Insulin Dose Suggestion and Monitoring System for Diabetes Mellitus Patients Using Rule-Based

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ABSTRACT

This paper presents the discussion of the needs of diabetes patients for effective management of Diabetes Mellitus. Diabetes management requires precise monitoring of blood glucose levels and accurate insulin dose calculations. However, it is challenging for diabetic patients to record their blood glucose levels and track the amount of carbohydrates in the foods they choose before each meal. Based on survey, it shows that 70% has difficulty to record the data. Therefore, diabetes patients need to manage their insulin administration timely. It depends on several factors such as carbohydrate intake, current blood glucose levels and individual preferences. To address this issue, this project will focus on developing a expert system using rule-based forward chaining technique that make use of Insulin-for-carb table to help diabetes patients in calculating the appropriate insulin dose for each meal. The system will also determine the carbohydrate content and recommend the appropriate insulin dosage if users record the foods and beverages they consume. The system also monitors insulin dosages and blood sugar levels. These users' feedback showed the similarity of healthcare professionals' practice. As conclusions, this system is reliable to enhance diabetes management and help in reducing the risk of both hyperglycemia and hypoglycaemia.

Keywords: Diabetes, Insulin, Expert System, Rule-Based, Forward Chaining

INTRODUCTION

Diabetes mellitus (DM) is a condition when the blood contains excessive amounts of glucose (sugar) as a result of inadequate or insufficient insulin. The function of insulin is to facilitate the transfer of glucose from the bloodstream into the body's cells, hence regulating the body's glucose balance. The treatment for diabetes patients is diet control, insulin and oral hypoglycaemics medication. Diabetes patients who need to consume insulin, have to check their blood sugar themselves, and record it manually on paper. They need to record it before and after eating four to seven times a day. Diabetic patients are advised to consume nutritious food with proper portion size. They also need to know the carbohydrates in the food taken to calculate the amount of insulin needed.

Based on interview with one of doctors in Dr Akmal Saleh Clinic, Dr Muhamad Hafiz Bin Abdullah, diabetes mellitus (DM) was a condition when the blood contained excessive amounts of glucose (sugar) as a result of inadequate or inefficient insulin. It resulted from insufficient production of the hormone insulin, which was generated by the pancreas, an organ in the body. The function of insulin was to facilitate the transfer of glucose from the bloodstream into the body's cells, hence regulating the body's glucose balance. This statement was be supported by Dottie (2014) that stated when insulin was either insufficient or ineffective, the blood glucose (sugar) level rises, resulting a disease known as diabetes mellitus. The normal range for random blood glucose

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is 7.8 mmol/L – 11.1 mmol/L. Furthermore, Dr. Hafiz explained that the treatments for diabetes patients were diet control, insulin and oral hypoglycemia medication. Mostly, insulin injections were given to diabetes patients Type 1. There are five types of insulin such as rapid-acting insulin, short-acting insulin, intermediate-acting insulin, mixed insulin and long-acting insulin. This statement was supported by insights from Nurul Hazwani Izni Binti Mohd Nizam, one of diabetic patient interviewed to gain an understanding of the process followed when administering insulin.

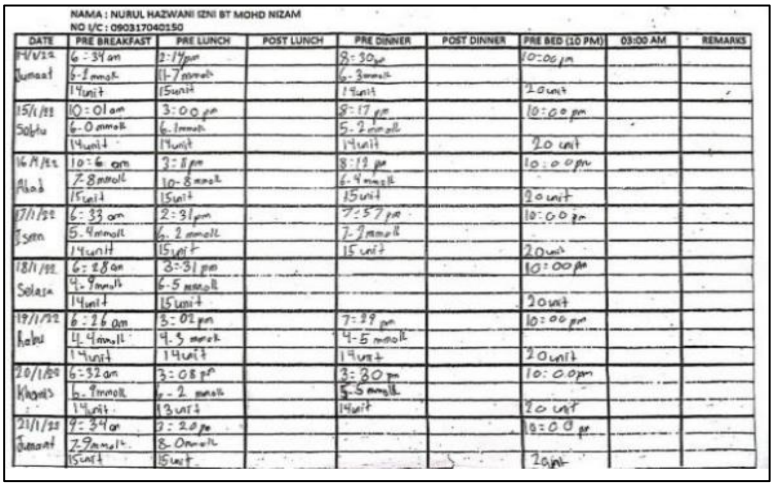

Figure 1: Glucometer monitoring chart

Diabetic patients who need to consume insulin, have to check their blood sugar themselves, and record it manually on paper as shown in Figure 1. They need to record it before and after eating four times a day. Diabetic patients are advised to consume nutritious food with proper portion size. They also need to know the carbohydrates in the food taken to calculate the amount of insulin needed.

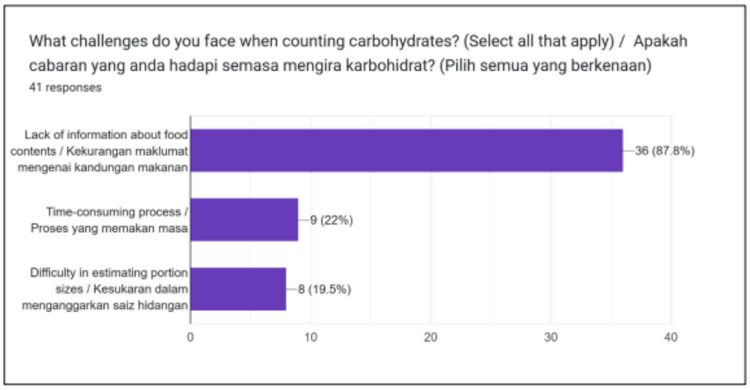

Figure 2: Survey Results on the Challenges Faced in Carbohydrate Counting Among Respondents

By manual process, patients experience difficulty in checking carbohydrates in food, make mistakes in calculating the insulin dose, and have inconsistencies in tracking their blood glucose level as survey done in Figure 2. Therefore, this paper addresses these issues by developing a system will calculating and determine the appropriate insulin dose using the Rule-Based Forward Chaining technique.

LITERATURE REVIEW

Diabetes

Diabetes is a collection of metabolic illnesses characterized by hyperglycemia caused by insulin secretion or action abnormalities, which result in long-term organ damage and dysfunction (Basevi, V., 2011). Based on Arneth et al., (2019), Type 1 and Type 2 diabetes are chronic diseases that afflict nearly 425 million people globally, causing changes in metabolites such as glucose, fructose, amino acids, and lipids

According to Brutsaert (2023), a common disease called diabetes mellitus is caused by the body's inability to control blood glucose levels, which causes the body to produce an excessive amount of urine. This occurs as a result of the body producing insufficient insulin or using it improperly. The World Health Organization (WHO) reports that the number of people with diabetes increased from 108 million in 1980 to 422 million in 2014, with low- and middle-income countries experiencing a disproportionate increase in cases compared to high income countries. The incidence of the condition is still rising, and it is becoming a major cause of death worldwide. In 2019, diabetes was directly responsible for almost 1.5 million deaths (Antar et al., 2023). Furthermore, 2.2 million deaths in 2012 alone were linked to hyperglycemia, a characteristic of diabetes (Cole & Florez, 2020).

There are two types of diabetes mellitus which are Type 1 and Type 2. In Type 1 Diabetes Mellitus (T1DM), sometimes referred to as juvenile diabetes or insulin-dependent diabetes, the pancreas generates little or no insulin on its own. It is a chronic illness. T1DM is the most frequent type of diabetes in children and adolescents (Endocrine, 2019). According to the Malaysian Diabetes in Children and Adolescents Registry (DiCARE) (2006-2008) study, 71.8% of children under 20 years old with diabetes mellitus had Type 1 diabetes. The median age of diagnosis was 7.6 years (IQR 4.6-10.8), with the majority (58.3%) presenting with diabetic ketoacidosis. Early detection of T1DM in children is crucial, especially before the onset of Diabetic ketoacidosis (DKA), which can lead to severe morbidity and mortality (Hong et al., 2017). Meanwhile, Type 2 Diabetes Mellitus (T2DM), usually affects adults and is brought on by insufficient or resistant insulin production in the body. According to Endocrine (2021), T2DM accounts for more than 90% of adult-onset diabetes cases in Malaysia. Diabetes and prediabetes can coexist with other noncommunicable diseases. T2DM, characterized by hypertension, dyslipidemia, and obesity, has a high worldwide and local prevalence and poses a significant socio-economic burden due to vascular consequences and premature death.

Insulin

For diabetic patients, keeping blood glucose levels within a certain range dramatically enhances outcomes and reduces mortality rates. The most successful medication for regulating blood sugar levels is insulin. Many diabetes patients eventually require insulin therapy to control their blood sugar levels as their condition worsens (Stewart, 2023).

In their study, Slattery D, Amiel S, & Choudhary P (2018) stated short- or rapid-acting insulin is administered with meals in patients receiving Multiple Daily Injections (MDI) for either Type 1 or insulin-requiring Type 2 diabetes in order to address glucose excursions during mealtimes. The insulin's pharmacology in relation to the meal's glucose profile. They must use insulin injections administered by syringes, insulin pens, or insulin pumps to control their condition. Modern insulin pumps continuously provide basal insulin by using an insulin analogue with a fast action. Bolus calculators for insulin pumps also determine the required units of insulin depending on food consumption, active insulin time, and parameters.

Expert System

According to Al-Mafrji et al. (2023) expert systems is the Knowledge-Based Systems (KBIS), a subset of Computer-Based Systems (CBIS) that studies the design and development of human-like computer systems with intelligence. Knowledge-based information systems can be used as an expert consultant for end users tally with its complexity. Therefore, knowledge-based information systems are widely used in various fields such as planning, translation and decision maker. There are four types of expert system architecture which are knowledge based, user interface, inference engine and memory (Ravi et al., 2022).

Firstly, Al-Mafrji et al. (2023) stated that knowledge base is a kind of storage that holds information gathered from various subject matter experts in a certain field. It is known as a huge repository of knowledge. It is the same as a database that holds information and rules specific to a given field or topic. The Expert System will be more accurate the larger the knowledge base. The knowledge base can also be seen as collections of objects and their attributes. Secondly, user interfaces allow communication between the user and the expert system. It enables users to input queries and receive response (Al-Mafrji et al., 2023). Thirdly, the inference engine applies inference rules to the knowledge base to make a conclusion as it is the main processing unit of the

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system. There are two inference engine which are forward chaining and backward chaining (Al-Mafrji et al., 2023). According to Anwar (2023), the method begins with the established rules and facts, then adds the conclusion to the known facts by using the inference rules is forward chaining. Meanwhile, backward chaining is the technique of backward reasoning develops the known facts first and works backward to reach the goal. Lastly, according to Janjanam et al., (2021) the working memory, output memory and interpreter is the components in Blackboard Architecture framework

Rule Based

Rule Based Systems (RBS) are computer programs from research into artificial intelligence. This system performs activities that are often performed by human experts by imitating human knowledge and behaviour (Anwar, 2023). The rule base and the inference engine are the two main parts of a rule-based system. The inference engine uses the facts in the rule-based to help generate new knowledge based on the facts. There are two types of rule-based technique such as forward and backward chaining techniques can be used, and the IF-THEN rule is frequently used in this process (Masri et al., 2019).

Forward Chaining

Forward chaining is a method used in expert systems and artificial intelligence to derive conclusions or make decisions based on a set of known facts and rules (Jalinus, 2019). It is a data-driven approach that starts with the available data and applies inference rules to extract more data until a goal is reached. This method is widely used in various fields such as medical diagnosis, agriculture, and technology to develop systems that can mimic expert decision-making processes.

Based on Rizki Gunawan Tanjung (2023), forward chaining begins with existing data and progresses to a conclusion by applying rules and deriving new information step by step. This method is particularly beneficial for solving problems that begin with preliminary information and continue to a final answer in a sequential manner. The inference engine evaluates rules and executes actions based on user input that meets the conditions (Jalinus, 2019).

According to Ramadhani et al., (2021), using a set of rules for behaviour is known as forward chaining. This approach involves selecting which rules to execute based on the data, and then executing the rules. Until a result is achieved, the procedure adds information to working memory. Typically, decision-makers receive support from the expert knowledge base based on the findings of their fact-finding efforts. The knowledge base representation used is known as rule-based and is expressed as statements to convey the issue of essential property and provide access to the data for methods of problem solving. The data is sorted and filtered to identify facts (If) and conclusions (Then). This analysis helps build the system's design (Henderi et al., 2022). An agent can draw conclusions from input perceptions by using forward chaining, frequently without the need for a specific inquiry. This will lead from a problem to its solution (Makolo et al., 2023).

RESEARCH METHODOLOGY

The Insulin Dose Suggestion and Monitoring System is designed, in order to illustrate the requirements into a thorough design that aligns with the project target. A rule-based method to calculate insulin doses for diabetes patients will be identified. The rule-based technique that is chosen is forward chaining. The system will apply the rules below:

Rule 1: IF a patient choose meal

IF a patient choose drink

THEN the system will calculate and total up the amount of carbohydrates

Rule 2: IF current blood glucose level > targeted blood glucose

THEN correction insulin dose is needed

Rule 3: IF blood glucose level < target range

THEN no correction insulin dose is needed

By considering these rules, a result is derived which is the mealtime insulin dose. The following is the example of mealtime insulin dose calculation:

Formula for Total Mealtime Insulin Dose:

Total Mealtime Insulin Dose = Carbohydrate Coverage Dose + Correction Dose

Based on the situation, the patient condition can be illustrated like this:

a) Total daily insulin (TDI): 65 units

b) Target blood glucose: 6.5 mmol/L

c) Blood glucose before meal: 15 mmol/L

d) Meal carbohydrates intake: 70 grams

ICR (using 500 rule) = 500 / 65 = 7.7 ~ 8 grams

Carbohydrate Coverage Dose = 70 / 8 = 8.75 units

ISF = 100 / 65 = 1.5 mmol/L

IC = (15-6.5) / 1.5 = 5.6 ~ 6 unit

Total Mealtime Insulin Dose = 8.75 unit + 6 unit = 14.75 units

Therefore, the total insulin dose that a patient needs to take is 14.75 units. By following the rules, the system determines the appropriate insulin dose for mealtimes by considering the blood glucose level at that time and the carbohydrate content of the meal. This ensures accurate and tailored insulin doses for efficient diabetes control.

RESULT AND DISCUSSION

Rule-based for insulin dose

This section discusses the rule-based expert system used to dynamically calculate the required insulin dose based on a patient's carbohydrate intake and blood glucose levels. The system employs forward chaining to infer the appropriate insulin carbohydrate dose from a set of predefined rules that are flexible and patient-specific. There were three parts of the calculations that were discussed which are Carb-to-Insulin Ratio Rules, Correction Factor and Total Insulin Dose.

Carb-to-Insulin Ratio Rules

The insulin dose suggestion system implemented a rule-based approach that executed stages in sequence. The system obtained different types of user data through data input including blood glucose levels and carbohydrate intake. The system required both basic numerical data and advanced information to determine proper insulin dosage. The first set of rules in the expert system calculated the insulin dose needed for a patient's carbohydrate intake based on their Insulin-to-Carb Ratio (ICR). This ratio varied from patient to patient, so the insulin dose was dynamically determined by dividing the carbohydrate intake by the patient’s

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specific ICR. The Knowledge Base Table: Insulin Carb Ratio stored the ICR values for different patients, allowing the system to calculate insulin doses according to each individual's ratio

Insulin to Carbohydrate Ratio →

Carbohydrate in grams ↓

	1:35	1:30	1:25	1:20	1:18	1:15	1:12	1:10	1:8	1:7	1:5	1:3
10	0	0	0.5	0.5	0.5	0.5	1	1	1	1.5	2	3.5
20	0.5	0.5	1	1	1	1	1.5	2	2.5	3	4	6.5
30	1	1	1.5	1.5	1.5	2	2.5	3	3.5	4	6	10
40	1	1	2	2	2	2.5	3	4	5	5.5	8	13
50	1.5	1.5	2.5	2.5	2.5	3	4	5	6	7	10	16.5
60	1.5	2	3	3	3	4	5	6	7.5	8.5	12	20
70	2	2	3.5	3.5	4	4.5	5.5	7	8.5	10	14	23
80	2	2.5	4	4	4.5	5	6.7	8	10	11.5	16	26.5
90	2.5	3	4.5	4.5	5	6	7.5	9	11	13	18	30
100	3	3	5	5	5.5	6.5	8	10	12.5	14	20	33
110	3	3.5	5.5	5.5	6	7	9	11	13.5	15.5	22	36.5
120	3.5	4	6	6	6.5	8	10	12	15	17	24	40
130	3.5	4	6.5	6.5	7	8.5	10.5	13	16	18.5	26	43.5
140	4	4.5	7	7	7.5	9	11	14	17.5	20	28	46.5
150	4	5	7.5	7.5	8	10	12.5	15	18.5	21.5	30	50
160	4.5	5	8	8	8.5	10.5	13	16	20	23	32	53.5
170	5	5.5	8.5	8.5	9.5	11	14	17	21	24.5	34	56.5
180	5	6	9	9	10	12	15	18	22.5	25.5	36	60
190	5.5	6	9.5	9.5	10.5	12.5	15.5	19	23.5	27	38	63.5
200	5.5	6.5	10	10	11	13	16.5	20	25	28.5	40	66.5

Figure 3: Insulin for carb table

(Sources: NHS, 2021)

The table shown in Figure 3 represented the Insulin-to-Carbohydrate Ratio (ICR) data used in the expert system. This table mapped different carbohydrate intake values (in grams) to their corresponding insulin doses, based on varying ICR values ranging from 1:35 to 1:3. Each entry in the table is dynamically used by the system to calculate the required insulin dose for carbohydrate intake, ensuring patient-specific precision. The system executed rule matching by analyzing input data against preestablished rules located in its knowledge base. The Insulin Carb Ratio table served as a vital element in the knowledge base to enable the system to calculate appropriate insulin doses from carbohydrate consumption amounts. The system conducted a search for rules that contained matching conditions with the input data including user insulin-to-carb ratio and carbohydrate intake

Next, the system executed the action from the matched rule after finding a match with the input data during this stage. The system determines insulin dosage through insulin-to-carb ratio calculations and performs insulin schedule adjustments when needed. The system updated its working memory before it started generating an output.

Condition: If the patient consumed a certain amount of carbohydrates (X grams), and their ICR is Y:1, then the insulin dose for the carbohydrates was calculated by dividing the carbohydrate intake (X) by the ICR (Y).

Rule 1: IF carbohydrate contents = 100

AND Insulin-to-Carbohydrate Ratio = 1:15

THEN insulin dose for carbs = 6.5 units

Rule 2: IF carbohydrate contents = 30

AND Insulin-to-Carbohydrate Ratio = 1:7

THEN insulin dose for carbs = 4 units

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However, the system entered conflict resolution mode when multiple rules activated simultaneously. The system used conflict resolution strategies to determine which rules should take precedence when multiple rules were active. The system applied a rule selection process that used both rule entry order and rule specificity to determine which rule would be executed first. Lastly, the system generated its output through the execution of rules during the final stage. The system generated the output which was insulin doses for carbohydrate intake.

The system structured and stored the data into a relational database to serve as the Knowledge Base to enhance efficiency. This database allowed for efficient retrieval and dynamic application of the insulin calculation rules during forward chaining. The key field in the database included:

a) Carbohydrate Intake (grams): Specified amount of carbohydrate consumed.

b) ICR (Insulin-to-Carbohydrate Ratio): Patient-specific ratio used for insulin calculations.

c) Insulin Dose (Units): The calculated insulin dose based on the carbohydrate intake and ICR.

The database schema followed a simple structure with three main fields:

a) Id (Primary Key)

b) carbAmount

c) ICR

d) InsulinCarbDose

By organizing this information into a database, the expert system can quickly infer the appropriate insulin dose based on input values, enhancing the system's scalability and flexibility.

Insulin Correction Factor

Once the carbohydrate-based insulin dose was determined, the correction factor was applied to adjust the insulin dose based on the patient's current blood glucose level relative to the target blood glucose level. The correction factor represented the amount of insulin needed to lower blood glucose by a specified value, typically defined as "1 unit of insulin reduces blood glucose by X mmol/L."

For example:

If the patient's current blood glucose level was 15.0 mmol/L, the target was 6.5 mmol/L, and the correction factor was 1.5 (1 unit of insulin reduced glucose by 1.5 mmol/L), the correction dose was calculated as follows:

Correction Dose = (Current Glucose−Target Glucose) / Correction Factor

= (15.0−6.5)/1.5 = 6 units

Total Insulin Dose Calculation

The total insulin dose was obtained by combining the insulin dose for carbohydrates intake and the correction dose:

Total Insulin Dose = Insulin Dose for Carbs + Correction Dose

Using the example values:

Total Insulin Dose = 4 units + 6 units = 10 units.

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Therefore, necessary bolus dose of insulin injected at mealtime was 10 units.

Thus, the rule-based forward chaining system provides an efficient mechanism for determining the insulin dose required for carbohydrate intake based on predefined rules. Subsequently, the correction factor is applied to adjust for blood glucose levels outside the target range. While the correction factor is not inherently part of the rule-based system, it complements the process by ensuring individualized insulin dosing tailored to the patient's condition needs.

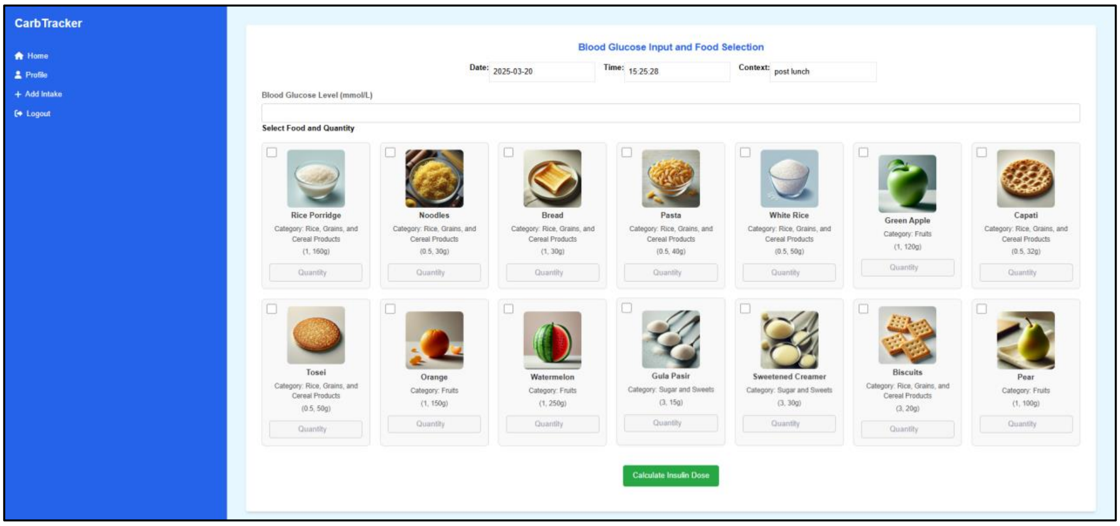

Figure 4: Blood Glucose Input and Food Selection

The Figure 4 shows Blood Glucose Input and Food Selection page. Patients can enter their blood glucose level in mmol/L through a specific text field on this interface. Users can choose between rice porridge and noodles and bread from a predefined list of food items while specifying their consumption amount. Patients can select food items from rice, grains, and cereal product categories through checkboxes and adjust quantity measurements in corresponding input boxes. Patients can determine their required insulin dosage by clicking the "Calculate Insulin Dose" button after entering all required information. The system helps diabetes patients track their blood sugar levels while providing them with the tools to determine appropriate insulin doses.

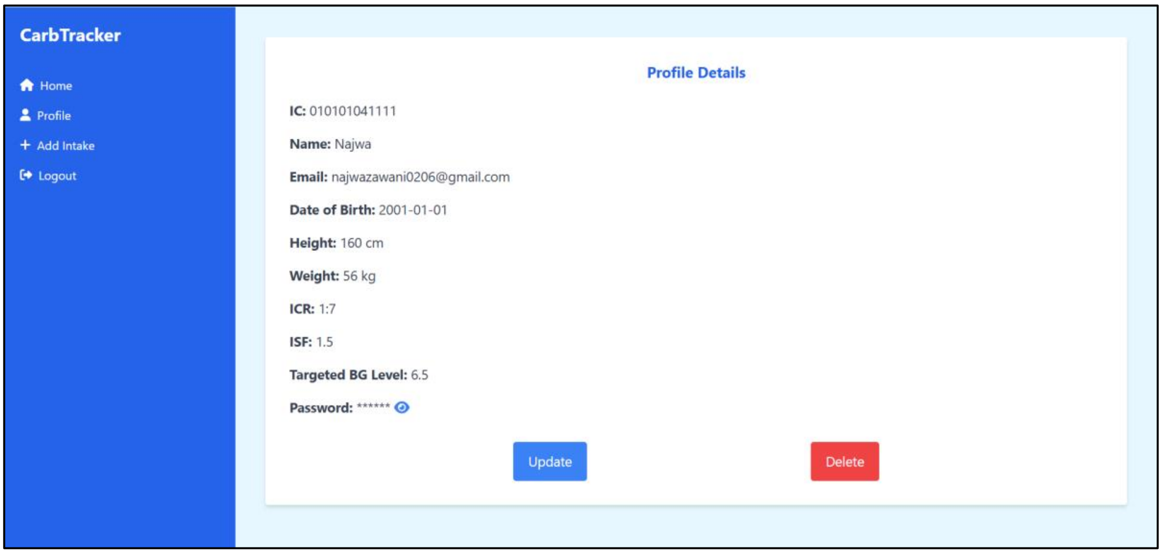

Figure 5: View Patient Profile

After logging in, the patient can access their profile to view their details such as IC number, name, email address, date of birth, height and weight as shown in Figure 5. The system contains essential health data which includes the Insulin to Carb Ratio (ICR) and Insulin Correction Factor (ISF) and Targeted Blood Glucose Level. The page contains two buttons which allow users to "Update Profile" for modifying details or "Delete

Profile" to remove their account from the system. The interface enables patients to maintain current information which leads to precise insulin dose recommendations.

System Testing

This section evaluates the web-based insulin dose suggestion system, which uses a rule-based forward chaining approach. The study was carried out in two stages to assess the system's accuracy and usability.

In the initial test of the system, the insulin dosage recommendations presented by the system were cross-checked against a reliable third-party calculator, namely the Insulin Dose Calculator by Omni Calculator, which is highly relied upon and presents transparent formulas of calculation of bolus insulin dosages (Michałowska, 2024). By using the same values of foods and beverages in both systems, the system and the Omni Calculator were compared to establish the system's precision. The result indicated a perfect match of 90% of the system to the Omni Calculator, upholding the authenticity of the system's rule-based calculations.

A pilot study was conducted with multiple users, including diabetic patients who manually calculate their insulin dosage, to evaluate the system in a real-world setting. Users were instructed to choose various food items into the system, after which the system's recommended insulin dosage was compared to the dosage that the person would have calculated manually. The study's results indicated that the system demonstrated outstanding accuracy in its output, while the results achieved by people solving the issues manually were nearly the same, though not precisely the same. Minor inaccuracies were observed, primarily due to variations in the estimating techniques and rounding processes used by the users in carbohydrate counting. However, the results indicate that the system can be used as an effective decision support tool in general. It makes the process of estimating insulin dosage easier, minimizes the chances of making mistakes, and can be particularly helpful for those who have recently been diagnosed with diabetes or those who have little knowledge about the dietary changes they need to make. In addition, the system accurately records and track the patients' blood glucose levels and insulin doses taken. This can help the users to review their past records, make better decisions and monitor their diabetes condition in the long run.

Table 1: The Users' Feedback of System

Point of Evaluation	**User 1**	**User 2**	**User 3**
Accuracy of insulin dose recommendation	**Found the system highly accurate with only small differences compared to manual calculation**	**Agreed that the system provided accurate results, with minor variation due to estimation**	**Observed close similarity between system and manual results with slight rounding differences**
User interface	**Found the system's interface was clear and simple, helping them choose food items easily**	**Said the design is easy to understand**	**Reported that the interface reduced confusion and made navigation smooth during use**
Mistake reduction	**Felt the system helped avoid calculation errors**	**Confirmed fewer mistake when using the system**	**Stated the system minimizes incorrect dosage estimation**
Blood glucose and insulin tracking	**Liked the system tracks records effectively**	**Found the record-keeping feature helpful for monitoring progress**	**Said it was helpful to check the history of insulin and glucose.**

Based on the users' feedback in table 1, the system has accurately suggested insulin doses that nearly match those suggested by healthcare professionals. The system also should enable complete monitoring, allowing patients and healthcare practitioners to easily track and analyse glucose trends over time.

CONCLUSION

The creation of a rule-based forward chaining system for managing insulin doses in diabetes patients marks a big step forward in personalised healthcare. This project successfully demonstrates how rule-based systems may automate and improve diabetes treatment. The approach not only makes it easier for patients to make decisions, but it also helps to improve long-term glucose control, which improves the quality of life for persons with diabetes (Herawan Hayadi et al., 2018).

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