BME 444
Glucose Homeostasis 2
April 17, 2025

Lesson 20 Student Exercises - Due by Apr 24

Modeling Type 1 Diabetes

Type 1 (insulin-dependent) diabetes is characterized by dysfunctional beta cells that cannot produce sufficient insulin to control blood glucose levels. This disorder typically appears during childhood and is also known as juvenile-onset diabetes. If an adult develops Type 1 diabetes it is known as ketone-prone diabetes. Type 1 diabetics must carefully monitor their blood sugar levels and be prepared to ingest a high sugar snack if blood glucose levels fall too low, or inject insulin if blood sugar levels are too high.

We can use the model that you developed above to explore how Type 1 diabetes changes the response to a glucose input.

1. Determine which parameter (greek letter) in your model is best suited to model a lack of insulin secretion in response to glucose.

2. Adjust this parameter to 0% of the value you used in Lesson 19 and generate a new transfer function. Plot the transient glucose and insulin response if $\dot{m}_{in\,GLU}$ is a step input with a value of 100 gm/hr and $\dot{m}_{in\,INS} = 0$.

3. Plot the transient glucose and insulin response if $\dot{m}_{in\,INS}$ is an insulin step input with a value of 100 gm/hr and $\dot{m}_{in\,GLU} = 0$.

4. How does glucose and insulin respond to a glucose step input compared to a non-diabetic? How does glucose and insulin respond to an insulin step input compared to a non-diabetic? Do the responses to a glucose step input make sense to you? Remember that the glucose homeostasis system is a regulator, and glucose levels closer to the input step magnitude are better.

5. The glucose tolerance test is a common test for diabetes. The patient fasts for 12 hours and then consumes a high-sugar beverage. Blood glucose levels are measured an hour later to see how quickly the glucose has been cleared from the body.

   We can model a glucose tolerance test by giving our system a “pulse” input. Change your glucose input to a pulse with amplitude 100 gm/hr that lasts from time 0.5 hr to 0.75 hr. Assume $\dot{m}_{in\,INS} = 0$.

Plot the transient glucose and insulin response of a normal patient and the Type 1 diabetic to the glucose tolerance test. How does each respond?

6. Are the Type 1 glucose and insulin transfer functions stable? How do you know?

7. Determine the steady-state error for $T_{GLU}(s)$ and $T_{INS}(s)$ for a Type 1 diabetic. For $T_{GLU}(s)$ SSE, assume $\dot{m}_{in\,INS} = 0$ and $\dot{m}_{in\,GLU}$ is a step input of amplitude 100 gm/hr. For $T_{INS}(s)$ SSE, assume $\dot{m}_{in\,GLU} = 0$ and $\dot{m}_{in\,INS}$ is a step input of amplitude 100 gm/hr. How does the steady-state error of a Type 1 diabetic compare to a healthy person?

Modeling Type 2 Diabetes

Type 2 (non-insulin-dependent) diabetes is characterized by a lack of tissue response to insulin. The pancreas senses blood glucose normally and produces insulin, but the tissues do not respond to increased insulin levels with increased glucose uptake. This type of diabetes usually occurs in adults and is sometimes known as *adult onset diabetes*.

We can use the model that you developed above to explore how Type 2 diabetes changes the response to a glucose input.

1. Determine which parameter (greek letter) in your model is best suited to model Type 2 Diabetes.

2. Adjust this parameter to 20% of the value you used in Lesson 19 and generate new equations for GLU and INS. Plot the transient glucose and insulin response if $\dot{m}_{in\,GLU}$ is a step input with a value of 100 gm/hr and $\dot{m}_{in\,INS} = 0$.

3. Plot the transient glucose and insulin response if $\dot{m}_{in\,INS}$ is an insulin step input with a value of 100 gm/hr and $\dot{m}_{in\,GLU} = 0$.

4. How do glucose and insulin respond to a glucose step input compared to a non-diabetic? How do glucose and insulin respond to an insulin step input compared to a non-diabetic? Do the responses to a glucose step input make sense to you? Remember that the glucose homeostasis system is a regulator, and glucose levels closer to the input step magnitude are better.

5. The glucose tolerance test is a common test for diabetes. Use the same pulse input for $\dot{m}_{in\,GLU}$ that you used in the Type 1 diabetic exercise and plot the transient glucose and insulin response of a normal patient and the Type 2 diabetic. How does each respond to the glucose tolerance test?

6. Are the Type 2 glucose and insulin transfer functions stable? How do you know?

7. Determine the steady-state error for $T_{GLU}(s)$ and $T_{INS}(s)$ for a Type 2 diabetic. For $T_{GLU}(s)$ SSE, assume $\dot{m}_{in\,INS} = 0$ and $\dot{m}_{in\,GLU}$ is a step input of amplitude 100 gm/hr. For $T_{INS}(s)$ SSE, assume $\dot{m}_{in\,GLU} = 0$ and $\dot{m}_{in\,INS}$ is a step input of amplitude 100 gm/hr. How does the steady-state error of a Type 2 diabetic compare to a healthy person?

8. Just from looking at the glucose responses to a step input and pulse (tolerance test), is it possible to tell a difference between a Type 1 diabetic and Type 2 diabetic? Why or why not?