BMD302

**Fuzzy-based dietary clinical decision support system for patients with multiple chronic conditions (MCCs)**

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**Abstract**

fuzzy-based clinical decision support system designed to assist patients with multiple chronic conditions (MCCs) in making dietary choices. The system utilizes fuzzy logic, which allows for the consideration of uncertainty and imprecision in medical data. By integrating patient-specific information with nutritional guidelines and medical knowledge, the system generates personalized dietary recommendations for individuals managing MCCs. This approach aims to improve patient outcomes by providing tailored dietary advice that considers the complex interplay of multiple chronic conditions.

**Introduction**

Nutrition informatics and intelligent systems, such as fuzzy logic, are crucial in assisting dietitians in setting diets and enhancing diet therapy and clinical practices. Fuzzy logic models, which are similar to human reasoning, are suitable for modeling complex systems with insufficient, vague, or unclear data. Since 1965, the fuzzy model has been widely applied in nutrition science, with studies focusing on designing intelligent models for chronic diseases like diabetes, blood pressure, dyslipidemia, and kidney diseases. Fuzzy logic has also been used to design decision support systems (DSS) to assist in adjusting diets for patients with multiple chronic conditions.

MCCs refer to patients with multiple chronic diseases simultaneously, lasting over a year and causing daily limitations and continuous medical care. These diseases often have common causes and can significantly impact care plans, treatment outcomes, and patient quality of life. One in every three people lives with MCCs globally, with diabetes being the most common chronic condition. Over 40% of patients have three or more comorbidities, and poorly controlled hyperglycemia is associated with the development and progression of chronic kidney disease. Hypertension, a symptom of diabetes, is also a significant cause of renal disease. However, these conditions often require a diet to prevent disease progression and ensure quality of life. Adherence to a diet to control fat is a non-pharmaceutical treatment for hypertension.

Lifestyle changes and inappropriate behavior, such as unhealthy diets and lack of physical activity, can lead to chronic conditions like malnutrition, ineffective management of multiple chronic conditions (MCCs), limitations caused by some chronic diseases, and prescribed drug interactions. This results in food insecurity for patients with MCCs, who have significantly less access to sufficient, reasonable, healthy, and appropriate food. Adhering to a healthy lifestyle, including a healthy diet and physical activity, can increase the life expectancy of patients with more than one chronic disease by 7.6 years in females and 6.3 years in males.

A healthy diet includes the right and balanced amount of macronutrients (carbohydrates, proteins, and fats) and micronutrients (vitamins and minerals) and provides enough water. Dietary guidelines like USDA My Plate and Harvard Healthy Eating Plate dictate the type and amount of food consumed from five major food groups based on an individual's age and physical activity level. These guidelines follow a protective diet, enabling individuals to make better decisions to prevent malnutrition, obesity, and chronic conditions like hypertension and diabetes.

Setting a special diet for each patient based on their needs is complex and time-consuming. A decision support system that integrates the best clinical evidence with best practices for severe conditions when patients are involved in multiple chronic diseases can be a suitable solution. These systems were primarily developed for drug treatments, errors, and drug interactions caused by the prescription of multiple drugs, and most diet management apps have been designed for the self-care of patients with MCCs.

This study aims to develop a knowledge-based clinical decision support system using Mamdani's fuzzy inference system to assist dietitians in arranging diets based on patients' clinical and anthropometric data and metabolic conditions (MCCs), thereby enhancing the ability to optimize macronutrient and food groups for patients with MCCs.

**Methodology**

***3.1 Criteria for inclusion and exclusion.***

This study modelled a clinical decision support system (CDSS) using fuzzy inference to assist dietitians in setting optimal diets for patients with multiple chronic conditions (MCCs). Data from adult patients over 18 years old with obesity, diabetes, high blood pressure, hypercholesterolemia, hypertriglyceridemia, nephrotic syndrome, or chronic kidney disease were used. Data from pregnant women, disabled individuals, recent surgical procedure patients, and athletes with specific diets were excluded. The study followed relevant guidelines and regulations, with informed consent obtained from all participants.

***3.2 Knowledge base system development***

A web-based platform was developed to enter patients' demographic data, including age, gender, current weight, height, physical activity level, and diseases. Adjusted total daily energy expenditure was also defined. A knowledge base of the model was developed using literature and expert input. A review of literature was conducted to determine the appropriate percentages of macronutrients for each disease. A questionnaire was developed based on the results and distributed to twelve qualified nutritionists. The questionnaire aimed to establish the appropriate percentage of macronutrients in the diet based on the body mass index for each disease.

The results of the questionnaire were used to develop fuzzy rules and design the model. The average of macronutrient percentages expressed in the questionnaire by experts was calculated and used in the fuzzy rules. For patients with kidney diseases, the weight variable was employed as an input, while the binary variable of obesity was used for non-kidney diseases. The recommended protein intake for renal patients was determined based on the nutrient substitution table of non-renal and renal patients.

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Eleven variables and ten variables were applied as input and output, respectively. A formula was used to determine the number of fuzzy rules, resulting in 1144 fuzzy rules. The list of input and output variables and their types, numerical values, and linguistic values is illustrated in Table 3.

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***3.3 Architecture of the fuzzy model.***

The fuzzy model was developed using MATLAB R2020b and the Mamdani inference method as the inference engine for defuzzification. This method is suitable for fuzzy sets, while the Sugeno method is used for linear or constant output membership functions. The Mamdani method is useful in health Decision Support Systems due to its visual and interpretative nature. It is executable in both multi-input and multi-output (MIMO) and multi-input and single-output (MISO) scenarios. The Gaussian Membership Function was used to determine input and output variable membership values. To improve speed and accuracy, the model was divided into five sub-models based on the number of simultaneous conditions. Sub-models 1 and 2 had 84 rules for one condition, 296 for two conditions, 424 for three conditions, 276 for four conditions, and 64 for five conditions. The model was designed to cater to scenarios with a maximum of five concurrent conditions. The centroid approach was used for fuzzification.

**Results**

The study involved 100 participants aged 20-80 years, with a mean of 53.4 years. The Wilcoxon test showed no statistically significant difference between the recommended diet by nutritionists and the one suggested by the model. The Pearson bivariate correlation test showed a strong correlation (close to one) between the diet recommended by nutritionists and the fuzzy model. The results indicated a suitable performance for the model, with no statistically significant difference between the two. The study's findings provide valuable insights into the effectiveness of diet recommendations in health care.

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**Discussion**

This study presents a high-accuracy Decision Support System (DSS) to assist nutritionists in sitting diets for patients with Multiple Chronic Conditions (MCCs). The system estimates the number of macronutrients and main food groups required by each patient, determining the healthy range of each food group based on nutritional guidelines and the patient's chronic conditions. A balanced diet intake of carbohydrates, protein, and fat is essential for controlling and treating their conditions.

Studies have shown that the amount of energy required from proteins in patients in the pre-dialysis stages is calculated according to their weight, and another study recommended that the number of macronutrients should be considered as 49-54%, 19-20%, and 21-26%, respectively. The model's outputs followed nutritional guidelines such as USDA My Plate and Harvard Healthy Eating Plate.

The system avoids arbitrary determination of the optimal consumption parameter and recommends its optimal value to dietitians by accurately calculating the patients' total daily energy expenditure via BMI. Fuzzy logic is one of the most appropriate ways to solve the problem of Multiple-Criteria decisions. Other algorithms have been used to set diets for patients with chronic diseases, such as decision tree hierarchical models like DIETOS and Jena. However, these studies showed higher accuracy with the decision tree method than the present study, and they were designed only for patients with chronic kidney diseases and could not use for MCCs.

Some studies have focused on self-care in patients with MCCs, such as 'SousChef', which employed heuristic functions to recommend a personalized diet based on information provided by the patient. However, this study was unique in proposing a model to help dietitians adjust the diet for patients with MCCs by calculating the number of macronutrients according to daily energy consumption, weight, the conditions the patient is suffering from, dietary guidelines, and nutrient substitution table.

To the best of our knowledge, no similar study has been found, and most studies in dietary recommendations focused on patients with a single disease or healthy individuals rather than MCCs. Therefore, finding similar studies that support the results was one of the limitations of this study.

**Conclusion**

The fuzzy logic algorithm is a suitable method for designing CDSSs for diet recommendation, improving the reliability, speed, and accuracy of dietitians' decision-making in setting optimal diets for patients with multiple chronic conditions (MCCs). The system can be extended to include rules related to micronutrient intake and fluid intake and can be helpful in clinical decision-making for different patients.