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Dynamic Modelling of Boosting the Immune System and Its Functions by Vitamins Intervention

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Abstract: The purpose of this paper is to demonstrate numerically the effect of modern diet on the functions of the immune system such as modifying, identifying and inhibiting the pathogens in an unhealthy model by the intervention of vitamins within thirty days. This paper used ordinary differential equations to formulate the model which contains two populations: one of normal cells in the presence of immune cells and the other with variables of vitamins as external factors. The paper proved that switching back to a healthy diet from a modern pattern diet resulted in a decrease in the percentage of deadly diseases as well as prevention from rapid growth of pathogens. In conclusion, the immune system functionality is directly proportional to the type of diet consumed. In the case of the Western-style diet, it has a detrimental effect on the immune system.

Keywords: *dietary; weakened immune system; boost immune system; vitamins consumption; nonlinear dynamic system.*

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1 Introduction

Processed food diet is characterized by a high consumption of proteins (especially meats), sugar, salt and fat comparatively to a healthy diet comprising of an intake of fruit and vegetables [1–3]. This diet is quite common around the world and contributes heavily in the development of fatal diseases. Pre-clinical experiments indicate that a high fructose and protein diet causes cancer, insulin resistance, impaired control and damages the immune system [4–6].

A protein is one of the main macronutrients essential for immunity and general health if taken in proper quantities. The studies found mortality rate in younger people who consume more than 20% calories from protein increased to 75% whereas the percentage of people dying by cancer had increased fourfold as compared to people who imbibe less than 10% calories from proteins [7]. Other studies observed the increase in death rate associated with a diet based on animal products and a high intake of carbohydrates; contrarily, a vegetable-based diet and a low carbohydrate intake reduced the mortality rate. Furthermore, malnutrition debilitates the immune system and increases mortality rate as well as elevates the risk of contacting lethal diseases [8].

Vitro studies have revealed that simple sugars reduce the white blood cells (phagocytes) and may elevate the inflammatory cytokines in the blood [9, 10]. Whereas a salty diet is associated with a risk of gastric cancer [11]. The salt in the diet causes a sodium and potassium imbalance, which can further cause a detrimental effect on the kidneys [12]. Retaining salt in the body also predominates risks of weight gain [13]. A fatty diet alters the lipids of the immune cells membranes and disrupts their function [14, 15].

In addition, the intake of a high fiber diet is associated with a lower risk of not only cardiovascular diseases but also cancer and respiratory diseases as well as infectious diseases. Nutritionists recommend an intake of 25-38g of fiber per day. This average is reduced further along the societal chair [16]. It is also noted that the Africans in rural areas consume more fiber than Western people [1]. Notably, Western people have a higher chance of obesity which is directly proportional to their diet which is mainly characterized by a heavy intake of processed foods, fatty foods and a reduced intake of nutrient rich foods as fruit and vegetables [17].

The immune system plays a huge role in the defence against carcinomas. Mathematical models are used to describe how the immune system defends by inhibiting cancer cells. Researchers propose that the interaction between immune cells and the target population such as viruses, bacteria, antigens and malignant cells is a dynamic process. Marey and others succeeded to formulate a model by using ordinary differential equations to portray this process [18]. Other researchers showed that the chance of developing fatal diseases is reduced for a person who follows a healthy diet which is related to food pyramid and vice versa [19].

Mathematical models are also used for prognosis and treatment plans for cancer [20, 21]. Tumor growth is a constant population in any mathematical model where cancer is studied. Several mathematical models use differential equations to prepare tumor-immune model interaction with radiation and chemotherapy [22–25]. Others focus on lifestyle and estrogen as culprit for developing cancer, especially malignant cancer in women [26–28]. Since normal cells can divide 50-60 times before dying ones, it can sometimes lead to the development of abnormal cells and cancer can occur in such a case. Thus, the mathematical model in this paper is formulated to understand the response of the immune system to prevent the growth of abnormal cells.

In this busy modern era, people are highly dependent on the Western-style diet consisting of fast food, cans and even frozen products which are readily available anytime and everywhere. One of the transparent reasons for this paper is to highlight the disadvantages of the Western-style diet to the function of the immune system. It also discusses one of the possibilities to increase the response of the immune system by modifying the diet pattern along with the intervention of vitamins within the first thirty days.

2 Materials and Methodology

Ordinary differential equations are used to describe the interaction between two populations: normal cells which begin to divide as abnormal cells and immune cells which respond to this action. The first model is formulated as

$$\begin{aligned} \frac{dN}{dt} &= rN(1-\beta N) - \eta IN, \\ \frac{dI}{dt} &= \sigma + \frac{\rho IN}{m+N} - \delta I - \mu IN, \end{aligned} \tag{1}$$

where $N[0] = 1$ [28] and $I[0] = 1.22$ [29] are initial values. The first equation reveals the change of normal cell population such that N is a normal cell. The parameter r represents the growth rate, and the rate of change from normal cells to abnormal cells during division is given by the parameter β. One of the functions of the immune system is to engulf and eliminate pathogens to prevent the body from developing cancer, which is represented by η. The second equation expresses the immune efficiency, where I denotes the immune cells. The fixed value of the immune system is represented by σ. The parameter δ is the rate of natural death of the immune cells, where the immune cells usually die off after thirty days. The term $\frac{\rho IN}{\omega+N}$ exhibits the Michaelis-Menten model of the immune cells, where ρ presents the growth of the immune cells stimulated by abnormal cells and m is the threshold rate of the immune cells. Finally, the reaction between abnormal cells and immune cells leads to a reduction in the number of immune cells, and this decrease is given by μ. All values of these parameters are identified in the literature, see Table 1.

Furthermore, the modification of the model, given the intervention of vitamins in thirty days as an external factor affecting both normal and immune cells and its improvement, is given by

$$\begin{aligned} \frac{dN}{dt} &= rN(1-\beta N) - \eta IN + c_1 VN, \\ \frac{dI}{dt} &= \sigma + \frac{\rho IN}{m+N} - \delta I - \mu IN + c_2 VI, \\ \frac{dV}{dt} &= k_1 + k_2 V, \end{aligned} \tag{2}$$

where the initial conditions are $N[0] = 1$ [28], $I[0] = 1.22$ [29] and $V[0] = 2$, the intervention of vitamins is denoted by V. The positive constants c_1 and c_2 show the interaction between vitamins, normal cells and immune cells, respectively. The constant rate of vitamins is represented by k_1 and the constant k_2 denotes the decreased rate of vitamins due to the reactivity between cells.

Parameter	Value	Definition and reference
r	0.431201	Rate of growth of normal cells [31]
β	$2.99 * 10^{-6}$	Rate of turn of normal cells to abnormal cells [32]
η	0.2	Rate of repaired abnormal cells [25]
σ	0.7	Fixed of immune source [33]
δ	0.57	Rate of natural death of immune cells[evaluate]
ρ	0.003	Response rate of immune cells [34]
m	0.427	Threshold rate of immune cells [33]
μ	0.82	Rate of decreasing of immune cells as a result
		of interaction with abnormal cells [31]
a	0.7	Amplitude of immune alteration [33]

Table 1: Parameters of the model and references.

3 Parameters Values

These models examine the ability of the immune system in preventing the body from pathogens without treatment. In order to achieve the aim of this paper, the values of the parameters should be selected under special conditions. The behaviour of these models has a significant relation to the parameters which demonstrate the result of an active immune system when the pathogens attack the body in the presence of abnormal cells where these parameters are represented by μ and η.

Firstly, there are no conditions for normal cells selection, where normal cells can choose any value. For example, the initial value of normal cells in [28,30] used $N(0) = 1$ and [31] used $N(0) = 10^5$. Whereas the immune cells are especially selected in the case of a weakened immune system without any medication. For that reason, the initial value of the immune cells is selected from [29], where the main problem with a HIV patient is a weakened immune system. Then, the value which is published in [29] is close to the case study of this model. In view of the fact that the initial values of vitamins can be used for intervention, their parameters and their effect on response of the immune system and growth of normal cells are based on the hypotheses of the model (1).

Secondly, the evaluation of the rate of growth of normal cells is by reference to the results of the experiment which is illustrated in [31] where the number of cells is examined for one week. During the process of the division and growth of normal cells there is a chance for abnormal division, then the rate of turn of the normal cells to abnormal cells is given in [32]. Whereas it is difficult to find a similar study which relates to the immune cells but it can also be assumed that the rate of growth of the immune cells follows the immune efficiency which is published in [33]. The growth of immune cells in this study should be close to the immune efficiency to satisfy the hypothesis of models which describes the effect of a change in dietary pattern to be close to a Western-style diet which causes a weakened immune system. Then, it is easy to evaluate the rate of death of the immune cells as in reference [28]. The response of immune cells also should reduce as given in [34] and the threshold rate of the immune system is evaluated by using the following function $m = (\sigma - \rho t)a$, where t=30 years.

Finally, the parameters η and μ describe the behaviour of both normal cells, abnormal cells and immune cells when a pathogen attacks the body. The first parameter η

associates with the ability of immune cells in engulfing and attacking the abnormal cells. This process occurs automatically if the immune cells are absolutely healthy and its activity diminishes if the body has a weakened immune system. That means the function of immune system stimulates when the abnormal cell appearance, and the rate of this stimulation is illustrated in [25]. As a result of this process, the number of immune cells will decreased. Thus, by reference to [31], it can use the same parameter of reapplication of normal and precancerous cells where the difference is between definitions relating to the building of models. Furthermore, in this paper, the parameter of μ should be greater than η where the model formulates assuming immune efficiency.

4 Numerical Simulation

The immune system can engulf and inhabit the pathogens as well if and only if the body has a strong immune system. Then, to modify the response of the immune system in the model (1) the parameters η and μ should satisfy the following inequality:

$$\text{The rate of parameter } \eta \geq \text{ The rate of parameter } \mu.$$

The diet pattern and lifestyle (as physical activity and irregular sleep) are risk factors of the immune system. This paper is focusing on the effect of switching back to a healthy diet from the Western-style diet by consumption a regular rate of vitamins on modifying the response of the immune system in the model (1). Thus, we are simulating the parameters c_1, c_2, k_1, k_2 that are related to the effect of vitamins intervention. These parameters should satisfy the following inequalities:

$$\text{The rate of parameter } k_2 > \text{ The rate of parameter } k_1,$$

$$\text{The rate of parameter } c_1 + \text{ The rate of parameter } c_2 \leq \text{ The rate of parameter } k_2.$$

Hence, the correlation between the vitamins intake and the behaviour of the immune system and normal cells is indicated by the model (2). Here, we are simulating the specified parameters as follows

$$\eta = 0.733, \mu = 0.312, c_1 = 0.261, c_2 = 0.231, k_1 = 0.164, k_2 = 0.960.$$

Hence, the numerical result of the modification of model (1) showed that the intervention of vitamins can boost the immune system and control the division of normal cells. Thus, it prevents the development of the pathogens.

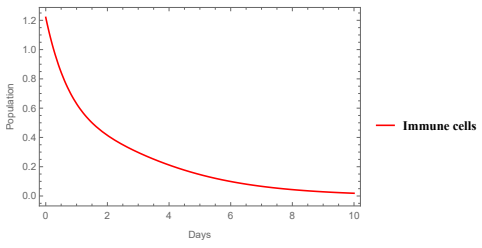

Figure 1: The behaviour of the immune system with unhealthy diet pattern within 10 days.

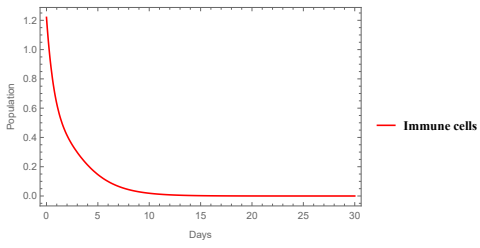

Figure 2: The behaviour of immune system with unhealthy diet pattern within 30 days.

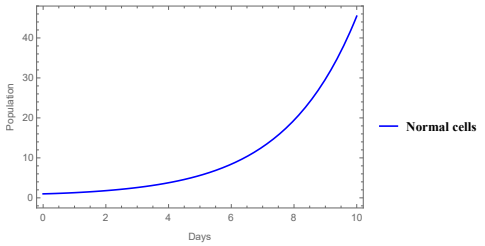

Figure 3: The behaviour of the normal cells with unhealthy diet pattern within 10 days.

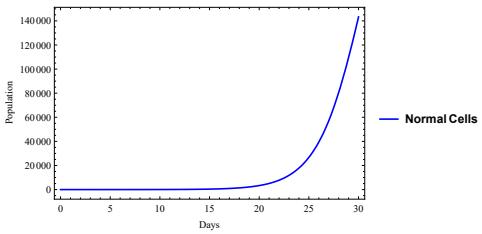

Figure 4: The behaviour of the normal cells with unhealthy diet pattern within 30 days.

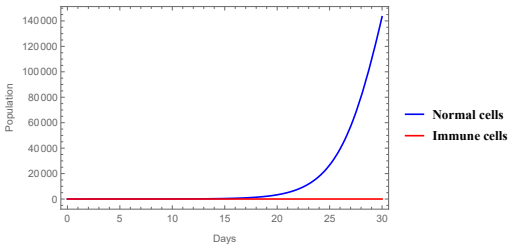

Figure 5: The behaviour of the model with unhealthy diet pattern within 30 days.

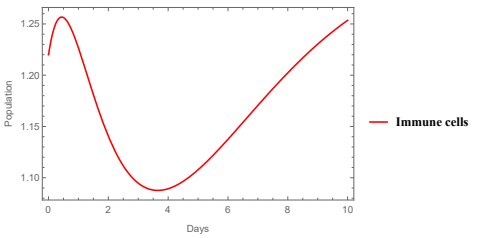

Figure 6: The behaviour of the immune system with modification of diet within 10 days.

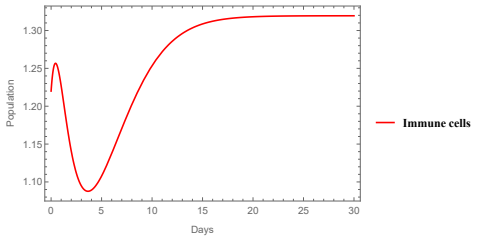

Figure 7: The behaviour of immune system with modification of diet within 30 days.

5 Results and Discussion

This paper used Mathematica 10.0 software to solve the nonlinear ordinary differential equations which described the behaviour of a weakened immune system and of that normal cells when a body is attacked by pathogens and abnormal division of cells took place. This type of division could lead to an emergence of carcinoma cells.

The numerical solution of an unhealthy model (an unhealthy diet as the Western-style diet) demonstrated the decrease in immune cells to zero within the first ten days from the appearance of abnormal cells, Figures 1, 2. This means that the immune system had a negative response and the immune cells (T cells and natural killer cells NK cells) were untenable to engulf and fight the abnormal cells. Furthermore, it may encourage the normal cells to divide and become cancerous cells. The result of previous studies such as [5, 6] support our idea that the Western-style diet

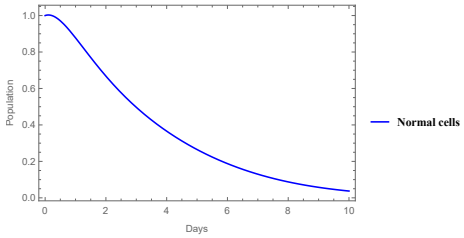

Figure 8: The behaviour of the normal cells with modification of diet within 10 days.

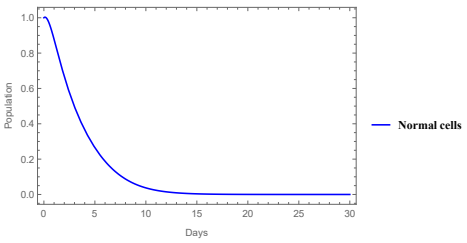

Figure 9: The behaviour of normal cells with modification of diet within 30 days.

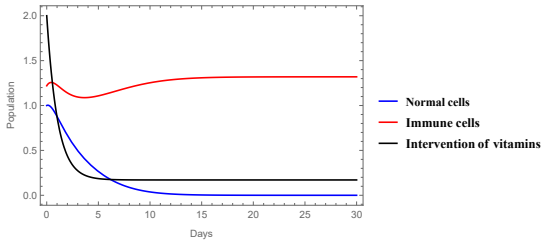

Figure 10: The behaviour of the model with modification of diet pattern within 30 days.

leads to an increase in the rate of glucose and insulin in the blood, thus causing abnormal cells to divide and grow as tumor cells.

Not only this, but the unhealthy diet has a significant impact on the behaviour of normal cells in the presence of abnormal cells in the body and the function of immune system may further weaken. The numerical solution showed that the population of normal cells elevated to 46 cells within the first ten days (Figure 3) and reached to 145000 cells approximately at the end of twenty days, Figure 4 indicated that the normal cells started to divide and grow without control. Sometimes, this way of division may cause cancer, where the growth and division of cells play an important role in protecting a human from cancer [30, 35]. The model of the unhealthy diet is illustrated in Figure 5.

Modification in the diet pattern reduces or delays the growth of tumor cells [36, 37]. In the unhealthy model, improvement was seen when intervened by vitamins. The numerical solution revealed that the intervention by vitamins affected both immune cells and normal cells. In this case, the vitamins stimulated the immune cells to increase and reach to 1.26 cells in the first day and the population of cells decreased dramatically to 1.9 cells on the fourth day. Following that, immune cells increased gradually until reaching 1.26 cells on the tenth day, Figure 6. The population of immune cells became stable at 1.32 cells, Figure 7 during the last twenty days. This result is identical to the findings of nutritionists that vitamins play an important role in boosting the immune system and supporting its functions [38, 39].

Moreover, a significant impact was observed on normal cells under the influence of vitamins. They were stable within the first twelve hours of the vitamins intake, then started to dramatically decrease to 0.1 cells in the first ten days, Figure 8. After that, the population of normal cells gradually decreases to zero within the last twenty days, Figure 9. This modification of unhealthy model is shown in Figure 10. So, an increased level of glucose, insulin resistance, obesity and cancer are disadvantages of the Western-style diet consumption. Previous studies found that

supplementation with vitamins D and C can improve glucose control and decrease serum insulin [40–43]. Other benefits of vitamin C are adipocyte lipolysis, which reduces the inflammatory response, preventing glucose metabolism, and secretion of leptin can isolate adipocyte [44–46]. Thus, consumption of vitamins can help to inhibit active abnormal cells into turning tumor cells indirectly.

Eventually, there is a complex relationship between dietary patterns and functions of the immune system which needs to be studied extensively. Our findings in this paper revealed numerically that there is a strong association between modification of the dietary pattern, boosting of the immune system and the division and growth of cells.

6 Conclusion

This paper illustrated that a modern diet (a Western-style diet) had an impact on the immune system function and the division of the normal cells when the pathogen had begun to attack the body. Consumption of a supplementary diet enabled a boost in the immune system and increased recognition of abnormal cells as foreign cells and helped eliminate them as well. Furthermore, an intake of vitamins played a huge role in getting the division of normal cells under control. Thus, an awareness must be put in motion of the concept of a healthy diet for all, especially the youth, for protecting against diseases and reducing the mortality rate due to common lethal diseases, particularly cancer.

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