Mathematics Model of Diabetes Mellitus Illness without Genetic Factors with Treatment

Nurul Fitriyah, Muhammad Wakhid Musthofa*, Pipit Pratiwi Rahayu

Department of Mathematics, Universitas Islam Negeri Sunan Kalijaga, Yogyakarta, Indonesia.
Corresponding author*: muhammad.musthofa@uin-suka.ac.id

Abstract
Diabetes Mellitus is a metabolic disorder characterized by an increase in glucose levels in the blood (hyperglycemia), which causes various chronic complications due to abnormalities in insulin secretion. Diabetes Mellitus is known as the Mother of Disease because it is the mother of various other diseases such as hypertension, heart disease, stroke and blindness. In this paper, what would be studied was a mathematical model of Diabetes Mellitus without genetic factors with treatment, the model used for the approach in this case was in the form of SEIIT. The analysis includes determining the model's equilibrium point, determining the basic reproduction number \( R_0 \) and analyzing the stability around the equilibrium point. Furthermore, numerical simulation using MAPLE was given based on the values of the related parameters in the mathematical model that describes the conditions in each subpopulation class.

Keywords: SEIIT, differential equation, equilibrium point, asymptotically stable.

Introduction
Diabetes Mellitus represents a heterogeneous group of disorders (Boutayeb, at al., 2006). Some can be identified based on the cause or typical pathogenesis, but in many cases this process is not fully understood (Khalda’Aesa, 2020). Diabetes is characterized by hyperglycemia and disturbances of carbohydrate, fat and protein metabolism associated with insulin secretion (Purwoko, at al., 2019). Typical symptoms are excessive thirst (polydipsia), frequent urination (polyuria), frequent hunger (polypagia), pruritus, which is followed by fatigue, lack of energy and the body becomes thin despite eating a lot (Putra, at al., 2013).

In Indonesia, it is estimated that there are 3% – 4% of the total population or almost 6 million people with diabetes (Sutanegara & Budhiarta, 2000). In people with Diabetes Mellitus, it is usually due to the pancreas or stomach salivary glands being unable or insufficient to produce the insulin hormone that the body needs, so that the burning of carbohydrates as fuel for the body is less than perfect. This can lead to an increase in glucose (sugar) levels in the blood (Soewondo & Pramono, 2011). Glucose levels in the blood that are more than the normal limit, will be excreted through urine. The urine of a diabetic patient that has not been handled carefully will contain glucose (Ali sjahbana, at.al., 2006).

Diabetes Mellitus is classified into two main categories: Type 1 Insulin Dependent Diabetes Mellitus (IDDM) and Type 2 Non Insulin Dependent Diabetes Mellitus (NIDDM) (Tisch & McDevitt, 1996). Type 1 (IDDM) is a condition in which the body is unable to produce its own insulin, so insulin injections are needed (Atkinson & Maclaren, 1994). Type 2 diabetes (NIDDM) occurs because the beta cells of the pancreas do not produce enough insulin, causing the liver, muscle and fat do not react properly to the insulin produced in the minimum amount (Hales & Barker, 1992).

The hadith of the Prophet Muhammad that, narrated from Abu Huraira, Rasulullah said: “There is no disease that Allah has created, except Allah has created a cure”. We were interested in studying the mathematical model of Diabetes Mellitus without genetic factors with treatments modeled in the form of SEII\(_T\) (Brauer and Castillo-Chaves, 2011), (Driessche, 2002). The model would search for a disease-free equilibrium point and an endemic equilibrium point, the value of Basic Reproduction Number \( R_0 \), then analyze the stability of the disease-free equilibrium point and the endemic equilibrium point and perform numerical simulations using MAPLE (Murray, J.D. 1993).

Results and Discussion

The assumptions used to form the mathematical model are as follows: the birth rate in the population is the same as the death rate, the effect of migration was...
ignored that the spread of disease is closed in a
population, there were no genetic factors that affect the
spread of Diabetes Mellitus.

The positive parameters used are: the recruitment rate
(birth rate) in the population is expressed by \( A \).
The natural death rate is expressed by \( \mu \). The infection
contact rate of susceptible individuals to latent
individuals is expressed by \( \beta \). The rate of transfer of
latent individuals to sick individuals without treatment
is expressed by \( \alpha \gamma \). The rate of transfer of latent
individuals to sick individuals in the presence of
treatment is expressed by \( \alpha \gamma \). The death rate due
to disease without treatment is expressed by \( \delta_1 \). The rate
of death due to disease in the presence of treatment
is expressed by \( \delta_2 \).

Based on the assumptions formed, the appropriate model is the \( I_T \)
model. To obtain a suitable model, the transfer
diagram is given in Figure 1.

\[
\begin{align*}
\frac{dN}{dt} &= A - \mu N - \delta_1 I - \delta_2 I_T \\
\frac{dE}{dt} &= \beta (N - E - I - I_T) E - \mu E - E \\
\frac{dI}{dt} &= \alpha \gamma E - (\mu + \delta_1) I \\
\frac{dI_T}{dt} &= (1 - \alpha \gamma) E - (\mu + \delta_2) I_T
\end{align*}
\]

\[(2)\]

The mathematical model of Diabetes Mellitus
without genetic factors with treatment has two
equilibrium points, namely the disease-free equilibrium
point \( P_0 = (I_T^*, 0, 0, 0) \) and the endemic equilibrium point
\( P_1 = (N^*, E^*, I^*, I_T^*) \), where

\[
\begin{align*}
N^* &= \frac{A - \delta_1 \alpha \gamma \mu (\beta A - \mu - \mu^2)}{\mu (\mu + \delta_1) \beta (1 + \mu)} \\
E^* &= \frac{A \beta - \mu (1 + \mu)}{\beta (1 + \mu)} \\
I^* &= \frac{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)}{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)} \\
I_T^* &= \frac{(1 - \alpha \gamma) \beta (\mu + \mu^2 + \mu \delta_1)}{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)}
\end{align*}
\]

The endemic equilibrium point \( P_1 \) exists, if \( R_0 > 1 \).
The basic reproduction number \( (R_0) \) in this disease
model was

\[
R_0 = \frac{\beta A}{\mu (1 + \mu)}
\]

Furthermore, the stability will be analyzed at each
equilibrium point. The Jacobian matrix for the
mathematical model of Diabetes Mellitus without
genetic factors with treatment was

\[
J_f(x) = \begin{bmatrix}
-\mu & 0 & -\delta_1 & -\delta_2 \\
\beta E & \beta (N - 2E - I - I_T) - \mu - 1 & -\beta E & -\beta E \\
0 & \alpha \gamma & (\mu + \delta_1) & 0 \\
0 & 1 - \delta_1 & 0 & -(\mu + \delta_2)
\end{bmatrix}
\]

For diseases \( P_0 = (I_T^*, 0, 0, 0) \) and \( P_1 =
(N^*, E^*, I^*, I_T^*) \), where

\[
\begin{align*}
N^* &= \frac{A - \delta_1 \alpha \gamma \mu (\beta A - \mu - \mu^2)}{\mu (\mu + \delta_1) \beta (1 + \mu)} \\
E^* &= \frac{A \beta - \mu (1 + \mu)}{\beta (1 + \mu)} \\
I^* &= \frac{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)}{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)} \\
I_T^* &= \frac{(1 - \alpha \gamma) \beta (\mu + \mu^2 + \mu \delta_1)}{\beta (\mu + \mu^2 + \delta_1 + \mu \delta_1)}
\end{align*}
\]

For the case of \( P_1 \) obtained a negative eigenvalue
for \( R_0 > 1 \) so that the endemic equilibrium point of \( P_1 \)
is locally asymptotically stable. While for \( P_0 \) obtained
eigenvalues $\lambda_1 = -\mu$, $\lambda_2 = -\mu - \delta_1$, $\lambda_3 = -\mu - \delta_2$ and $\lambda_4 = \beta \frac{\alpha}{\mu} - 1 - \mu$. Because all the parameters used are positive, then for $R_0 < 1$ point $P_0$ is local asymptotically stable and if $R_0 > 1$ then $P_0$ is unstable.

Simulation was done by assigning values to each parameter according to $R_0$. This simulation was given to provide a geometric picture of the existence and stability theorem of the equilibrium points of this model.

Based on the explanation of the meaning of the parameter values, the value of $A$ was the recruitment rate (birth rate) in the population, the value of $\mu$ the natural death rate, the value of $\beta$ the rate of infective contact of susceptible individuals to latent individuals, the value of $\alpha \gamma$ the rate of transfer of latent individuals to sick individuals without treatment, the value $(1 - \alpha \gamma)$ of the rate of transfer of latent individuals to sick individuals with the treatment, the value of $\delta_1$, the rate of death from disease without treatment and the value of $\delta_2$, the rate of death from disease with the treatment.

It is assumed that the individual death rate was 63 years, then

$$\mu = \frac{1}{63 \times 12} = 0.00132, \beta = 0.0009$$

This means that there are 9 susceptible individuals who become latent if there were 1000 susceptible individuals who come into contact with latent individuals, it was assumed that the rate of transfer of latent individuals to sick without treatment, the value $(1 - \alpha \gamma)$ of the rate of transfer of latent individuals to sick individuals with the treatment, the value of $\delta_1$, the rate of death from disease without treatment and the value of $\delta_2$, the rate of death from disease with the treatment.

A. Simulation for $R_0 < 1$

Simulation for $R_0 < 1$, given the parameter values, i.e.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $A$       | 1     | $\delta_2$ | 0.00134 |
| $\mu$     | 0.00132 | $\beta$ | 0.0009 |
| $\delta_1$ | 0.00139 | $\alpha \gamma$ | 0.004 |

From the parameter values that had been given, the value of $R_0 = 0.68$ was obtained. So that one equilibrium point is obtained when $R_0 < 1$, namely the point $P_0 = (\frac{A}{\mu}, 0, 0, 0)$ locally asymptotically stable. To illustrate the conditions in class $N(t)$, $E(t)$, $I(t)$ and $I_I(t)$ graphs were presented in Figure 2 and Figure 3.

In Figure 2 and Figure 3, respectively, $N(t) \to \frac{A}{\mu}$ means that with increasing time the number of individuals in the vulnerable population will reach the equilibrium point of $N(t)$, $E(t) \to 0$, $I(t) \to 0$, and $I_I(t) \to 0$ means that the number of individuals in each population will decrease over time.

B. Simulation for $R_0 > 1$

Simulation for $R_0 > 1$, given the parameter values, i.e.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $A$       | 2     | $\delta_2$ | 0.00134 |
| $\mu$     | 0.00132 | $\beta$ | 0.0009 |
| $\delta_1$ | 0.00139 | $\alpha \gamma$ | 0.004 |

From the parameter values that had been given, the value $R_0 = 1.36$ was obtained. So that we get 2 equilibrium points when $R_0 > 1$, namely point $P_0 = (\frac{A}{\mu}, 0, 0, 0)$ unstable and $P_1 = (N^*, E^*, I^*, I_I^*)$ asymptotically stable local. To illustrate the conditions in classes $N(t)$, $E(t)$, $I(t)$ and $I_I(t)$ graphs are presented in Figure 4, Figure 5, Figure 6, and Figure 7.
Latent individuals would always be present in the population due to infective contact for subpopulations $S(t)$ and $E(t)$. From Figure 6, it is obtained that $I^*(t) \rightarrow I_0^*(t) = 0.8$ means that the number of sick individuals will always exist in the population because there are still individuals who have bad habits. From Figure 7, it was obtained that $I_0^*(t) \rightarrow I_0^*(t) = 200$ means that the number of individuals who were sick with treatment will always exist in the population because there are still individuals who had bad habits.

**Conclusion**

From the above presentation, it was obtained

1. The value of Basic reproduction number ($R_0$) for the model of Diabetes Mellitus without genetic factors with treatment was $R_0 = \frac{\beta A}{\mu(\mu+1)}$.

2. The mathematical model of Diabetes Mellitus without genetic factors with treatment had two equilibrium points, namely:
   a. Disease-free equilibrium point $P_0 = \left( \frac{A}{\mu}, 0, 0, 0 \right)$.
   b. Titik ekuilibri mendemik $P_1 = (N^*, E^*, I^*, I_t^*)$ dengar.
   c. The equilibrium point is $P_1 = (N^*, E^*, I^*, I_t^*)$ with,
      
      - $N^* = \frac{A}{\mu} - \frac{\delta_1 a y (A - \mu - \mu^2)}{(\mu + \delta_1)\beta(1 + \mu)} - \frac{\delta_2 (1 - ay) (A - \mu - \mu^2)}{(\mu + \delta_2)\beta(1 + \mu)}$
      
      - $E^* = \frac{Aa y (A - \mu - \mu^2)}{\beta(1 + \mu)}$
      
      - $I^* = \frac{a y (A - \mu - \mu^2)}{(\mu + \delta_2)\beta(1 + \mu)}$
      
      - $I_t^* = \frac{(1 - ay) (A - \mu - \mu^2)}{(\mu + \delta_2)\beta(1 + \mu)}$

3. The disease-free equilibrium point $P_0 = \left( \frac{A}{\mu}, 0, 0, 0 \right)$ was locally asymptotically stable with the condition that $R_0 < 1$, and the endemic equilibrium point $P_1 = (N^*, E^*, I^*, I_t^*)$ local asymptotically stable with condition $R_0 > 1$.

**References**

Boutayeb, A., Chaetouani, A., Achouyab and E.H. Twizell. 2006. A Non-Linear Population Model of Diabetes Mellitus. Korea.

Khalda’Asa, L. (2020, April). Mathematical Modeling Effect Habbatussauda on Diabetes Mellitus. In Proceeding International Conference on Science and Engineering (Vol. 3, pp. 379-382).

Purwoko, A. E., Astuti, I., Asdie, A. H., & Sugiyanto, S. (2019). Effect of Soybean-based Food Supplement on Insulin and Glucose Levels in Type 2 Diabetes Mellitus Patients. Indonesian Journal of Pharmacy, 30(3), 208.

Putra, W. H. N., Samo, R., & Sidiq, M. (2013, November). Weighted ontology and weighted tree similarity algorithm for diagnosing diabetes mellitus. In 2013 International Conference on Computer, Control, Informatics and Its Applications (IC3INA) (pp. 267-272). IEEE.
Sutanegara, D., & Budhiarta, A. A. G. (2000). The epidemiology and management of diabetes mellitus in Indonesia. Diabetes research and clinical practice, 50, S9-S16.

Soewondo, P., & Pramono, L. A. (2011). Prevalence, characteristics, and predictors of pre-diabetes in Indonesia. Medical Journal of Indonesia, 20(4), 283-94.

Alisjahbana, B., Van Crevel, R., Sahiratmadja, E., Den Heijer, M., Maya, A., Istriana, E., ... & Van Der Meer, J. W. M. (2006). Diabetes mellitus is strongly associated with tuberculosis in Indonesia. The International Journal of Tuberculosis and Lung Disease, 10(6), 696-700.

Tisch, R., & McDevitt, H. (1996). Insulin-dependent diabetes mellitus. Cell, 85(3), 291-297.

Atkinson, M. A., & Maclaren, N. K. (1994). The pathogenesis of insulin-dependent diabetes mellitus. New England journal of medicine, 331(21), 1428-1436.

Hales, C. N., & Barker, D. J. (1992). Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. Diabetologia, 35(7), 595-601.

Brauer, F., and Castillo-Chaves, C. 2011. Mathematical Models in in Population Biology and Epidemiology, Text in Applied Mathematics 40, Springer-Verlag, New-York.

Driessche, P., Watmough, J. 2002. Reproduction Numbers and Sub-threshold Endemic Equilibria for Compartmental Models of Disease Transmission, Journal of mathematical Bio-Sciences. 180, 29-48.

Murray, J.D. 1993. Mathematical Biology 2nd Edition. Springer-Verlag. Berlin.
