Virtual therapy using Type 1 Diabetes Direct Simulator

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Abstract. This paper introduces the Type 1 Diabetes Simulator (T1DDS) and presents its potential in virtualization of type 1 diabetes mellitus therapy. The body of a person with type 1 diabetes does not produce insulin and this hormone must be supplied from the outside constantly to avoid death. Moreover, the insulin doses must be correct in order to minimize short- and long-term health complications. The dose determination is challenging due to the high dynamics of the insulin – glucose metabolic system. For the reason computer therapy aided systems have been developed for last decades to help solve the problem. Type 1 Diabetes Direct Simulator (T1DDS) is the author’s original computer program that imitates physiology of a type 1 diabetic. The aim of the simulator is to enable virtual medical interaction with such a patient within the scope of blood glucose level change after a meal intake and insulin administration. The paper illustrates the ideas behind the direct simulator. Describes and argues its model assumptions and explains its implementation. An exemplary application in medical education is presented and discussed as well.

1. Introduction
The aim of this paper is to present the author’s advances in his research work on creating a computer system for type 1 diabetes therapy assistance. It focuses on one part of the system a software simulator called T1DDS which is short for Type 1 Diabetes Direct Simulator. The epithet “direct” has been explained further in the text. The simulator itself can be considered as a diabetic virtual patient and this dimension is emphasized here. The ideas, assumptions, simplifications, usage and advocacy of the simulator have been included in this paper. The paper starts with a description of the diabetes and its analysis form an engineering point of view.

Please note the disclaimer below.

Any information contained in the paper are not intended to provide personal medical advice. If you need medical advice about diabetic problems you must contact a diabetes specialist.

1.1. Pathogenesis of type 1 diabetes
Type 1 Diabetes (T1D), which is a disease different form type 2 diabetes (T2D), develops as a result of autoimmune destruction of pancreatic beta cells that are responsible for physiological insulin production. The insulin hormone is used for glucose absorption and the human body does not have any substitution for it. After exceeding the 80% destruction level of beta cells the person starts suffer from severe insulin deficiency which manifests in the state of permanent hyperglycemia (high blood glucose level) [1-4]. This is due to the fact that any level of insulin secretion impairment itself does
not change the glucose output from the gastrointestinal tract into blood stream after each meal but the
deficit of the hormone disenables glucose intake by most of body tissues. The level of 80% usually
ends the latent phase and starts life–threatening condition. The process of autoimmune destruction of
beta cells does not stop and beta cells never regenerate. Lack of treatment leads to death and the
treatment process lasts until end of life. However, properly conducted therapy means that the diabetes
patient’s life does not differ significantly from the life of a healthy person. There is even a term in
modern medicine such as “healthy person with diabetes”.

Type 1 Diabetes usually strikes children and young adults, i.e. before 30 years of age, but this form
of diabetes can occur even in the 8th and 9th decades of life [2]. It is estimated that the number of
patients with type 1 diabetes accounts for around 10% of all diabetes [1,4], which is about 50 millions
people around the world nowadays. All these facts justify every effort made to improve type 1
diabetes treatment methods.

1.2. Specificity of the day-to-day type 1 diabetes therapy
The core part of type 1 diabetes therapy is supplying a patient body with medical insulin from the
outside in the way of subcutaneous injections. The medical insulin substitutes the patient’s own
insulin. The therapy is difficult and oppressive due to the fact that the insulin demand is not constant.

The demand depends mainly on consumed meals. Each meal requires calculating and injecting
a correct dose of insulin called an insulin bolus or just a bolus. The dose should be calculated based on:
1) the amount of carbohydrate, fat and protein in the meal, 2) meal digestion time described by its
glycemic index, 3) insulin bioactivity curve that depends on insulin type. Moreover sometime it is
recommended to divide the calculated dose of insulin into portions that are injected repeatedly during
a longer period of time. Correctly designed bolus guarantees that blood glucose is kept in a safe range
after having the meal.

Next to the meal boluses there is independent demand for insulin that must be covered. The
demand arises from the normal liver action, which secretes glucose into blood stream in a circadian
routine. The glucose also needs insulin to be absorbed otherwise stays in blood resulting in
hyperglycemia. The liver action, which depends on daytime, must be estimated for each patient
individually. After the estimation proper insulin doses may be prescribed. Base insulin is delivered as
extra injections of long-lasting insulin type or by a proper programmed insulin pump.

Another important issue of the therapy are two sensitivities for carbohydrate and insulin separately.
Carbohydrate sensitivity tells how much the blood glucose increases after consuming a unit of
carbohydrates (usually 10g) on the contrary insulin sensitivity informs how much the blood glucose
decreases after taking a unit of insulin (usually 0,01 ml of modern manufactured insulin). Both
sensitivities are personally estimated and then used for calculations of boluses and base insulin doses.

1.3. Type 1 diabetes therapy with an insulin pump
This paper focuses on the therapy with the use of an insulin pump. A modern insulin pump is an
electronic medical device of the size of a soap bar or smaller. Such a pump is continuously connected
to a patient. The pump is designed for administration of insulin according to its settings (program).
Insulin enters patient’s body by infusion set, which cannula (small tube) stays in the subcutaneous
tissue. In this way continuous infusion of insulin can be achieved. Moreover, the patient is equipped
also with a glucose meter (GM) and optionally a continuous blood glucose monitoring system (CGM)
in order to control their blood glucose concentration. The medical equipment is a personal life support
system. The ability to use this system directly affects the health and comfort of life of the patient. The
patient (or their caretaker) is responsible for: 1) checking the blood glucose concentration at least a
few times a day, 2) keeping a diary of the measurements, 3) composing dietary plan, 4) matching
boluses with meals, 5) estimating liver action, 6) estimating insulin sensitivity, 7) estimating
carbohydrate sensitivity. All the data is required for programming the insulin pump. This
programming is carried out by the doctor or the patient himself. This not a simple task and the work
undertaken by the author is to facilitate this process.
2. Engineering analysis of the therapy of type 1 diabetes

From an engineering point of view the therapy is a problem of controlling. If a person with type 1 diabetes is treated as a control object (figure 1), then according to medical practice its internal state is described by blood glucose concentration (BG) and glycated hemoglobin level (GHB). However, it should be noted that the level of GHB results from the long-term course of BG and for this reason it is not treated as independent state in this paper.

In the recognized object, the control input signals are: food consumed (F), administered insulin (I), and glucagon (G). Glucagon is a hormone that can be injected in the same way as insulin. It stimulates the liver to release extra portion of glucose into blood stream as a response. In a standard therapy is used only as emergency medicine. Returning to the analysis the object is disturbed by: PE – physical effort, ME – mental effort, S – secondary sickness (e.g. cold), MS – mood state. All the factors can affect the object by changing temporarily its liver action, insulin and glucose (carbohydrate) sensitivities. The object produces output that can be measured: 1) glucose concentration in the interstitial fluid logged by a personal continuous glucose monitoring system (CGM), 2) the level of glycated haemoglobin given by a laboratory haemoglobin test (HBT), 3) glucose concentration in venous blood determined in also in a laboratory, 4) capillary blood glucose obtained by personal blood glucose meter (GM) at home, 5) urine glucose and 6) ketone bodies in urine presence detected at home with strip tests. The enumerated set of output signals is redundant. In addition to the measurable output signals listed, there are also immeasurable or hardly measurable signals marked together with the symbol X. This group includes behaviour (X1), mood (X2) and appearance (X3).
Figure 2. On the left: everyday therapy with the use of an insulin pump, CGM and glucometer and the subset of signals taken into account. On the right: its engineering interpretation. Legend: 1 – the patient as a controller, 2 – the same patient as an object under control, 3 – meal plan, MP – signal that modulates signal F.

Table 1. Descriptions of the signals on figure 2.

| Signal | Description | Interpretation |
|--------|-------------|----------------|
| F      | Diet plan of several meals a day. Each meal is described by the content of carbohydrates, fat and proteins, glycemic index and the time of consumption. | Each meal is a single rectangular pulse. The meal plan is a series of the pulses. The value of the pulse is calculated on the basis of the amount of carbohydrates, fats and proteins. The glycemic index describes signal inertia. |
| I      | Pre-programmed insulin doses. A single dose of insulin is described by the volume, type of insulin and time of administration. | Discrete signal |
| CGM    | A series of measurements of glucose concentration in the interstitial fluid. Measurements are made continuously at 5-minute intervals. | Discrete signal |
| MP     | Diet decision | Modulation of signal F |

In everyday therapy routine only a subset of the enumerated signals is used. Depending on this subset, one can distinguish types of T1D therapy or types of controlling. Figure 2 shows schematically a therapy with use of an insulin pump, CGM and a glucometer. The presented work focuses on this type of therapy. In this case the glucometer is only used to calibrate the CGM twice a day and for this reason the GM signal is not included in the control system. The controlled quantity is the CGM signal, which is required to stay in the range from 70 to 130 mg/dl. However short postprandial increases up to 160 mg/dl after having meals are accepted. Signal F i.e. meals is treated as planned disturbance. Planning consists in determining the number, occurrence times and size of meals consumed. The signal F always results in increase of the signal CGM. The control signal I is insulin administered in programmed doses. The signal I always results in decrease of the signal CGM. Both signals F and I
are characterized by inertia, that means that effects of the signals is present up to a few hours after their occurrence. The controlling process consists in choosing the signal I and/or modulating the signal F by signal MP in such a way that the assumed aim is achieved. The controller in the system presented in the picture is a human (often the same patient) who prepares a meal plan and sets the insulin pump. The person always uses some intuitive biocybernetic model of a patient with type 1 diabetes.

Presented control system can be described as: 1) closed hybrid with planned and measurable disturbances, 2) stabilization system at a given output, 3) discrete system. The table 1 contains descriptions of the signals present in the system.

3. Modern Type 1 Diabetes simulators

Despite the fact that T1D is a common disease over the world there are only few diabetes simulators developed so far. Two of them are presented shortly in this paper. Both are metabolic compartment simulators that means that they are based on mathematical models of biological processes. It should be noted here that other alternative models are also being developed for example: Single / Dual Hormone Virtual Patient Population [14] or Multivariable Integrated Metabolic & Physiologic Simulator [15]. The both last models are being developed and tested mainly for use in so called artificial pancreatic systems and are not available as stand-alone applications [16].

3.1. Simulator T1DMS

Undoubtedly T1DMS (Type 1 Diabetes Metabolic Simulator) know also as UVA/Padova Type 1 Diabetes (TID) Simulator is nowadays the most advanced and reliable computer simulator in the field of diabetes [5-7]. It is the first (and currently only) in silico diabetes model accepted by the FDA (U.S. Food and Drug Administration) as a substitute for pre-clinical animal testing of new treatment strategies for Type 1 Diabetes Mellitus. The simulator is being developed at University of Padova (Italy) and University of Virginia (USA).

![Figure 3. A view of T1DMS metabolic model structure [7].](image_url)

Quoting [5]: “The model puts in relation plasma concentrations, that is, glucose and insulin, with glucose fluxes, that is, endogenous glucose production, glucose rate of appearance, glucose utilization, renal extraction, and insulin fluxes, that is, rate of insulin appearance from the subcutaneous tissue and insulin degradation. The glucose subsystem consists of a 2-compartment model: insulin-independent utilization occurs in the first compartment, representing plasma and rapidly equilibrating tissues, while
insulin-dependent utilization occurs in the second compartment, representing slowly equilibrating tissues. The insulin subsystem is also described with 2 compartments, representing liver and plasma, respectively. Subcutaneous insulin kinetics is represented by a 3-compartment model. Endogenous glucose production is assumed to be linearly dependent on plasma glucose concentration and a delayed insulin signal. Glucose rate of appearance is described with a model of glucose transit through the stomach and intestine, with the stomach represented by 2 compartments, while a single compartment is used to describe the gut; the rate constant of gastric emptying is a nonlinear function of the amount of carbohydrates in the stomach. Glucose utilization during a meal has 2 components: insulin-independent utilization by the brain and the erythrocytes takes place in the first compartment and is constant, while insulin-dependent utilization takes place in the remote compartment and depends nonlinearly from glucose in the tissues.”

The simulator is based on a dozen differential equations and several dozen parameters. The number of the equations depends on a version of the simulator and used functions. The most popular version incorporates 16 equations and 42 parameters. The huge number of parameters is not an issue for users of the computer program because the developers provide a database of “in silico subjects” that set the parameters. The model is implemented in Simulink. Sample output of the the program is shown at Figure 4. Unfortunately both the TIDMS simulator and the accompanying database is not publicly available.

3.2. Simulator AIDA
According to [8-10] AIDA is a freeware computer program that permits the interactive simulation of plasma insulin and blood glucose profiles for demonstration, teaching, self-learning, and research purposes. The software was originally developed in 1991 and the latest version has been published in 2012. AIDA incorporates a compartmental model that describes glucose – insulin interaction in a type 1 diabetes person (Figure 5). The model contains a single glucose pool representing extra cellular glucose (including blood glucose) into which glucose enters via both intestinal absorption and hepatic glucose production. Glucose is removed from this space by insulin-independent glucose utilization in red blood cells and the central nervous system as well as by insulin-dependent glucose utilization in the liver and periphery; the latter taking place mostly in muscle and adipose tissue. Hepatic and peripheral handling of glucose in the model are dealt with separately. Glucose excretion from the extra cellular space takes place above the renal threshold of glucose.

The duration of the period in which glucose entry from the stomach into the duodenum is constant and maximal has been defined as a function of the carbohydrate content of the meal ingested. Thus the time course of the systemic appearance of glucose is described by either a modified trapezoidal or triangular function depending on the quantity of carbohydrate in the meal.

The model contains separate compartments for plasma and active insulin. Insulin is removed from the former by hepatic degradation while the latter is responsible for glycemic control. The activation and deactivation of insulin are assumed to obey first-order kinetics. The only insulin input into the model comes from the absorption site following subcutaneous injection.

The model is based on 4 differential equations along with twelve auxiliary relations. Configuration of the model involves determining values for: 1) insulin elimination rate, 2) two parameters for

![Figure 4. A glimpse of TIDMS output. Plasma glucose profile in response to three meals and boluses [7].](image-url)
insulin pharmacodynamics, 3) reference basal level of insulin, 4) constant for enzyme mediated glucose uptake, 5) rate of insulin-independent glucose utilization, 6) reference value for glucose utilization, 7) slope of peripheral glucose utilisation vs insulin line, 8) rate constant for glucose absorption from the gut, 9) maximal rate of gastric emptying, 10) maximal rate of gastric emptying, 11) volume of distribution for glucose per kg body weight, 12) body insulin sensitivity parameter, 13) hepatic insulin sensitivity parameter.

The model’s predictions allow a 24 hour simulation of blood glucose profiles for hypothetical patients to be generated. It comes with 40 ready-to-use case scenarios and further scenarios may be added by users. The AIDA simulator does not explicitly cater for pump usage and allows for 4 insulin injections per day. Figure 6. Presents sample output of the program.

4. The author’s original simulator T1DDS
The simulator T1DDS has been created as a part of a computer system assisting a user of an insulin pump. An additional (unexpected) application of the simulator is its educational functionality. It turns out that it can be used as a virtual patient to explain and train diabetic therapeutic procedures.
The simulator was designed to be very close to the biocybernetic intuitive model of a person with type 1 diabetes used by medical staff and trained patients. This model was identified on the basis of popular medical literature [1], the author's participation in training for diabetics and his own experience in taking everyday care of a T1D patient continuously since 2016. The model was described as ‘direct’ (as a synonym for simple) and the computer program implementing it as a direct simulator. The presented direct model significantly differs from the metabolic models used in the AIDA and T1DMS simulators and cannot be compared with them.

The intuitive direct model, as simplified, only slightly employs modern knowledge about physiology and metabolism. However, the model is widely used (often unconsciously) by thousands of people around the world with positive results. It is this fact that has encouraged the author of the article to describe this model in an engineering way, implement it in the form of a computer program and then check its capabilities.

4.1. The T1DDS structure
The T1DDS simulator corresponds to the block no. 2 at the Figure 2. It consists of 4 internal modules (Figure 7): a glucose module, an insulin module, a storage module and a consumption module.

The glucose module (1) represents the whole gastrointestinal tract and it is the first internal source of glucose supplied form the outside. The module receives the signal F (meal) in the form of rectangular pulse and then generates internal signal f25, which describes the appearance of glucose in the system after the meal. The digits 2 and 5 indicate the source and outlet of the signal. The task of this module is to realize the time delay that is observed between consumption of a meal and the appearance of glucose in blood derived from digestion of the meal. Figure 8 shows sample action of this module.

Each meal is described by its content of carbohydrates, fat, protein and the resultant glycemic index. Each component is converted into glycemic loads named FC, FF, FP respectively. It is assumed that 1g of carbohydrates results finally in appearance of 1g glucose in the system, 1g of fat changes into 0.9g of glucose, and 1g of protein in 0.4g. Then each of these 3 parts of the meal is considered separately.
Figure 7. Modular design of the T1DDS simulator: 1 – external interface, 2 – glucose module, 3 – insulin module, 4 – storage module 5 – consumption module. Cubes symbolize glucose, drops – insulin. Names of internal signals are explained in the text.

The next assumption concerns the digestion process of the 3 nutrient parts, which is described in the model by applying the beta distribution:

\[ f(t) = c \cdot t^{\alpha-1} \cdot (1 - t)^{\beta-1}, \]  

where the argument \( 0 \leq t \leq 1 \). Shape parameters \( \alpha, \beta \) and a normalization constant \( c \) depend on glycemic index of the meal. Values of the parameters have been determined based on [13] and are \( \alpha=2, \beta=4, c=20 \) for meals with glycemic index below 55, \( \alpha=2, \beta=6, c=42 \) in the case of the index between 55 and 70 and \( \alpha=2.8, \beta=10, c=476 \) for the index above 70. The differences apply only to the carbohydrate part, while the fat and protein components are always characterized by low glycemic index values. After substituting appropriate parameters for the formula (1) three functions are obtained \( f_C, f_F, f_P \) for each component of the meal. The functions are specified on the range of \( <0,1> \) with the integral equal to 1.

In order to obtain signal function \( f_{24} \), these three functions should be scaled and add according to the formula (2):

\[ f_{25}(T) = F_C \cdot f_C(t/T_C) + F_F \cdot f_F(t/T_F) + F_P \cdot f_P(t/T_P), \]  

where \( F_C, F_F, F_P \) indicate glycemic loads of carbohydrate, fat and protein part respectively, parameters \( T_C=3h, T_F=6h, T_P=6h \) mean total times of the digestion process of the parts, \( T \) is time in minutes. Formula (2) reveals the last assumption i.e. linearity of the digestion process. Figure 8. shows functions \( f_{25} \) obtained for 3 meals each of which consists only of 10g carbohydrates but differing in glycemic index.

The insulin module 2 (Figure 7) represents the subcutaneous tissue, where insulin is injected. It is the only source of insulin in the system supplied form the outside. The module receives the signal \( I \) (insulin) in the form of a rectangular pulse and then generates internal signal \( i_{35} \), which describes the appearance of insulin in the system after the injection. The job of this module is to realize the time delay that is observed between administration of insulin and its appearance in blood. Each injection is described by a dose of insulin given in units U (1U=0.01ml of of modern manufactured insulin) and its type. The insulin absorption rate depends on its type and is described by so called insulin curves. The insulin curve has been adopted form [11]. Figure 9 shows response of the module after injection of 1U bolus for different types of insulin.

The storage module 4 (figure 7), which represents the liver, is the internal source of glucose in the system. The module is charged by glucose module, which is indicated by signal \( f_{24} \). However, the signal \( f_{24} \) is not modelled directly and for this reason is drawn with a dashed line. It is assumed that the module is always charged. A feature of this subsystem is continuous 24-hour glucose supply. The supply is described by the function \( f_{45} \) (figure 10), which is an arbitrary function. The function is a
part of the configuration of the simulator. Designing a virtual patient for simulation means among others giving the function.

\[ F(t) = \begin{cases} \text{at } T=0: \\ 10g \text{ carbs} \end{cases} \]

**Figure 8.** Response of the glucose module to a meal consisted of 10g of carbohydrate in 3 variants of glycemic index.

The consumption module 5 (figure 7) represents the overall metabolism and is the destination for the glucose and insulin. This module has its state BG that is the value of blood glucose concentration. The value is increased by constantly incoming glucose (signals f25 and f45) and decreased by also constantly incoming insulin (signal i35). The increase depends directly on the amount of glucose.

**Figure 9.** Response of insulin module after injection of 1U of insulin. Plots has been prepared for popular commercial insulin.
entered and glucose sensitivity (GS). Similarly, the decrease depends directly on the amount of insulin and insulin sensitivity (IS). Both sensitivities depend on daytime and are described by two arbitrarily selected functions (Figure 11). The functions are configuration of the simulator. Designing a virtual patient for simulation means also giving the functions.

\[
BG_{i+1} = BG_i + GS_i \cdot (f_{25i} + f_{45i}) - IS_i \cdot i_{35i}
\]

where GSi and ISI indicate glucose and insulin sensitivity at timestamp Ti.

Interpreting informally the described situation, it can be said that the “f” signal channels transfer glucose to the metabolic module, while the channel “i” transfers insulin. The glucose and insulin react with each other causing a change in the state of this module, i.e. blood glucose concentration. The current blood glucose value determines the value of the signal CGM. From engineering point of view the T1DDS is a linear system of discrete time.

5. Virtual therapy using T1DDS
The computer simulator T1DDS described above is one of the components of type 1 virtual diabetes therapy system (Figure 12). Other components of this therapy are: an insulin pump, a continuous glucose monitoring system (CGM), a meal plan, a common clock and an user interface. The clock in 1 minute steps activates the remaining parts in the correct order. All these components have been coded.
in Java and linked into a computer application. During the computer simulation the user is able to: 1) input meals and accompanying insulin boluses, 2) program the base insulin that the pump administers, 4) observe the CGM signal. The user can change insulin doses (bolus and base) and modify the meal plan in order to achieve the therapeutic aim. The user interacts with the system at chosen time moments. The system operates autonomously between the interactions. There is no limit to the maximum simulation time, but a range of glucose concentration is set beyond which the simulations stops. It was assumed that only blood glucose values between 30 and 400 mg/dl are acceptable. Outside this range, the simulator can also work, but this situation is too different from the real one and therefore does not present any value.

5.1. An example of virtual therapy

The presented therapy lasts for 3 days. This is a hypothetical situation in which a therapist starts working with a patient who uses an insulin pump with NovoRapid insulin inside and CGM system in their everyday therapy. The records of blood glucose levels are not correct and the pump settings need to be changed. The patient is a virtual one configured (designed) according to figure 13. As one can see both sensitivities for glucose and insulin of the patient are constant and equal: GS = 100mg/dl / 10g, IS = 100mg/dl / 1U. Liver action is also constant and equals 4g/h, which means that the pump administers base insulin at the rate of 0.4U/h. The values suggests that the patient is a child but it is not important here. The therapist does not know the configuration. All the decisions are made based on CGM records only.

Having the patient configuration and the therapeutic plan it is possible to perform a computer simulation. The simulation covers a single day. From a technical point of view, it may take a longer period, but then the glucose values will repeat themselves, because the daily settings do not change. The result of the simulation is the course of glycemia seen in figure 15. The therapist finds the blood glucose levels to be incorrect. Recorded values significantly exceed the 200 mg/dl threshold and

![Diagram of components of type 1 diabetes therapy](image)

**Figure 12.** Components of the type 1 diabetes therapy: 1 – common clock, 2 – T1DDS as a virtual patient, 3 – meal plan, 4 – CGM, 5 – insulin pump, 6 – user interface.
therefore pose health hazard for the patient. It means that glycemias must be first brought to acceptable limits.

Figure 13. Configuration of the T1DDS virtual patient used in the example simulation.

In this situation the therapist proposes changes: 1) increasing and bringing the first breakfast bolus forward, 2) decreasing and setting the second breakfast bolus back, 3) increasing and setting the lunch bolus back, 4) decreasing and setting the afternoon tea bolus back, 5) increasing and bringing the dinner bolus forward. This way the therapy plan B has been created (Figure 16). The next simulation is performed for the new plan. The result of this simulation is also the glycemic course seen in Figure 17. The therapist states improvement of the patient’s glycemia records but notes that blood glucose levels exceed the limit of 160mg/dl after lunch. There are also two unwanted spikes around 7 and 11 pm. There is a need to eliminate all these events.

Figure 14. The initial therapeutic plan. The plan A.

The therapist proposes another series of changes: 1) slightly reduction in the bolus for the first breakfast, 2) bringing the second breakfast bolus forward, 3) bringing the lunch bolus forward, 4) bringing the afternoon tea bolus forward, 5) increasing and bringing the dinner bolus forward. This way the second therapy plan C has been created (Figure 18). The next simulation shows the effect of applied changes (Figure 19). We can state that the aim of the therapy has been achieve. There are still two oversteps the postprandial threshold after afternoon tea and dinner, but they are of minor significance taking into account the initial CGM records.
Figure 15. CMG recorded glucose concentration as response to the plan A.

Summing up the virtual therapy, it should be stated that changing the insulin administration plan significantly improved the patient's glucose records. However, the therapist should also work to eliminate glucose fluctuations between 6pm and 12pm in order to ensure a better quality of the patient's live. Such fluctuations may adversely affect the patient's well-being.

The next issue is the bolus that is administered 45 minutes before the dinner. It is doubtful whether the real patient is able to comply with this regime. Therefore, despite the achieved goal, the therapist should try to create better therapeutic plans.

Figure 16. The first change of the therapeutic plan. The plan B. The changes in relation to the plan A are marked in red.

6. Summary and conclusions
In this paper the author’s original computer simulator of a person with type 1 diabetes has been presented. The inspiration of the simulator was the intuitive biocybernetic model commonly used by medics and patients in everyday therapy. The model is much easier than the metabolic ones used in T1DMS or AIDA simulators. The existence of the intuitive model is justified by the fact that it can be used in daily therapy to make the necessary estimates and therapeutic decisions even without computing equipment. Models based on a system of differential equations and calibrated by several dozen parameters cannot be used in this way. Although the intuitive model is inaccurate or even unjustified from the scientific point of view, it works well in tens of thousands of therapeutic cases. This is evidenced by living and well-functioning patients. This fact encouraged the author of the article to describe this model from an engineering point of view and implement it in the form of a computer program. The model has been described in detail in this article. Additionally, sample results of simulation using this model have been presented.
Figure 17. CMG recorded glucose concentration as response to the plan B.

Figure 18. The second change of the therapeutic plan. The plan C. The changes in relation to the plan B are marked in red.

Figure 19. CMG recorded glucose concentration as response to the plan C.

The simplicity of the model should be noted. The configuration of the model requires only three 24-hours functions: 1) insulin sensitivity, 2) glucose sensitivity and 3) liver action. The concepts behind the functions are well understood by people dealing with diabetes therapy. The functions obviously depend on the age, weight, height and sex of a person, but these features do not occur
directly in the simulator. The virtual patient is obtained by setting these three functions. It means that any virtual patient with any expected characteristics can be easily created. The characteristics may be stable during simulation or may be modified according to given program. It can therefore be said that the patient is as real as it is well configured. In the author’s opinion, such approach of building a simulator of a person with type 1 diabetes is, despite justified controversy, still promising.

Unfortunately, no verification of the obtained simulation results has been presented, because this task turned out to be impossible for the author on the day the article was written. The AIDA program was freely available but did not support insulin pumps. The T1DM program was not available to the author. Clinical trials, on the other hand, required involvement of a large number of specialists and expensive medical equipment and therefore were unreachable as well.

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