Original Research Article

Optimal exercise time to control glucose in type 2 diabetes

Abstract

Aims/ objectives:To find an optimal glucose level when different rate of exercise are performed.
Study design: Cross-sectional study.
Place and Duration of Study: Sunyani Regional Hospital, between September 2018 and May 2019.
Methodology: Computer simulations are performed on our glucose model for a period of 50 weeks for people who are type 2 diabetic.
Results: The simulations show the effects of different rate of exercise on glucose levels. When the rate of physical exercise was less than 0.4, it shows that glucose levels rises to more than $200mg/dL$ making the conditions of type 2 diabetic patients unstable. Rate of exercise between 0.4 to 0.79 also shows that glucose levels falls sharply therefore does not make type 2 diabetic patient get a normal glucose level for a long period. The rate at 0.8 shows that type 2 diabetic patient will achieve a normal glucose level for a long period of time therefore making it optimal. Type 2 diabetic patients could not perform exercise with a rate of 0.9 to 1.0 due to their health condition.
Conclusion: The optimal rate for exercise was at a rate of 0.8 which can help regulate the blood glucose levels to a normal. Therefore, brisk walking for at least 30 min daily can be recommended as the principal form of physical exercise.

Keywords: Simulation; Exercise; Type 2 diabetes; Mathematical modeling

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

1 Introduction

Diabetes is a metabolic disorder that affects the body that causes blood glucose levels to rise higher than normal. Type 2 diabetes is characterized by insulin resistance and more often it develops in adults, but children can also be affected. About 80% of the 371 million diabetics live in low and middle income countries, nearly five million deaths were due to diabetes and more than $471 billion was spent on health care for diabetes in 2012 (IDF, 2012). The prevalence of diabetes has increased drastically in Africa. Ghana is one of the 32 countries of the IDF in African. 425 million people have diabetes in the world and more than 16 million people in African, it is estimated to be around 41 million by 2045. 518,400 cases of diabetes were recorded in Ghana in 2017 (IDF, 2017). There are challenges facing the fight of the disease such as lack of funding for noncommunicable diseases, lack of research available on diabetes, lack of availability of medications, differences in urban and rural patients, and inequity between public and private sector health care (Sonak *et al*, 2017).

1.1 Study Area

The research was done in the Brong-Ahafo Region of Ghana. The regions demography includes these details: The region had a total of 690 health facilities comprising 29 Hospitals, 82 Health

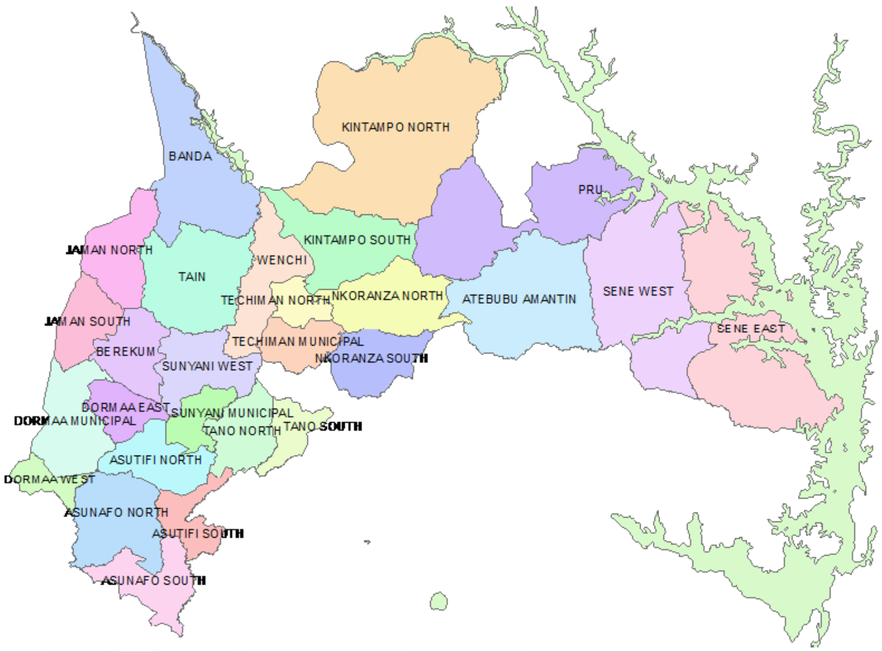

Figure 1: Map of Brong Ahafo Region of Ghana

Centres, 112 Clinics, 43 private Maternity Homes and 423 Functional Community Health Planning Services (CHIPS). There were 1,393 outreach points in the region and 3,292 communities. 9 districts out of the 27 districts do not have district hospitals, however, three of them have benefitted from the newly constructed polyclinics. The remaining 6 without hospital or polyclinic are Asunafo South, Banda, Nkoranza North, Sene East, Sunyani West and Techiman North. The region had 15 health training institutions in the following towns; Kintampo (College of Health Sciences), Tanoso Community Health Nurses Training School (CHNTS), Sunyani Nurses Training College (NTC) and Health Assistant Training School (HATS), Berekum Nurses and Midwife Training College (NMTC), Goaso (Midwifery), Dormaa Municipal (Midwifery), Ntotroso (NMTC) and Seikwa (HATS), Kwapong (CHNTS), Yamfo (College of Health), Dadiesoaba (NTC), Sampa (CHNTS), Techiman Krobo (CHNTS), Wenchi (NTC) and Techiman Holy Family Nursing and Midwifery College (NMTC). Research at the Sunyani Regional Hospital revealed that a high number of people in the Sunyani municipality have high blood pressure and high blood sugar levels but are not aware of their status. A total of 99 cases of diabetes were recorded at the hospital (Ghanaweb, 2003). Obesity is associated with diabetes among women in the region. 22 out of the 35 cases studied on epidemiological and clinical factors in diabetes patients at Kintampo in the region were females and 13 males. 41 to 50 age group had the peak incidence for females and from 51 to 60 age group for males (Ghanaweb, 2005).

1.2 Literature review

Mathematical models have been developed based on variables which include the concentrations of glucose in the blood, the concentration of glycogen in the liver, the concentration of the hormone glucagon, and the concentration of insulin in the blood. The main aim of diabetes treatment is to maintain the glucose level in the blood to a normal level. The ability to lower blood glucose depends on how the β cells responds to glucose (Bergman *et al*, 1981). (Chaikivska *et al*, 2015) developed mathematical models which were based on digestion of receipted glucose depending on the volume of consumed carbohydrate. The Levenberg-Marquardt method was used to identify the blood glucose dynamics. An increase in exercise intensity increases glucose uptake by the working tissues (Wasserman *et al*, 1991). (Ontan-Garca *et al*, 2013) worked in generating in-phase bursting electrical activity (BEA) in β cells with different behaviors such as active, inactive and continuous spiking cells based on mathematical models using a discrete time coupling. Based on numerical simulations, synchronization in the insulin release is obtained from β cells with different behaviors. (Erica, 2012) also develop mathematical models based on insulin resistance and cell dysfunction. The determinants in cell failure was explored, from the perspective of endoplasmic reticulum stress and the unfolded protein response. It was concluded that with a basis for age related insulin resistance, nutrient plays an important role in health which helps in cell and molecule mechanisms. (Minghu, 2015) proposed three dynamic models to study the mechanism of glucose insulin regulatory system and the possible causes of diabetes. The progression of diabetes comes along with the apoptosis of pancreatic β cells. A dynamical system model is formulated based on physiology and studied by geometric singular perturbation theory. Liapunov function, Hopf bifurcation and backward bifurcation was used in the analysis. It was found that the intermittent rests of β cells in insulin secretion are essential for the cells to survive through the observation of the existence of a limit cycle.

2 Methdology

We will formulate a new type 2 diabetic model that involves exercise. The formulated model is in the form of a system of differential equations. This mathematical models has a compartmental structure $G(t)$, $X(t)$, $Y(t)$ and $Z(t)$ which depicts the flow of insulin and glucose between tissues such as the liver, muscle and heart.The model inputs are the Intravenous (IV) insulin infusion rate H and the rate of glucose absorption from the gut following a meal C. The model parameters v_n for $n = 1, \cdots, 3$ is the transfer rate. The mathematical model developed from the schematic diagram in figure 2 is given below:

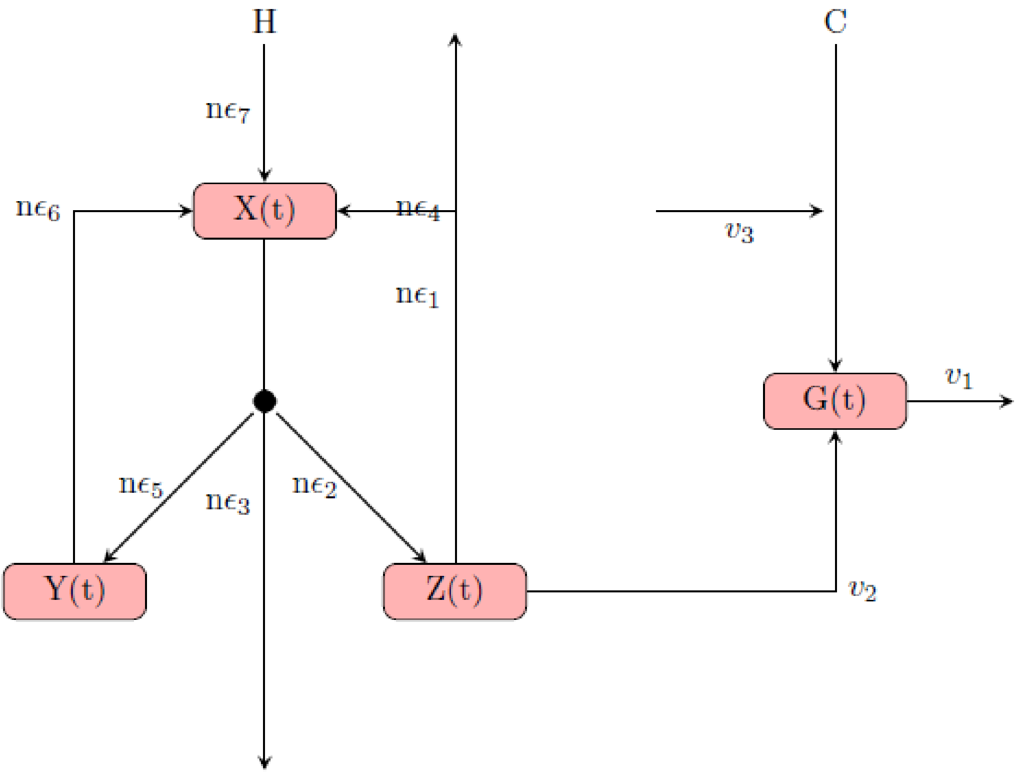

Figure 2: Insulin kinetics and glucose metabolism model with exercise

$$\frac{dG}{dt} = -(v_1 + nv_2 Z(t))G(t)a_1 + \beta(t) + v_3 + C + rj_2j_3 - \gamma_1 j_1 j_4 - c_1 j_1 - l_1 \quad (2.1)$$

$$\frac{dX}{dt} = nH\epsilon_7 + nZ(t)\epsilon_4 - nX(t)\epsilon_3 + \beta(t) - \gamma_2 j_1 j_4 - c_2 j_4 - l_2 \quad (2.2)$$

$$\frac{dY}{dt} = nX(t)\epsilon_6 - nY(t)\epsilon_5 + \beta(t) - \gamma_2 j_1 j_4 - c_2 j_4 - l_3 \quad (2.3)$$

$$\frac{dZ(t)}{dt} = nX(t)\epsilon_2 - nZ(t)\epsilon_1 + \beta(t) - \gamma_2 j_1 j_4 - c_2 j_4 - l_4 \quad (2.4)$$

Table 1: Variable and descriptions

Symbol	Description	Parameter value	Source
$G(t)$	Plasma glucose concentration		
$X(t)$	Insulin mass in the blood		
$Y(t)$	Insulin mass in a remote compartment in fast equilibrium		
$\beta(t)$	Represents the β cells		
$Z(t)$	Insulin mass in a remote compartment in slow equilibrium	10	Estimated
C	Rate of appearance of exogenous glucose following a meal	80	Estimated
H	Intraveanous insulin delivery rate	150	Brian RH (2001)
v_1	Fractional transfer rate	0.5	Brian RH (2001)
v_2	Fractional transfer rate	0.7	Brian RH (2001)
v_3	Fractional transfer rate	2.570	Brian RH (2001)
ϵ_1	Fractional transfer rate	0.021	Brian RH (2001)
ϵ_2	Fractional transfer rate	0.042	Brian RH (2001)
ϵ_3	Fractional transfer rate	0.435	Brian RH (2001)
ϵ_4	Fractional transfer rate	0.021	Brian RH (2001)
ϵ_5	Fractional transfer rate	0.394	Brian RH (2001)
ϵ_6	Fractional transfer rate	0.142	Brian RH (2001)
ϵ_7	Fractional transfer rate	0.47	Brian RH (2001)
n	Effect of physical exercise	0.8	Estimated
a_1	Represents pulsatile input function	$cos24$	Estimated
r	Stoichiometric kinetic constant involved in the production of glucose	0.25	Frank N. (2015)
γ_1, γ_2	Stoichiometric kinetic constant involved in the	0.5,	Frank N. (2015)
	action of insulin on glucose	0.15	Frank N. (2015)
c_1, c_2	Catabolic degradation pertaining to exponential	0.85	Frank N. (2015)
	decay kinetics	0.0001	Frank N. (2015)
l_1	Linear decay kinetics rate	10.5	Frank N. (2015)
l_2	Linear decay kinetics rate	0.0025,	Frank N. (2015)
l_3	Linear decay kinetics rate	0.0025	Frank N. (2015)
l_4	Linear decay kinetics rate	0.0025	Frank N. (2015)
j_1	Concentration of glucose in the blood plasma	10	Estimated
j_2	Concentration of glycogen in the blood plasma	40	Estimated
j_3	Concentration of glucagon in the blood plasma	50	Estimated
j_4	Concentration of insulin in the blood plasma	10	Estimated

The effect of physical exercise is calculated by finding the proportion of heartbeat for a given minute. Given the maximum heartbeat of 175 beats per minute. Table 1 describes the variable and parameters used in the model equation.

2.1 Simulations

The authors used exercise as the only tool to check the glucose dynamics of a type 2 diabetic patient. Simulations were performed to find the level of exercise and the length of time in which glucose levels in a diabetic patient could be stabilized. Our developed glucose model is as shown below.

$$\frac{dG}{dt} = -(v_1 + nv_2 Z(t))G(t)a_1 + \beta(t) + v_3 + C + rj_2j_3 - \gamma_1 j_1 j_4 - c_1 j_1 - l_1$$

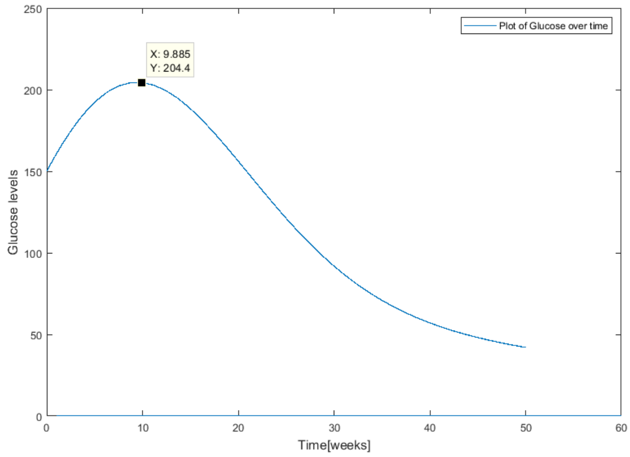

Figure 3: Plot of glucose when exercise rate is 0.35

Figure 3 shows the rise of glucose levels when exercise rate is 0.35. Glucose level rises to $204.4mg/dL$ which can lead to complications making the condition of the diabetic patient unstable.

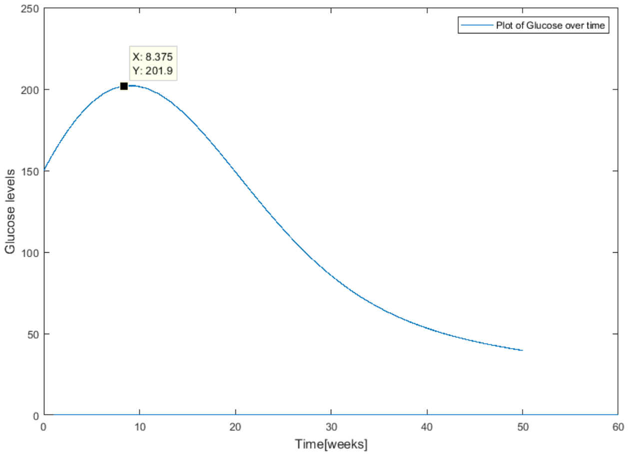

Figure 4: Plot of glucose when exercise rate is 0.37

Figure 4 shows the rise of glucose levels when exercise rate is 0.37. Glucose level rises to $201.9mg/dL$ which can lead to complications making the condition of the diabetic patient unstable.

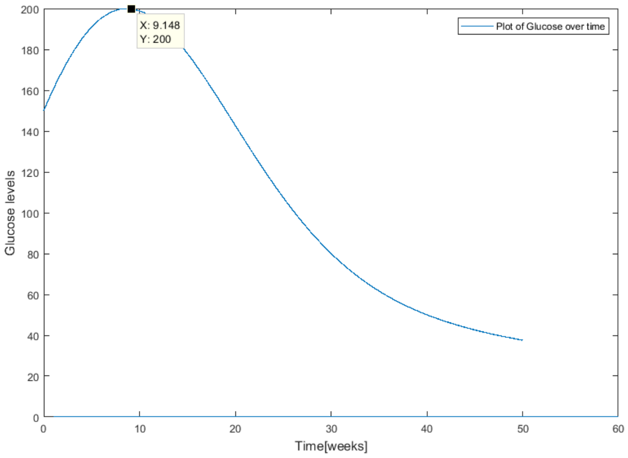

Figure 5: Plot of glucose when exercise rate is 0.39

Figure 5 shows the rise of glucose levels when exercise rate is 0.39. Glucose level rises to $200mg/dL$ which can lead to complications making the condition of the diabetic patient unstable.

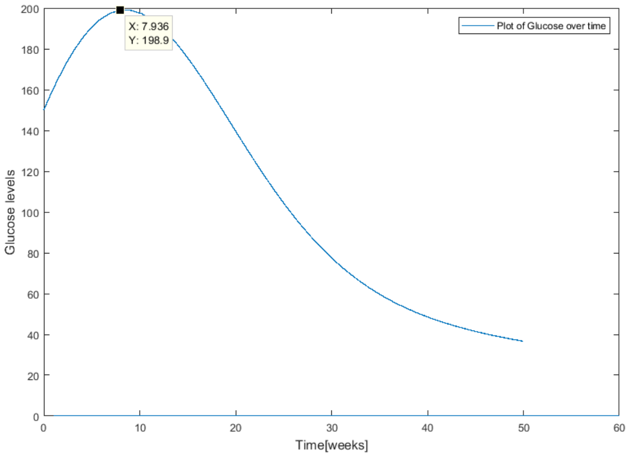

Figure 6: Plot of glucose when exercise rate is 0.4

Figure 6 shows the rise of glucose levels when exercise rate is 0.4. In this case glucose levels rises to $198.9mg/dL$ and begins to drop. Type 2 diabetic patient will have a normal glucose level at the end of the 30th week.

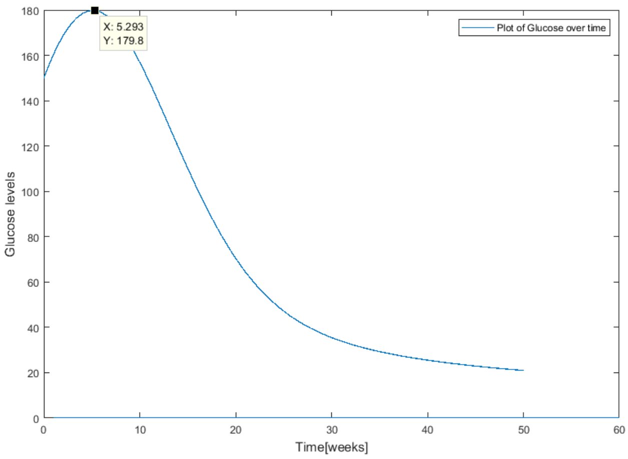

Figure 7: Plot of glucose when exercise rate is 0.5

Figure 7 shows the rise of glucose levels when exercise rate is 0.5. In this case glucose levels rises to $197.8mg/dL$ and begins to drop. Type 2 diabetic patient will have a normal glucose level at the end of the 25th week.

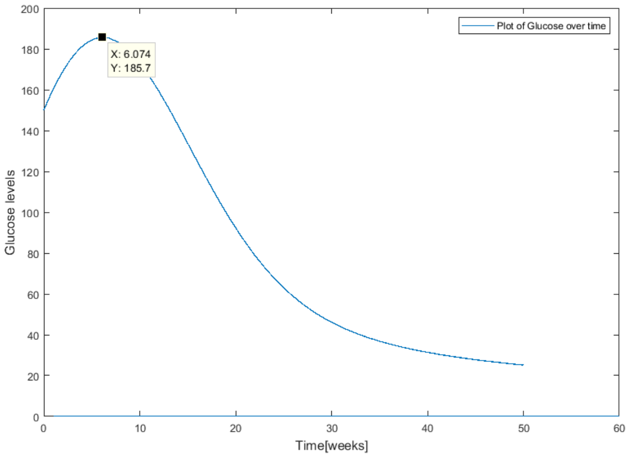

Figure 8: Plot of glucose when exercise rate is 0.6

Figure 8 shows the rise of glucose levels when exercise rate is 0.6. In this case glucose levels rises to $185.7mg/dL$ and begins to drop. Type 2 diabetic patient will have a normal glucose level at the end of the 23rd week.

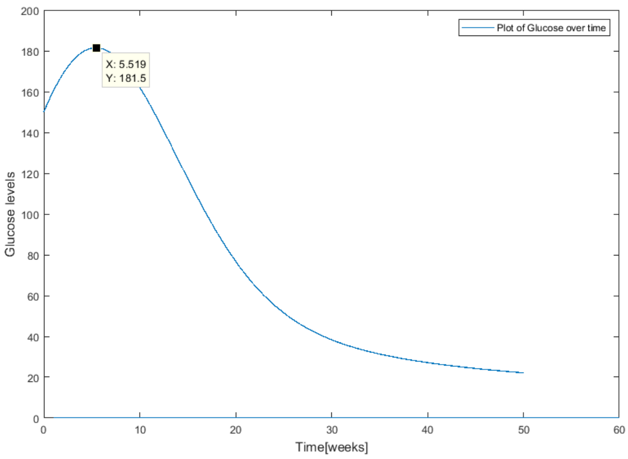

Figure 9: Plot of glucose when exercise rate is 0.7

Figure 9 shows the rise of glucose levels when exercise rate is 0.7. In this case glucose levels rises to $181.5mg/dL$ and begins to drop. The condition of type 2 diabetic patient will be stable.

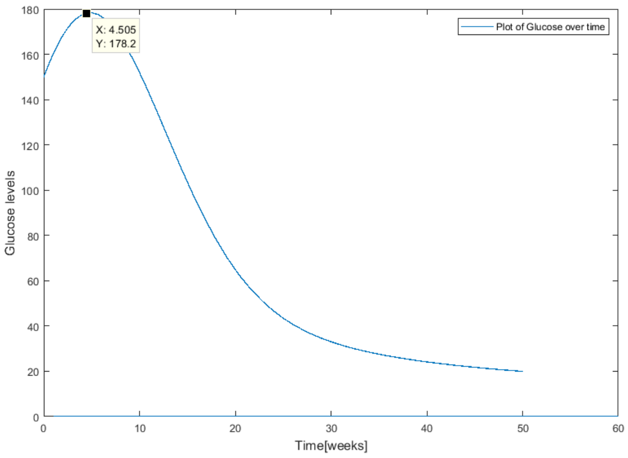

Figure 10: Plot of glucose when exercise rate is 0.8

Figure 10 shows the rise of glucose levels when exercise rate is 0.8. In this case glucose levels rises to $178.2mg/dL$ and begins to drop. The condition of type 2 diabetic patient will be stable.

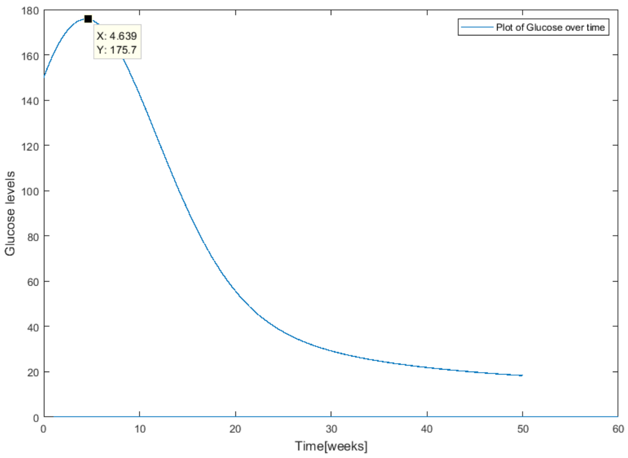

Figure 11: Plot of glucose when exercise rate is 0.9

Figure 11 shows the rise of glucose levels when exercise rate is 0.9. In this case glucose levels rises to $175.7mg/dL$ and begins to drop. The condition of type 2 diabetic patient will be stable.

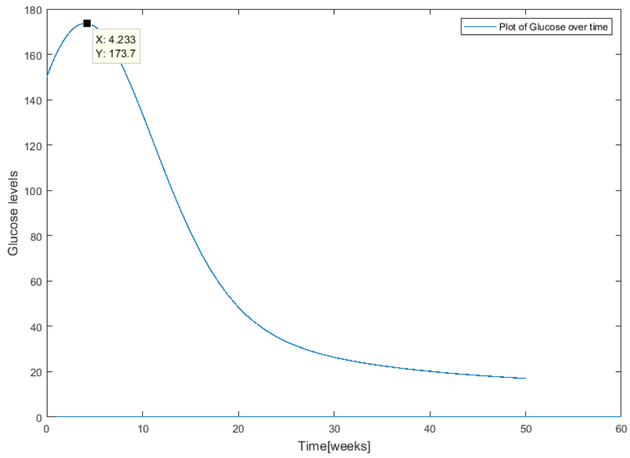

Figure 12: Plot of glucose when exercise rate is 1

Figure 12 shows the rise of glucose levels when exercise rate is 1. In this case glucose levels rises to $177mg/dL$ and begins to drop. The condition of type 2 diabetic patient will be stable.

3 Results and Discussion

Figure 3 to figure 5 shows that the conditions of a diabetic patient will not be stable due to high level of glucose. Figure 6 shows the rise of glucose levels to $198.9mg/dL$ and it begins to drop. This occurs at the end of the 7th week, the type 2 diabetic patient will have a normal glucose level at the end of the 30th week, Figure 7 shows the rise of glucose levels to $197.8mg/dL$ and it begins to drop. This occurs at the beginning of the 5th week, the type 2 diabetic patient will have a normal glucose level at the end of the 25th week, when the rate of exercise is 0.6 glucose level rises to $197mg/dL$ in 9 weeks and begins to fall figure 12. Glucose levels become normal at the end 30 weeks. Figure 9 shows the rise of glucose levels to $181.5mg/dL$ and begins to drop. This occurs in the middle of the 6th week, the type 2 diabetic patient will have a normal glucose level at the end of the 22nd week. When the rate of exercise is 0.8 from figure 10 glucose level rise to 178.2 in the middle of the 4th week and starts to fall. This is the optimal rate of exercise because the benefit of exercise last for a long period of time. Figure 11 shows the rise of glucose levels to $175.7mg/dL$ and begins to drop. This occurs in the middle of the 4th week, the type 2 diabetic patient will have a normal glucose level at the end of the 18th week. In figure 12 glucose level rises to 173.7 in the beginning of the 4th week and starts to fall. Glucose level becomes normal before the 20th week.

4 CONCLUSION

From the computer simulation of this paper, when the exercise was present in the model it shows that glucose level rises to a point and falls back to normal making the condition of type 2 diabetes stable. This can be seen in figure 6 to figure 12. When exercise was taken out of the model, glucose level rises very high and resulting in complications making the diabetic condition unstable. When the exercise rate was 0.8, glucose level was optimal from figure 10. Type 2 diabetes patients should try and exercise with a rate of 0.8 to get an optimal glucose level as seen from figure 10.

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