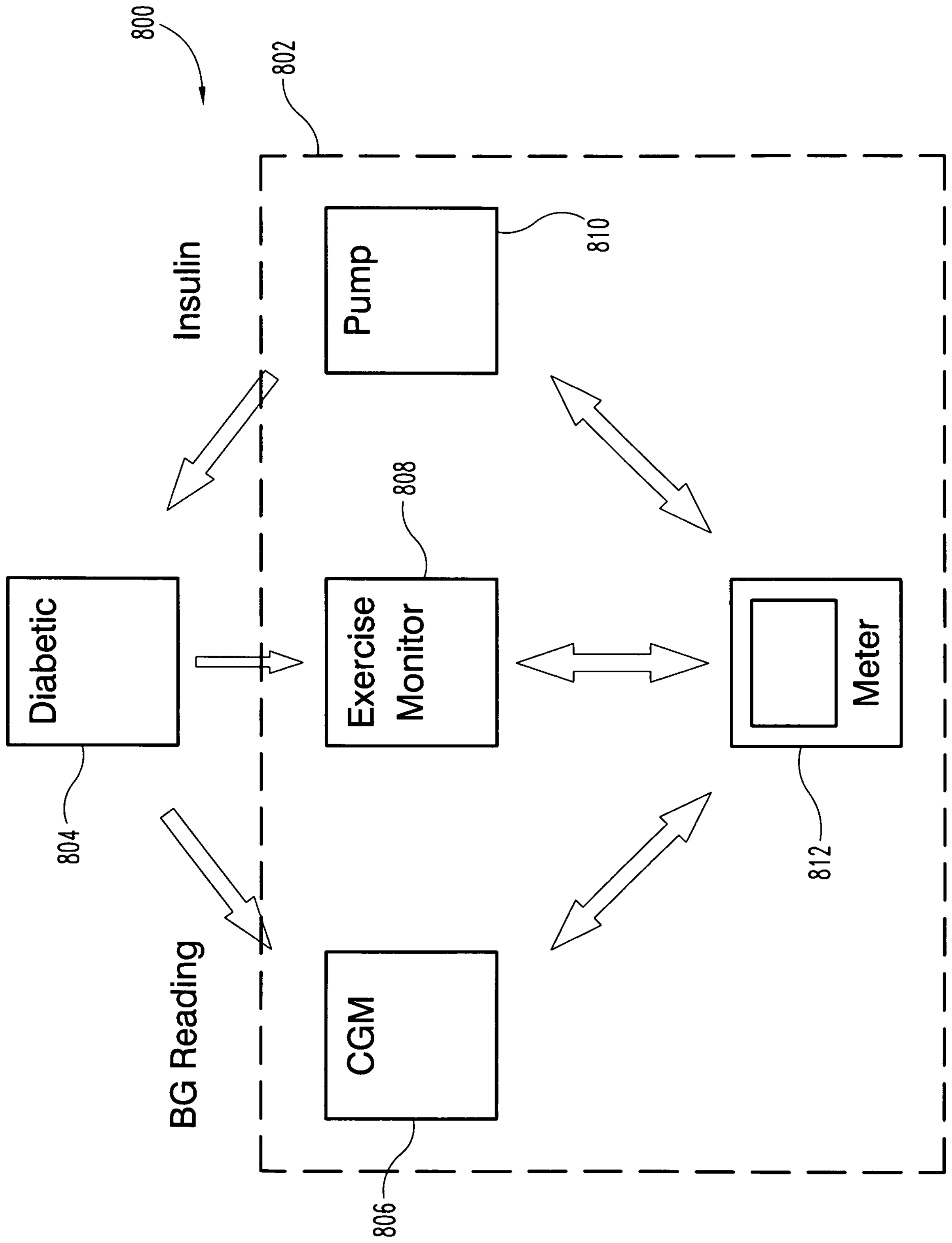
800
802
Insulin
Pump
810
Diabetic
804
Exercise Monitor
808
Meter
812
BG Reading
CGM
806

Fig. 8

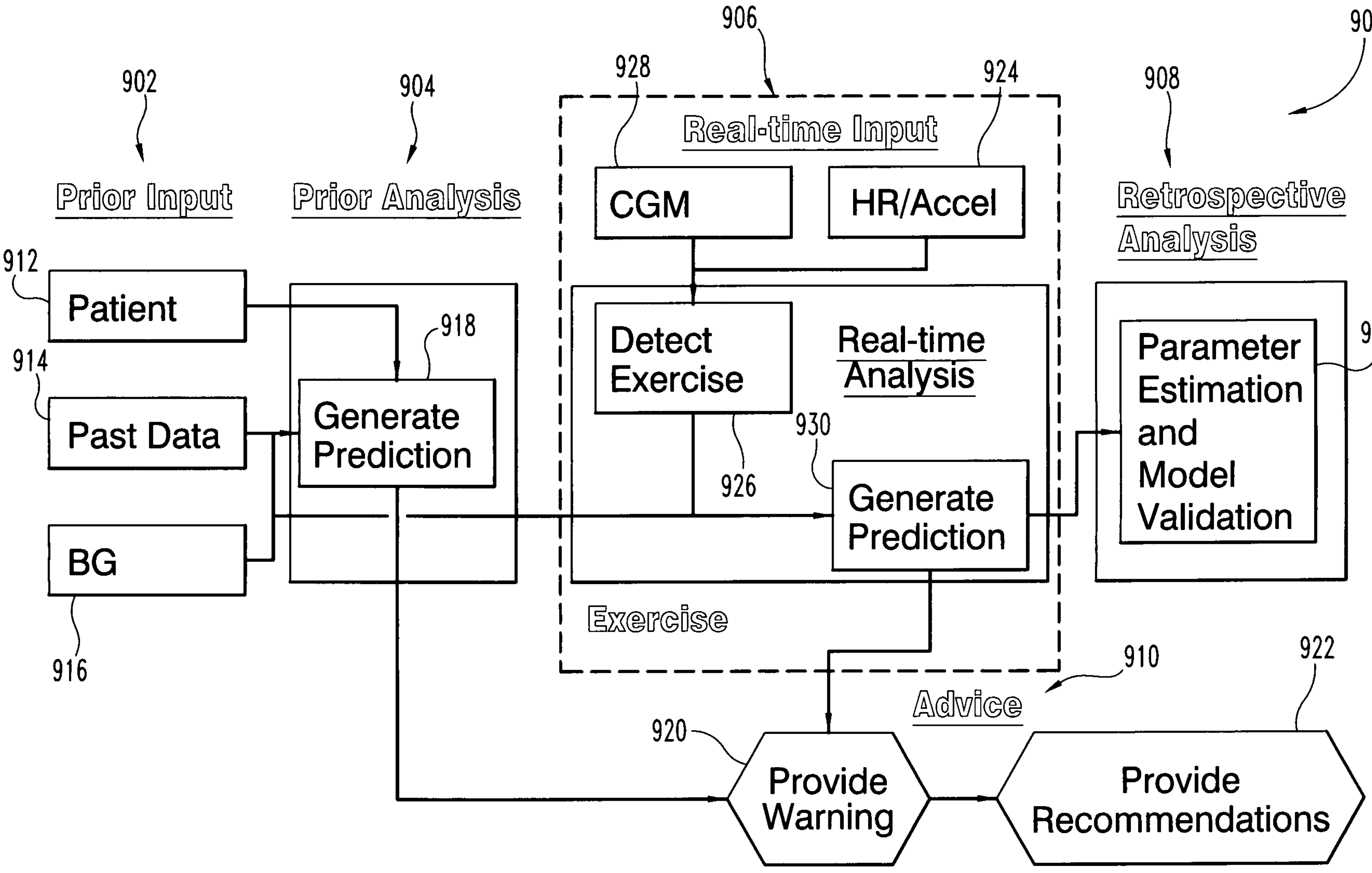
900
902
904
906
908
928
924
Real-time Input
Prior Input
Prior Analysis
CGM
HR/Accel
Retrospective Analysis
912
Patient
918
Detect Exercise
Real-time Analysis
932
Parameter Estimation and Model Validation
914
Past Data
Generate Prediction
930
926
Generate Prediction
BG
916
Exercise
910
922
Advice
920
Provide Warning
Provide Recommendations

Fig. 9

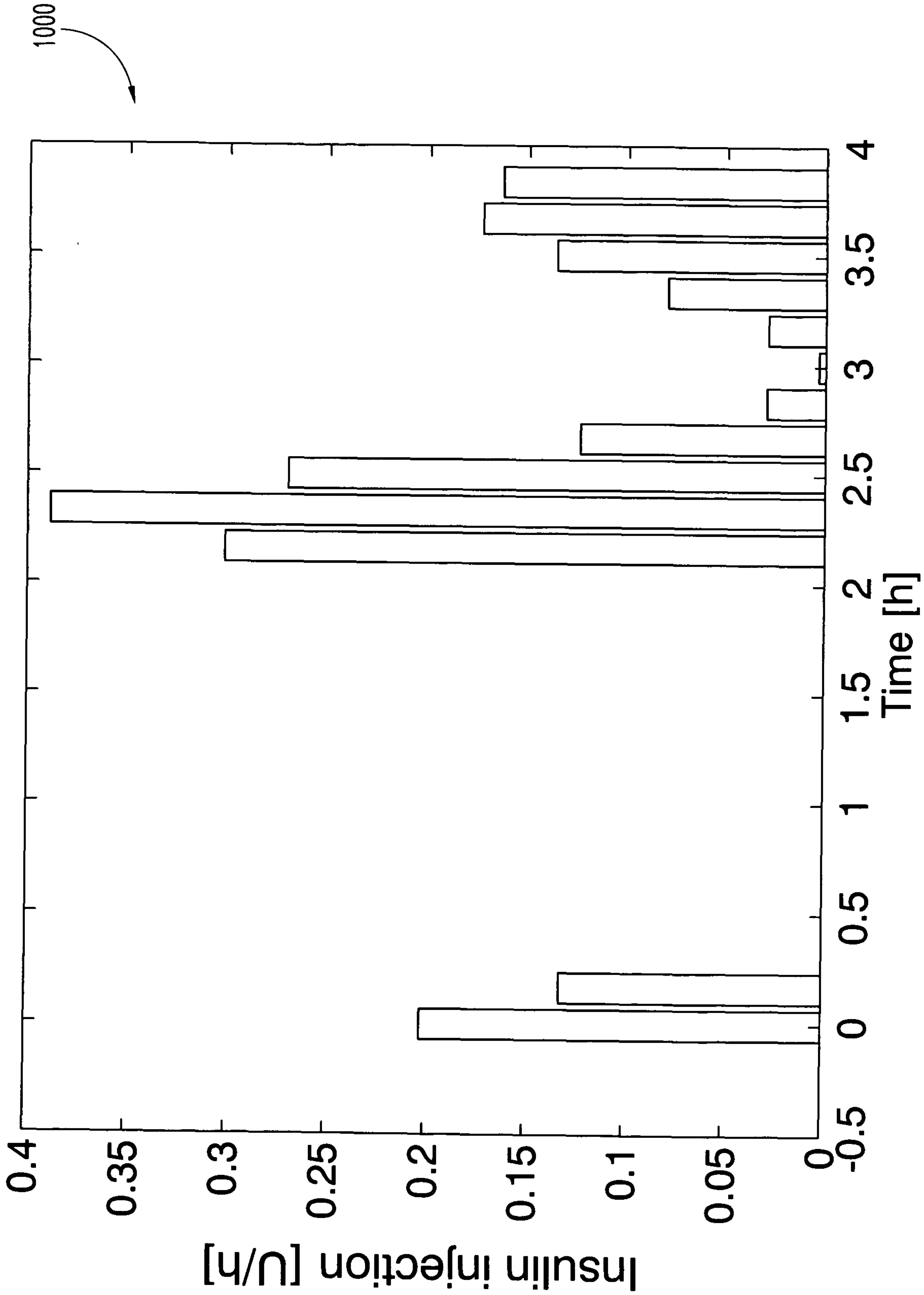
1000
Insulin injection [U/h]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
Time [h]

Fig. 10

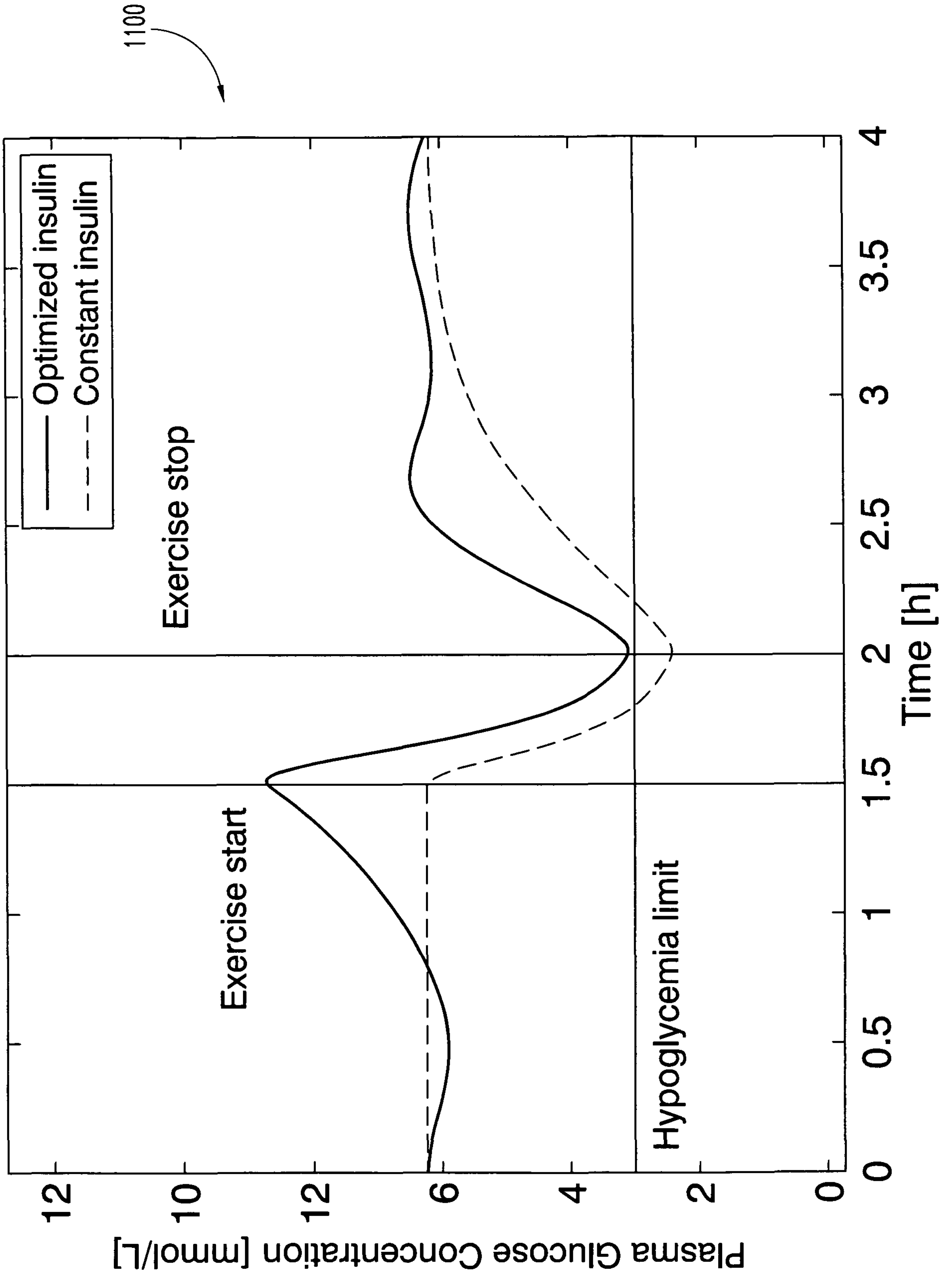
1100
Optimized insulin
Constant insulin
Exercise start
Exercise stop
Hypoglycemia limit
Plasma Glucose Concentration [mmol/L]
12
10
12
6
4
2
0
Time [h]
0
0.5
1
1.5
2
2.5
3
3.5
4

Fig. 11

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 2009006129 A1 **[0005]**
- EP 1873667 A2 **[0006]**

Non-patent literature cited in the description

- **A. ROY ; R.S. PARKER.** Dynamic Modelling of Exercise Effects on Plasma Glucose and Insulin Levels. *Journal of Diabetes Science and Technology,* 2007, vol. 1 (3), 338-347 **[0007]**
- **E. A. GULVE.** Exercise and Glycemic Control in Diabetes: Benefits, Challenges, and Adjustments to Pharmacotherapy. *Physical Therapy,* 2008, vol. 88 (11), 1297-1321 **[0008]**

专利名称(译)	考虑身体活动对葡萄糖调节系统的影响的系统和方法		
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[标]申请(专利权)人(译)	罗氏诊断公司		
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摘要(译)

描述了一种用于考虑有氧运动对个体的血糖水平的影响的系统和方法。在本公开的系统的至少一个实施例中，该系统包括计算设备，该计算设备用于至少部分地基于运动模型来生成个体的未来血糖水平的预测，其中运动模型基于以下参数： 独立于有氧运动的强度，以及至少基于运动模型的预测进行动作的手段。