# Vércukorszint dinamikák klaszterezése 1-es típusú cukorbetegségben

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## Type 1 diabetes [2]

Type 1 diabetes is an autoimmune disease in which the body's immune system mistakenly attacks the insulin-producing beta cells in the pancreas. These beta cells make insulin, a hormone that allows blood sugar (glucose) to enter the body's cells and provide energy. When enough beta cells are destroyed, the pancreas produces little or no insulin, making it necessary to take insulin to survive.

Without sufficient insulin, glucose cannot move from the bloodstream into the cells, causing blood sugar levels to rise. This condition, called hyperglycemia, can lead to long-term damage to the heart, kidneys, eyes, nerves, and other organs if left untreated.

Type 1 diabetes is often diagnosed in children, teenagers, and young adults, but it can develop at any age. The exact cause of the disease is not fully understood, and researchers are still studying what triggers the immune system to attack the pancreas. Currently, there is no known way to prevent type 1 diabetes.

People with type 1 diabetes can live long and healthy lives by carefully managing their condition. A treatment plan, developed with a healthcare team, usually includes taking insulin, following a balanced diet, staying physically active, and monitoring blood glucose levels regularly. Having a strong support system from family, friends, and healthcare providers is also essential for maintaining health and achieving personal goals.

## Treatment of Type 1 diabetes [1]

Managing Type 1 diabetes (T1D) primarily revolves around insulin therapy, which replaces the insulin your body no longer produces. Since T1D

is a self-managed condition, you'll make daily decisions about your insulin needs to keep your blood sugar levels in a target range.

Insulin comes in various forms, each with different speeds of onset and duration of action. You'll likely need a combination:

- Basal Insulin (Long-Acting): Provides a continuous, background level of insulin to manage glucose between meals and overnight.
- Bolus Insulin (Mealtime and Correction): Specific doses you take when you eat (to cover carbohydrates) and to correct elevated blood sugar levels.

You can administer insulin in several ways:

- Multiple Daily Injections (MDI): Involves drawing a dose from an insulin vial using a syringe for injection into the fatty tissue beneath the skin.
- Insulin Pens: Pre-filled devices used to inject specific doses into the fatty tissue.
- Insulin Pumps: A device that delivers insulin continuously through a small tube inserted under the skin, aiming to mimic the natural function of the pancreas. Doses can also be delivered on demand.

# First simulator py-mGIPsim

The mGIPsim (Metabolic Glucose-Insulin Physiology Simulator) is an open-source metabolic simulator that models the changes in blood glucose and insulin levels of 20 virtual Type 1 Diabetes (T1D) patients under various therapeutic, dietary, and physical activity conditions. The system's purpose is to provide a realistic simulation environment for research, education, and development purposes, where users can examine the dynamics of glucose-insulin regulation using customizable parameters.

The simulator is written in Python and uses a vectorized, JIT (Just-In-Time) compiled computational model, which enables fast and efficient execution even with large amounts of simulation data. The system has a modular structure, making it easy to extend with new patient models, insulin dosing strategies, or control algorithms.

The software offers several user interfaces:

- Graphical User Interface (GUI) – A Streamlit-based web application that allows for interactive parameter setting and visualization.

- Interactive Command Line Mode (CMD) – A console user interface where the simulation can be configured step-by-step.
- Simple Command Line Interface (CLI) – A simulation that can be run from a single command line with predefined parameters.

mGIPsim supports various insulin therapy protocols, including:

- MDI (Multiple Daily Injections),
- SAP (Sensor-Augmented Pump Therapy),
- Hybrid Closed-Loop rendszerek.

By varying parameters for meals, exercise, and insulin administration, the simulation can demonstrate the time-course of blood glucose levels over several days. The model also takes into account individual physiological differences, so each of the 20 virtual patients has a distinct metabolic dynamic.

The project is a valuable tool for research and development for testing insulin dosing algorithms, simulating diabetes management strategies, and teaching digital healthcare systems. For developers, the modular code structure and documented API interface allow for the integration of new models or the customization of the simulation logic.

## Second simulator: DMMS.R

The DMMS.R (Diabetes Mellitus Metabolic Simulator - Research) is a professional metabolic simulator developed for research purposes. The application is capable of modeling the physiological processes of Type 1 and Type 2 Diabetes, as well as prediabetes, in virtual patients. The simulator includes 55 virtual subjects, categorized into different patient groups: Type 1 children, adolescents, and adults; Type 2 adults; and prediabetic adults. Each subject has unique, predefined metabolic parameters. The simulator's primary goal is to provide preliminary and safe support for clinical trials.

The simulation is based on a compartmentalized glucose-insulin metabolic model that tracks the dynamics of hormones, blood glucose levels, and insulin at minute-level time resolution. The model accounts for meals, physical activity, insulin administration, pharmacological treatment, and circadian rhythm. The system supports insulin pharmacokinetics and pharmacodynamics, bioavailability, slow-release formulations, and the calculation of the amount of active insulin (Insulin-On-Board).

The DMMS.R has a modular structure, consisting of three main components:

- Virtual Patient Database: Contains the various metabolic characteristics.
- Mathematical Simulation Engine: Calculates the physiological processes.
- Graphical Interface: Used to configure the simulation.

The simulator allows for the configuration of various sensor, controller, and delivery elements:

- Ideal or noisy CGM and SMBG sensors (Continuous/Self-Monitoring of Blood Glucose).
- Meal, correction, and basal insulin controllers.
- Insulin pumps and injection delivery systems.

Pharmacological treatments, exercise programs, and meals can be prescribed for the patients within the program. Noise can also be applied during the simulation to model real-world measurement and administration uncertainties.

The simulation results are presented through:

- Detailed time-series graphs.
- CVGA (Control-Variability Grid Analysis).
- Individual and population-level statistical indicators.

The data can be exported in CSV and MATLAB formats.

The DMMS.R primarily serves research, development, and medical device validation purposes. It is suitable for the preliminary study and testing of insulin pumps, drug therapies, and digital diabetes management systems without the need for experimenting on real patients. The program is specifically designed for a clinical research environment.

# Szimulátorok összehasonlítása

(A dokumentumban nem szerepel tartalom.)

## Result on both simulators with the same inputs

The objective of the experiment is to investigate how the insulin levels of 20 healthy adults change over the course of one day following three standardized meals. All participants receive the same amount of carbohydrates for breakfast, lunch, and dinner, ensuring that differences between the measured insulin responses are attributable solely to individual physiological variations.

During the study, participants do not engage in exercise and are prohibited from consuming any snacks, treats, or supplementary foods. They receive only the three meals specified in the protocol:

- Breakfast at 7:00 AM: 60 grams of carbohydrates
- Lunch at 1:00 PM: 75 grams of carbohydrates
- Dinner at 7:00 PM: 60 grams of carbohydrates

The simulation is run for a duration of one day (24 hours).

In subsequent experimental phases, a separate analysis will be performed to determine how the addition of snacks and the incorporation of physical activity modify the insulin response.

## Hivatkozások

[1] Management and treatment. *Cleveland Clinic*. URL: `https://my.clevelandclinic.org/health/diseases/21500-type-1-diabetes`.

[2] Understanding Type 1 Diabetes | ADA. URL: `https://diabetes.org/about-diabetes/type-1`.