



Research Article

Modeling Diabetic Neuropathy in Type 2 Diabetes Patients via the Absorbing Markov Chain in Techiman Municipality, Ghana

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Abstract

Diabetes is one of the top ten diseases that causes death, and it has become a major concern in many countries, with type 2 diabetes accounting for 96% of diabetes cases. The progression of type 2 diabetes to neuropathy is a complex process influenced by various factors, including glycemic control, duration of diabetes, and individual characteristics. Absorbing chains are one of the applications of Markov chains, which are used to determine how long patients remain in a transient state before they are absorbed. The study objective was to predict the mean sojourn time (average time) that type 2 diabetic patients live with the disease before they enter the absorbed state (i.e., amputation of the limbs or death). Fasting blood sugar levels and neuropathy conditions developed by type 2 diabetic patients were divided into eight states. The states were further classified into transient and absorbing states, where States 1-6 (low FBS, normal FBS, moderate FBS, high FBS, and numbness) formed transient states, and States 7 and 8 were absorbing states (amputation of limbs and death). The results revealed that the average time for patients with a low FBS state to stay with the disease before their limbs are amputated or to die is 14 years, and the average time for those with normal and moderate FBS states is 27 years each. Patients in the high and numbness states have average stay times of 26 and 23 years, respectively, to live with the disease before their limbs are amputated or they die. However, patients in the ulcer state have an average of two years to live with the disease before their limbs are amputated or die. In conclusion, patients' condition deteriorates gradually as they transition to the complication stage, and patients are more likely to have their limbs amputated or die.

Keywords

Markov Chain, Neuropathy, Transition, Fasting Blood Sugar Level, Transient States, Absorbed States

1. Introduction

1.1. Background and Review

Diabetes is a non-communicable disease whose origin dates back to the seventeenth century. The earliest records of diabetes were from the Egyptians, and it was characterized by

weight gain and frequent urination. The term "mellitus" was introduced by the English anatomist and physician Thomas Willis to describe the sweet flavor of urine in individuals with diabetes [1].

Diabetes mellitus (DM) is a long-term metabolic condition

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characterized by elevated blood sugar levels, which can lead to significant harm to the kidneys, heart, blood vessels, eyes, and nerves. Approximately 422 million individuals are affected by diabetes globally, with a significant portion residing in lower- and middle-income nations; annually, approximately 1.5 million people succumb to diabetes-related complications [2]. According to the International Diabetes Federation (IDF), 537 million people are living with diabetes, and this number is expected to rise to about 643 million and 783 million in 2045. Approximately 6.7 million deaths from diabetes were recorded in 2021, Sun et al. [3]. Recently, the number of diabetes cases has increased globally, positioning it among the top ten leading causes of death.

The Institute for Health Metrics and Evaluation (2023) has projected that the number of diabetes cases worldwide will increase from 529 million to 1.3 billion by 2050, resulting in a worldwide prevalence rate of 6.1%. In 2011, more than 371 million individuals around the world were diagnosed with diabetes, with an anticipated 7.7% increase by 2030 [4]. This rise is particularly significant in urban areas of sub-Saharan Africa (SSA), where diabetes rates are expected to double.

The prevalence of type 2 diabetes mellitus (T2DM) in Africa has increased to 4.9%, with a significant majority of cases occurring in individuals under 60 years of age [5]. In Ghana, this epidemic affects at least 6% of the adult population, with strong correlations with age and obesity. Approximately 23% of adults are classified as overweight, driven by factors such as advanced age, female sex, urban living, higher income, and tertiary education. Furthermore, epidemiological data demonstrate that the interplay of acculturation, urbanization, and genetic predispositions plays a crucial role in the prevalence of T2DM among Ghanaians [6]. Also, the prevalence of diabetes in Ghana ranges from 3.3% to 8.3% [7] and this is linked to moderate and high socio-economic status, advanced age, and low physical activity among adults [8].

Diabetes complications are classified into microvascular and macrovascular categories. Microvascular complications are the most common and result from persistent exposure to hyperglycaemia [9]. Peripheral neuropathy is a microvascular complication caused by nerve damage and affects 1% of adults with diabetes [10]. One out of three diabetic patients is affected by peripheral neuropathy [11]. Diabetic neuropathy is significantly linked to HbA1c levels and other factors such as poor glycaemic control, advanced age, and duration of diabetes [12]. Patients who consume alcohol have a higher risk of developing complications than non-consumers [13]. Diabetic neuropathy is a serious complication that increases patient morbidity and reduces quality of life [14].

1.2. Statement of the Problem

T2DM is a significant health problem with increasing prevalence worldwide. In urban Ghana, the prevalence rate of T2DM was high among adults aged 40–60 years. Almost 23% of these adults are overweight, which can be attributed to advanced age,

female sex, the urban environment, high income, and tertiary education [6]. T2DM incidence has increased exponentially in developing countries and modernized populations, where patients face multiple risk factors, some of which include the development of microvascular and macrovascular complications, life-threatening complications, and financial burdens in treating the disease. [15].

Although some studies have been conducted on the complications of this disease in urban areas in the country, the associated risk factors, hospitalization trends, etc., have been explored in this study, a different methodological approach, the use of Markov chains to predict the average time patients with type 2 diabetes live with the disease before their limbs are amputated or they die of the disease, has been used. Knowledge of the average duration of stay is crucial for health practitioners and patients in the prevention and treatment of diabetes or its related complications.

1.3. Objective of the Study

The objective of this study was to model the neuropathy progression of type 2 diabetes patients to absorbed states.

1.4. Specific Objectives

- 1) To determine the average time patients stay with the disease in each of the transient states.
- 2) To determine the overall average time patients stay with the disease in the transient state before their limbs are amputated or they die of T2DM.
- 3) Find the probabilities of a patient's limb being amputated or a patient dying in the absorbed state.

2. Methodology

2.1. Study Design

This retrospective study examined 131 T2DM patients who visited the diabetic clinic at the Holy Family Hospital in Techiman Municipal from October 2022 to October 2023. Data on fasting blood sugar (FBS) levels and other neuropathy conditions were collected from 131 T2DM patients from October 2022 to October 2023. The data were analyzed and classified into eight states, with States 1-6 classified as transient and States 7--8 classified as absorbing.

2.2. Ethics Approval and Consent

Permission was sought from the hospital, and Approval was given to use the data, which was already in existence, to be used for this research. This manuscript is a product of a thesis reviewed and passed by the University of Cape Coast Graduate School review board. Data was authorised and cleared using standard procedures of the Directorate of Ghana Health

Service, and permission was granted by the Holy Family Hospital in Techiman, Ghana.

2.3. Absorbing Markov Chains

A Markov chain is an absorbing chain if it is impossible to leave a state once it is entered (i.e., $P_{ii} = 1$). In an absorbing Markov chain, there is at least one absorbing state, and it is

possible to enter an absorbing state from any of the transient states (not necessarily in one step).

A transient state is a state where when a patient leaves, the probability of the patient returning to the same state is less than one. Let us consider that there are $(s-m)$ transient states $(t_1, t_2, \dots, t_{s-m})$ and m absorbing states $(a_1, a_2, \dots, a_m)$; then, we have a transition probability matrix as shown in P :

$$P = \begin{matrix} & \begin{matrix} t_1 & t_2 & \dots & t_{s-m} & a_1 & a_2 & \dots & a_m \end{matrix} \\ \begin{matrix} t_1 \\ t_2 \\ \vdots \\ t_{s-m} \\ a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} & \begin{bmatrix} q_{11} & q_{12} & \dots & q_{1(s-m)} & r_{11} & r_{12} & \dots & r_{1m} \\ q_{21} & q_{22} & \dots & q_{2(s-m)} & r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \dots & \vdots & \vdots & \vdots & \dots & \vdots \\ q_{(s-m)1} & q_{(s-m)2} & \dots & q_{(s-m)(s-m)} & r_{m1} & r_{m2} & \dots & r_{mm} \\ 0 & 0 & \dots & 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots & 0 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{matrix} \quad (1)$$

Equation (1) can be represented in the canonical form as:

$$P = \begin{bmatrix} Q & R \\ O & I \end{bmatrix} \quad (2)$$

where Q is a $(s-m)$ by $(s-m)$ matrix (a matrix that shows a transition from a transient state to another transient state), R is an $(s-m)$ by m matrix (a matrix that shows a transition from a transient state to an absorbed state), O is an m by $(s-m)$ zero matrix, and I is an m -by- m identity matrix. Thus, Q describes the probability of transitioning from a transient state to another transient state, whereas R describes the probability of transitioning from a transient state to an absorbing state.

From equation (2), the partitioned matrix gives the following matrices:

$$Q = \begin{bmatrix} q_{11} & q_{12} & \dots & q_{1(s-m)} \\ q_{21} & q_{22} & \dots & q_{2(s-m)} \\ \vdots & \vdots & \dots & \vdots \\ q_{(s-m)1} & q_{(s-m)2} & \dots & q_{(s-m)(s-m)} \end{bmatrix} \quad (3)$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \dots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mm} \end{bmatrix} \quad (4)$$

$$O = \begin{bmatrix} 0 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & 0 \end{bmatrix} \quad (5)$$

$$I = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & 1 \end{bmatrix} \quad (6)$$

2.4. Waiting Time and Total Time Spent in Transient States Before Absorption

Let W be the waiting time in transient states before entering the absorbing state:

$$W = (I - Q)^{-1} \quad (7)$$

and

W_t represents the total period spent in the transient state before being absorbed:

$$W_t = (I - Q)^{-1} (1_{s-m}) \quad (8)$$

where

$$1_{s-m} = (1, 1, \dots, 1)' \quad (9)$$

2.5. Absorption Probability

Let AP be the expected absorption probability in the absorbed state; then,

$$AP = WR \quad (10)$$

Equation (10) gives the absorption probability in each state of the absorbed states.

2.6. Classification of the Health Status of Patients into States

The health status of patients was grouped into eight states according to their fasting blood sugar (FBS) levels, neuropathy conditions (numbness, ulcers, and amputation of limbs), and death. Table 1 shows the states of the T2DM patients.

Table 1. States of patients (T2DM).

States	Health status	FBS Level/condition
S1	Low FBS	<3.9 mmol/L
S2	Normal FBS	3.9 - 5.7 mmol/L
S3	Moderate FBS	5.8 - 6.9 mmol/L
S4	High FBS	≥7.0 mmol/L
S5	Numbness	Hyperglycemia

States	Health status	FBS Level/condition
S6	Ulcers	Wounds
S7	Amputation	Loss of limbs
S8	Death	no life

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The data were analyzed via IBM SPSS Staistics 27 and MATLAB R2007b application software.

3. Results and Discussions

3.1. Results

Table 2. Transitions of the health state of patients from 2022-2023.

STATES	1	2	3	4	5	6	7	8	TOTAL
1	0	1	0	1	0	0	0	2	4
2	1	16	5	6	3	0	0	0	31
3	0	4	0	14	1	0	0	0	19
4	2	9	7	40	3	0	0	2	63
5	0	0	0	5	5	1	0	0	11
6	0	0	0	0	0	1	1	0	2
7	0	0	0	0	0	0	1	0	1
8	0	0	0	0	0	0	0	0	0
TOTAL	3	30	12	66	12	2	2	4	131

Table 3. Transition probabilities of T2DM patients from 2022—2023.

STATES	1	2	3	4	5	6	7	8
1	0	0.25	0	0.25	0	0	0	0.5
2	0.032	0.52	0.161	0.194	0.096	0	0	0
3	0	0.211	0	0.737	0.052	0	0	0
4	0.032	0.142	0.111	0.635	0.047	0	0	0.032
5	0	0	0	0.455	0.454	0.091	0	0
6	0	0	0	0	0	0.5	0.5	0
7	0	0	0	0	0	0	1	0
8	0	0	0	0	0	0	0	1

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Table 2 shows the movement of patients from one state to the other within the study period. This influences the probability calculations in Table 3.

The transition probability matrix in Table 3 shows the transition of diabetes patients from one state to another. In the low-FBS state, 25% of patients transitioned to either a normal-FBS state or a high-FBS state, while 50% of them died within the year. In State 2, 52% of T2DM patients remained in their present state (normal FBS), whereas 16% and 19% of them transitioned to moderate and high FBS states, respectively. In State 3, 74% of T2DM patients transitioned to a high-FBS state, and 21% of them moved to a normal state (which indicates an improvement in their condition). However, 5% of them developed numbness in the feet.

In State 4, 64% of patients whose fasting blood sugar levels were above 7 mmol/L (high FBS level) remained in the same condition, and 3% of them died within the year. For patients

who were hyperglycemic and developed numbness of the limbs (State 5), approximately 46% of them regressed to a high FBS state, and 45% of them remained in the same condition.

3.1.1. The Average Time Spent in Each State of the Transition

The transition probability matrix in Table 3 is partitioned into the canonical form:

$$\pi = \begin{pmatrix} Q & R \\ O & I \end{pmatrix} \quad (11)$$

Q represents a transition from a transient state to another transient state and is a 6×6 matrix; R represents a transition from a transient state to an absorbed state and is a 6×2 matrix. O is a zero matrix, and I is the identity matrix (absorbed state).

Table 4. Partitioning of Transition probabilities.

	1	2	3	4	5	6	7	8
1	0	0.25	0	0.25	0	0	0	0.5
2	0.032	0.516	0.161	0.194	0.097	0	0	0
3	0	0.211	0	0.737	0.052	0	0	0
4	0.032	0.143	0.111	0.635	0.048	0	0	0.032
5	0	0	0	0.455	0.455	0.090	0	0
6	0	0	0	0	0	0.5	0.5	0
7	0	0	0	0	0	0	1	0
8	0	0	0	0	0	0	0	1

$$Q = \begin{bmatrix} 0 & 0.25 & 0 & 0.25 & 0 & 0 \\ 0.032 & 0.516 & 0.161 & 0.194 & 0.097 & 0 \\ 0 & 0.211 & 0 & 0.737 & 0.053 & 0 \\ 0.032 & 0.143 & 0.111 & 0.635 & 0.048 & 0 \\ 0 & 0 & 0 & 0.455 & 0.455 & 0.091 \\ 0 & 0 & 0 & 0 & 0 & 0.5 \end{bmatrix} \quad (12)$$

$$R = \begin{bmatrix} 0 & 0.5 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0.032 \\ 0 & 0 \\ 0.5 & 0 \end{bmatrix} \quad (13)$$

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (14)$$

$$O = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

The expected time spent in each state of the transient process, W, is given as:

$$W = (I - Q)^{-1} \quad (16)$$

$$(I - Q) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & 0.25 & 0 & 0.25 & 0 & 0 \\ 0.0323 & 0.5161 & 0.1613 & 0.1935 & 0.0968 & 0 \\ 0 & 0.2105 & 0 & 0.7368 & 0.0526 & 0 \\ 0.0317 & 0.1429 & 0.1111 & 0.6349 & 0.0476 & 0 \\ 0 & 0 & 0 & 0.4545 & 0.4545 & 0.0909 \\ 0 & 0 & 0 & 0 & 0 & 0.5 \end{bmatrix} \quad (17)$$

$$(I - Q) = \begin{bmatrix} 1 & -0.25 & 0 & -0.25 & 0 & 0 \\ -0.323 & 0.4839 & -0.1613 & -0.1935 & -0.0968 & 0 \\ 0 & -0.2105 & 1 & -0.7363 & -0.0526 & 0 \\ -0.0317 & -0.1429 & 0.1111 & 0.3651 & -0.0476 & 0 \\ 0 & 0 & 0 & -0.4545 & 0.5455 & -0.0909 \\ 0 & 0 & 0 & 0 & 0 & 0.5 \end{bmatrix} \quad (18)$$

$$W = (I - Q)^{-1} = \begin{bmatrix} 1.3241 & 3.2793 & 1.2936 & 6.8826 & 1.3072 & 0.2377 \\ 0.6605 & 7.4748 & 2.6743 & 13.2189 & 2.7378 & 0.4977 \\ 0.6354 & 5.9780 & 3.5146 & 13.9544 & 2.6174 & 0.4758 \\ 0.6359 & 5.6424 & 2.5001 & 14.3113 & 2.4911 & 0.4529 \\ 0.5298 & 4.7011 & 2.0830 & 11.9239 & 3.9089 & 0.7106 \\ 0 & 0 & 0 & 0 & 0 & 2 \end{bmatrix} \quad (19)$$

The expected time spent in the transient process of each state is projected in years since the data were collected within one year. Patients who were in State 1 (low FBS) were expected to stay in that condition for one year before moving to the next state in the transient state. If the patient transitions from a low-FBS state to a normal FBS state, he/she is expected to stay in that condition for three years before moving to the next state. However, if a patient transitions from a low-FBS state to either a moderate or high-FBS state, the patient is expected to stay in these states for at least one year or seven years, respectively, before moving to the next state.

Additionally, if a patient is classified in State 2 (normal FBS), s/he is expected to remain at a normal FBS level for approximately seven years before transitioning to any other state. If the patient subsequently transitions to a moderate FBS level or a high FBS level, the patient is expected to stay in these conditions for approximately three years and thirteen years, respectively. However, if a patient transitions from a normal FBS level to a numb state or an ulcer state, s/he is expected to stay in these states for approximately three years and less than one year, respectively.

In addition, a patient who was classified in State 3 (moderate FBS) is expected to stay in that condition for approximately four years before transitioning to any other state of the transient state. If the patient transitions to either a normal FBS or a low FBS state, s/he is expected to spend approximately six years and less than a year, respectively, in these states. Nevertheless, if the patient transitions to either a high-FBS or numbness state, s/he is expected to stay in these states for fourteen years and approximately three years, respectively.

Again, a patient who starts in a high-FBS state has a maximum of fourteen years in that state before transitioning to any other state in the transient state. After that, if the patient transitions to either a normal FBS or a low FBS state, s/he is expected to stay in these states for five years and less than a year,

respectively. However, if the patient transitions to either a moderate FBS or numbness state, the patient is expected to stay in these conditions for approximately three years and two years, respectively.

Additionally, if a patient is classified as being in State 5 (experiencing numbness), the patient is expected to stay in this state for at least four years before transitioning to any other state in the transient state. Afterward, if the patient transitions to a moderate or a high FBS state, then s/he can stay in these states for at least two years and 12 years, respectively. The patient can also stay for less than a year if s/he transitions to low-FBS states. Nevertheless, if the patient transitions to a normal FBS state or an ulcer state, then the patient can remain in these conditions for approximately five years or less than one year, respectively.

Finally, if a patient begins in State 6 (ulcer), the patient does not have a chance of transitioning into any state in transient states but will remain in his/her current condition for two years before being amputated or dying.

3.1.2. Total Time Spent in Transient States Before Absorption

Let W_t be the total time spent in the transient state before being absorbed.

where $t = 1, 2, 3, 4, 5, 6$

Let N be a matrix of ones:

$$N = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \quad (20)$$

$$W_t = WN \quad (21)$$

$$W_t = \begin{bmatrix} 1.3241 & 3.2793 & 1.2936 & 6.8826 & 1.3072 & 0.2377 \\ 0.6605 & 7.4748 & 2.6743 & 13.2189 & 2.7378 & 0.4977 \\ 0.6354 & 5.9780 & 3.5146 & 13.9544 & 2.6174 & 0.4758 \\ 0.6359 & 5.6424 & 2.5001 & 14.3113 & 2.4911 & 0.4529 \\ 0.5298 & 4.7011 & 2.0830 & 11.9239 & 3.9089 & 0.7106 \\ 0 & 0 & 0 & 0 & 0 & 2 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \quad (22)$$

$$W_t = \begin{bmatrix} 14.3244 \\ 27.2639 \\ 27.1756 \\ 26.0337 \\ 23.8572 \\ 2 \end{bmatrix} \quad (23)$$

From equation (14), the average time spent in transient states by patients classified under a low FBS state before they are absorbed (amputation of limbs or death) is 14 years. Patients who were classified into normal FBS and moderate FBS states had an average time of 27 years each in transient states before they either had their limbs amputated or died from their condition. Patients who are in a high-FBS state have an average time of 26 years in a transient state before they enter the absorbed state, where their limbs are either amputated (as a result of slow-healing ulcers spreading to other parts of the

body) or die from the disease. Furthermore, patients who have developed numbness of the feet or hands have a mean sojourn time of 24 years in transient states before they enter the absorbed state. These patients, after 24 years, will either have their limbs amputated or die because of T2DM complications.

Finally, patients who have already developed diabetic ulcers have a mean sojourn time of two years in a transient state before entering an absorbed state. Their condition is expected to worsen in two years; hence, their limb will be amputated because of their condition.

3.1.3. Absorption Probability

The expected absorption probability (EAP) when a patient becomes absorbed in an absorbing state S_j from a transient state S_i is given as:

$$EAP = WR \quad (24)$$

$$EAP = \begin{bmatrix} 1.3241 & 3.2793 & 1.2936 & 6.8826 & 1.3072 & 0.2377 \\ 0.6605 & 7.4748 & 2.6743 & 13.2189 & 2.7378 & 0.4977 \\ 0.6354 & 5.9780 & 3.5146 & 13.9544 & 2.6174 & 0.4758 \\ 0.6359 & 5.6424 & 2.5001 & 14.3113 & 2.4911 & 0.4529 \\ 0.5298 & 4.7011 & 2.0830 & 11.9239 & 3.9089 & 0.7106 \\ 0 & 0 & 0 & 0 & 0 & 2 \end{bmatrix} \begin{bmatrix} 0 & 0.5 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0.0317 \\ 0 & 0 \\ 0.5 & 0 \end{bmatrix}$$

$$EAP = \begin{bmatrix} 0.1188 & 0.8802 \\ 0.2489 & 0.7493 \\ 0.2379 & 0.7601 \\ 0.2264 & 0.7716 \\ 0.3553 & 0.6429 \\ 1 & 0 \end{bmatrix} \quad (25)$$

From the expected absorption probabilities in equation (15), the likelihood that a patient with a low FBS level will have his or her limbs amputated in the absorbed state is 0.1188, and the likelihood that the patient will die in the absorbed state is 0.8802. The probability that patients with normal FBS levels will have their limbs amputated in the absorbed state is 0.2489, and the likelihood that they will die in the absorbed state is 0.7493. Patients who have moderate and high FBS levels have probabilities of 0.2379 and 0.2264 of their limbs being amputated in the absorbed state and 0.7601 and 0.7716 probabilities of dying in the absorbed state, respectively.

Similarly, patients who have developed numbness of the feet and hands have a 0.3553 probability of their limbs being amputated and a 0.6429 probability of dying in the absorbed state, whereas patients who have developed diabetic ulcers have a 100% chance of their limbs being amputated and a zero

chance of dying in the absorbed state.

Generally, the probability of patients dying in the absorbed state is greater than the probability of patients who have their limbs amputated, except for those who have developed diabetic ulcers and who have a 100% chance of having their limbs amputated.

3.2. Discussion

The transition of patients from a moderate FBS level (pre-diabetes) to a high FBS level (diabetes) was high (73.68%) within one year. Most patients with normal and high FBS levels remained in the same state throughout the year. Low FBS (hypoglycemia) is a serious condition among T2DM patients, since 50% of patients in that state died within the year. Patients are encouraged to attend their routine hospital visits every two to three months to check their glucose (HbA1c or FBS test) level in addition to high blood pressure, and blood lipids, etc. since it contributes significantly to high blood sugar and this may lead to nerve damage, limb numbness, and ulcers and eventually causes amputation of the limbs.

The average time spent in each state of the transient state revealed that patients spent more years in State 4, which is the

diabetes state, after which most of them began to develop numbness and gradually moved to an ulcer state and later entered the absorbed state (amputation of limbs or death). Patients who have low FBS levels and enter State 4 can stay there for at least six years before leaving that state. Patients who transition from a normal FBS state and a state of numbness to a diabetic state can remain there for 13 years before leaving the state, and those who transition from a moderate FBS state can stay there for at least 14 years, which is the same as those who are already in that state. Patients who enter State 6 (diabetic ulcers) spend less than a year in that state. This stage is characterized by rapid deterioration of the patient's condition, and patients are amputated when they leave that state.

The mean sojourn time of patients in transient states with low FBS is 14 years, whereas it is 27 years for those with normal FBS. The mean sojourn times for patients with high FBS levels and those experiencing numbness were 26 and 23 years, respectively, whereas patients who had diabetic ulcers had a mean sojourn time of only two years. Patients who are in the ulcer state have a zero chance of transitioning to any other state in the transient state. Therefore, after two years, these patients are expected to enter the absorbed state, where their limbs can be amputated.

In conclusion, T2DM can be managed to prolong the life span of patients if they adhere to good dietary practices and take their medication regularly. This is evident in the mean sojourn time, which showed that patients could live with the disease for up to 27 years before their limbs were amputated or they died from their condition. This is similar to the findings of Srikanth's study on diabetic retinopathy, where the mean sojourn time of T2DM patients in transient states ranged from 8--15 years before they went blind and even 23 years in the city of Taiwan [16]. When patients enter the absorbing state (amputation of limbs and death), they have a higher probability (0.6429 to 0.8802) of dying than being amputated. This shows that most T2DM patients do not reach the last transition state before they die.

4. Conclusions

The study predicted that the average number of Type 2 Diabetes patients are expected to stay in each state of the transient state, with the State 4 (high FBS) level having a longer stay period than the other states do. Patients who were classified in State 4 and those patients who transitioned from other states to State 4 had an average stay time of six to fourteen years.

Additionally, the overall average time (mean sojourn time) of type 2 diabetes patients are expected to live with the disease in transient states before their limbs are likely amputated or possibly die is between 14 and 27 years, except for patients in the ulcer state, who likely have approximately two years of stay in transient states.

Finally, when patients entered the absorbed state (amputation of limbs or death), patients from States 1--5 had a greater probability (0.6429--0.8802) of dying in the absorbed state

than being amputated in their limbs. There is a 50% chance of an ulcer diabetic patient getting his/ her leg amputated. However, patients in the ulcer state, if they are absorbed (amputated), you remain in that state until you die.

Abbreviations

AP	Absorption Probability
DM	Diabetes Mellitus
EAP	Expected Absorption Probability
FBS	Fasting Blood Sugar
SSA	Sub-Saharan Africa
Mmol/L	Millimole per Litre
T2DM	Type 2 Diabetes Mellitus
HbA1c	Hemoglobin A1c

Supplementary Material

The supplementary material can be accessed at <https://doi.org/10.11648/j.bsi.20261101.13>

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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