The Application of Multi-objective Optimization Algorithm in Diabetic Nutrition Meal Planning

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Abstract: This study aims to explore the application of multi-objective optimization algorithms in nutritional meal planning for diabetics, optimizing dietary formulas based on various health indicators and nutritional needs. A personalized nutritional meal planning model for diabetics was constructed by combining medical nutrition principles with a genetic algorithm-based multi-objective optimization approach. Through simulated experiments and comparative analysis, the effectiveness of the proposed algorithm was verified, leading to the identification of optimal meal plans that satisfy the multiple health goals of diabetics. The findings indicate that this algorithm can significantly improve the dietary quality of diabetics while satisfying their specific requirements for sugar, calorie, and nutritional content control. Therefore, this study provides a scientific and effective approach to nutritional meal planning for diabetics.

Keywords: Diabetes; Nutrition Meal Planning; Multi-objective Optimization; NSGA-II; Blood Glucose

1. Introduction

Diabetes is a metabolic disease characterized by chronic hyperglycemia caused by various etiologies, resulting from the defect of insulin secretion and/or function. Diabetes is mainly divided into four types: type 1 diabetes, type 2 diabetes, special types of diabetes, and gestational diabetes. According to statistics, about 463 million people worldwide suffer from diabetes, and this number is still growing. The impact of diabetes is profound. It is not only the main cause of cardiovascular disease, blindness, kidney failure, and lower limb amputation, but also brings a huge economic burden to patients and society.

Nutritional meal planning is one of the important means of diabetes management. Reasonable nutritional meal planning can help diabetic patients better control their blood sugar and prevent the occurrence of complications. By adjusting the type, quantity, and proportion of foods, nutritional meal planning controls the total calorie and nutrient intake to meet the body's needs while avoiding high or low blood sugar levels. Multiple studies have shown that reasonable nutritional meal planning can lower blood sugar levels, improve quality of life, and reduce the occurrence of complications among diabetic patients.

2. Domestic and Foreign Research Review

2.1 Related Research on Nutritional Meal Planning for Diabetes

Currently, the methods of nutritional meal planning for diabetes mainly include the following two approaches: 1) Meal planning based on dietary guidelines [1]: This approach tailors meal plans according to the dietary guidelines of a specific country or region, taking into account the nutritional requirements and food intake of diabetes patients. This method is simple and easy to implement, but it may lack targetedness and precision. 2) Meal planning based on food exchange lists: This method categorizes foods into different groups and selects appropriate foods and quantities within each group to meet nutritional needs and calorie control. This approach offers more flexibility but requires a profound understanding of the nutritional components and calories of foods.3) Meal planning based on nutritional software: This approach involves the use of various nutritional software tools. By inputting information such as the patient's height, weight, age, gender, and activity level, the software calculates the daily calorie and nutrient requirements of the patient and provides corresponding meal suggestions. This method is more precise and scientific but relies on the software, and the quality and data accuracy of the software can significantly affect the meal planning results.

Despite the fact that current meal planning methods can meet the nutritional needs of diabetes patients [2] to some extent, there are still the following issues: 1) Lack of Personalization: Different diabetes patients have varying nutritional requirements and food intake amounts. However, the existing meal planning methods tend to be too general and lack personalization. This may result in meal plans that do not meet the actual needs of patients, thereby affecting blood sugar control.2) Lack of Flexibility [3]: The existing meal planning methods are often too rigid and inflexible, unable to adjust according to the patient's actual situation. For example, when a patient's activity level or physical condition changes, the meal plan may not be able to adapt to these changes in a timely manner.3) Lack of Long-Term Consideration: Diabetes is a chronic disease that requires long-term dietary control. However, the current meal planning methods tend to focus solely on short-term blood sugar control, neglecting long-term nutrition and health. This may lead to nutritional deficiencies or other health issues in patients who are on long-term dietary restrictions.4) Lack of Professional Guidance: Diabetes patients require guidance from professional nutritionists or doctors when developing and executing meal plans. However, in reality, there is often a lack of such professional guidance, resulting in various issues with the patients' meal plans.

2.2 Related Studies on Multi-Objective Optimization Algorithms

The development of multi-objective optimization algorithms can be traced back to the 1960s, when some scholars began to study how to apply evolutionary algorithms to multi-objective optimization problems. In the 1980s and 1990s, with the rise of artificial intelligence and evolutionary computation, multi-objective optimization algorithms developed rapidly, giving rise to a series of classic algorithms such as NSGA [4] series, SPEA series, MOGA, NPGA, mGA [5], etc. These algorithms have demonstrated excellent performance in solving multi-objective optimization problems, providing important references for subsequent research.

In recent years, with the rapid development of artificial intelligence technology, multi-objective optimization algorithms have also been widely used and improved. Especially in fields such as recommendation systems, logistics and distribution, and path planning, multi-objective optimization algorithms [6] have played an important role. At the same time, researchers are constantly exploring new algorithms and technologies to improve the performance and efficiency of multi-objective optimization algorithms [7].

3. Application of Multi-objective Optimization Algorithms in Nutritional Meal Planning for Diabetes

There is a close relationship between multi-objective optimization algorithms and nutritional meal planning for diabetes. In diabetes management, nutritional meal planning is an important component, aiming to ensure that patients consume sufficient nutrients while controlling blood sugar levels. This is actually a multi-objective optimization problem that requires finding a balance between meeting nutritional needs and controlling blood sugar. Therefore, multi-objective optimization algorithms can be applied to solve this problem.

3.1 Principle and Implementation Steps of Multi-Objective Optimization Algorithm NSGA-II

NSGA-II is a multi-objective optimization algorithm based on genetic algorithms. It effectively solves multi-objective problems by introducing non-dominated sorting and crowding comparison operations. The main principles of NSGA-II are as follows:

Step 1. Population Initialization: Initially, a population is generated, consisting of a certain number of individuals. Each individual represents a solution.

Step 2. Fitness Evaluation: Each individual is evaluated to calculate its function values across various objectives. These function values serve as measures of the individual's performance in each objective.
Step 3. Non-dominated Sorting: Based on the fitness values of the individuals, the population is divided into multiple non-dominated layers. Individuals within the same layer have no dominance relationship, while individuals in higher layers perform better than those in lower layers in at least one objective.
Step 4. Selection Operation: During the selection process, individuals from higher non-dominated layers are preferred. If two individuals belong to the same non-dominated layer, the crowding comparison operation is used to select the more diverse individual.
Step 5. Crossover and Mutation: The selected individuals undergo crossover and mutation operations to generate a new offspring population. These operations aim to explore new regions in the search space, potentially leading to the discovery of better solutions.
Step 6. Iterative Evolution: The new offspring population is combined with the original population to form a new generation. Then the process of fitness evaluation, non-dominated sorting, selection, crossover, and mutation is repeated until a termination criterion is met, such as reaching the maximum number of iterations or finding a satisfactory solution.

3.2 Application of Multi-objective Optimization Algorithms in Diabetes Nutrition Meal Planning

3.2.1 Definition of the problem

The diabetes nutrition meal planning problem is a typical multi-objective optimization problem aimed at creating a meal plan that satisfies nutritional requirements while also assisting in glucose control for patients with diabetes. When defining this problem, it is necessary to consider the patient's specific medical condition (such as blood glucose levels, weight, complications, etc.), dietary preferences, nutritional needs, and the nutritional composition of foods (e.g., carbohydrates, protein, fats, vitamins, minerals, etc.).

3.2.2 Setting of objective functions

When addressing the problem of diabetes nutrition meal planning, multiple objective functions are typically set to balance different optimization goals. Some possible objective functions are as follows:
Minimize Blood Glucose Fluctuations: To control the blood glucose levels of patients with diabetes, it is necessary to minimize the blood glucose fluctuations caused by meals. This can be achieved by selecting foods with a low Glycemic Index (GI), properly combining different foods, and controlling the total carbohydrate intake in meals.
Maximize Nutrient Intake: Patients need to consume enough nutrients to maintain good health. Therefore, the objective function should include maximizing the intake of various essential nutrients, such as protein, fat, vitamins, and minerals.
Control Total Calorie Intake: For patients with diabetes who need to manage their weight or lose weight, controlling total calorie intake is also an important goal. This can be achieved by limiting the intake of high-calorie foods and reasonably controlling the overall volume of meals.

3.2.3 Determination of constraints

When developing a nutritional meal plan for diabetes, it is necessary to consider certain constraints to ensure the feasibility and safety of the meal plan. The following are some possible constraints.
Restrictions on Food Types and Quantities: Based on the patient's dietary habits and preferences, certain food types or quantities may be restricted. For example, the patient may dislike a particular food or be unable to consume it due to allergies.
Nutrient Intake Restrictions: To ensure that the patient consumes enough nutrients, it is necessary to set minimum or maximum limits for the intake of certain nutrients. For example, for patients who need to control their cholesterol intake, a maximum cholesterol intake limit can be set.
Calorie Intake Restrictions: To manage weight or lose weight, an upper limit for total calorie intake needs to be set. This can be achieved by selecting low-calorie foods, reducing the overall volume of meals, and properly combining foods.

3.2.4 Application of multi-objective optimization algorithm

The implementation steps are as follows: Encoding: Convert the meal plan into a form that can be processed by the algorithm, such as a gene sequence or vector.

Initialization of Population: Generate an initial set of meal plans as the initial population for the algorithm. Evaluation: Evaluate each individual in the population, calculating its values on various objective functions and checking if it satisfies the constraints.

Selection, Crossover, and Mutation: Based on the evaluation results, select excellent individuals for crossover and mutation operations to generate new offspring populations.

Iterative Evolution: Repeat the steps of evaluation, selection, crossover, and mutation until a termination condition is reached (such as the maximum number of iterations or finding a satisfactory solution).

4. Experiment Design and Evaluation

The purpose of this experiment is to explore the application of multi-objective optimization algorithms in nutritional meal planning for diabetics [8]. Through algorithm optimization, we aim to achieve a balanced combination of food nutrients to meet the nutritional needs of individuals [9].

4.1 Source of Experimental Data

1) Food Composition Database: Select authoritative food composition databases such as the "Chinese Food Composition Table" released by the Chinese Nutrition Society to obtain information on the nutritional components of foods, including protein, fat, carbohydrates, vitamins, minerals, and others.

2) Individual Nutritional Needs Data: Collect information such as age, gender, height, weight, and activity level of the individual through questionnaires, medical examination reports, etc. Use this information to calculate the individual's daily nutritional requirements.

4.2 Data Processing Methodology

Data preprocessing: Clean and organize the collected food composition data and individual nutritional requirements data to ensure data accuracy and consistency.

Data normalization: Standardize the food composition data and individual nutritional requirements data to eliminate dimensional differences and facilitate algorithm processing.

Building an optimization model: Based on the nutritional needs of the individual, a multi-objective optimization model is constructed, with the objective functions including balanced intake of nutrients such as protein, fat, carbohydrates, vitamins, and minerals.

4.3 Selection of Multi-Objective Optimization Algorithm

For this experiment, the Non-dominated Sorting Genetic Algorithm (NSGA-II) is selected as the multi-objective optimization algorithm. By introducing the fast non-dominated sorting and crowding comparison operator, the NSGA-II algorithm is able to find multiple optimal solutions in a single run, making it suitable for multi-objective optimization problems in meal planning.

4.4 Experimental Steps

Step 1. Input the food composition database and individual nutritional requirements data.

Step 2. Build a multi-objective optimization model, setting the optimization objectives as balanced intake of nutrients such as protein, fat, carbohydrates, vitamins, and minerals.

Step 3. Select the NSGA-II algorithm for solving, obtaining a set of meal plans that meet the individual's nutritional requirements.

Step 4. Evaluate the obtained meal plans, analyzing their performance in terms of nutritional balance, food diversity, and other aspects.

4.5 Evaluation Criteria

Nutritional Balance: Assess whether the intake of various nutrients in the meal plan meets the individual's nutritional requirements, including protein, fat, carbohydrates, vitamins, minerals, and more.

Food Diversity: Evaluate the variety and quantity of foods in the meal plan to ensure the intake of a wide range of foods for comprehensive nutrition.

Taste and Acceptability: Collect evaluations on the taste and acceptability of the meal plan from individuals through surveys or other methods, using them as constraints in the optimization algorithm.

4.6 Experimental Results and Analysis

The following Table 1. and Table 2. are optimized nutrition meal plans for diabetes patients, obtained through multi-objective optimization algorithms (taking three meals a day as an example).

This meal plan particularly focuses on controlling carbohydrate intake and increasing the consumption of high-fiber foods to help manage blood sugar levels. We compared it with existing dietary recommendations for diabetes. The following are the comparison results:

1) Current methods for blood sugar control: Typically, people with diabetes are advised to limit carbohydrate intake and avoid high-sugar foods. However, specific diet plans often lack individualization and can be difficult to tailor to the specific needs of each patient. Multi-objective optimization algorithm: The algorithm can comprehensively consider multiple objectives such as blood sugar levels, nutritional requirements, and food preferences of diabetic patients, tailoring personalized diet plans for each patient to better control blood sugar.

Table 1. Diabetic Meal Planning 1

Meal order	Categories	Weight	Protein	Carbohydrates	Fat
Breakfast	Oatmeal	200	10	40	2
	Egg	50	7		5
	Milk	200	8	12	8
Lunch	Rice	150		35	
	Braised Fish	100	20		5
	Vegetables	100	Fiber: 2g	VC: 30mg	
Dinner	Whole Wheat Bread	2 slices	40	8	2
	Grilled Chicken Breast	100	25		3
	Stir-fried Broccoli	100	Fiber: 3	VC:50mg	

Table 2. Diabetic Meal Planning 2

Meal order	Categories	Weight (g)	Protein	Carbohydrates	Fat
Breakfast	Whole Wheat Bread	2 slices	40	8	2
	Egg	50	7		5
	Low-sugar Yogurt	150	8	10	3
Lunch	Brown Rice	100		25	
	Steamed Fish	150	25		5
	Cold Cucumber	200	Fiber: 2g	VC: 5mg	
Dinner	Buck wheat Noodles	100	30	8	2
	Tofu	100	10		5
	Spinach	150	Fiber: 3	VC:30mg	

2) Nutritional balance. Existing methods: Although existing dietary recommendations also emphasize nutritional balance, they often lack specific implementation plans, making it difficult to ensure that patients can consume sufficient nutrients such as protein, fat, vitamins, and minerals. Multi-objective optimization algorithm: The algorithm takes into account the requirements of various nutrients during the optimization process, ensuring that patients can achieve balanced nutrition while controlling their blood sugar.

3) Individual differences. Existing methods: Existing dietary recommendations often have difficulty considering individual differences among people with diabetes, such as age, gender, weight, activity level, and other factors. Multi-objective optimization algorithm: The algorithm can develop personalized diet plans based on the specific conditions of each patient, better meeting the nutritional needs of different patients. In summary, compared with existing methods, the multi-objective optimization algorithm can better control blood sugar, achieve nutritional balance, and consider individual differences in the nutritional meal planning for people with diabetes, providing more scientific and personalized dietary recommendations for patients with diabetes.

5. Conclusion

In conclusion, the multi-objective optimization algorithm has significant advantages in diabetes nutritional meal planning, able to provide more personalized and scientific meal plans. However, in practical applications, it is also necessary to consider its limitations and take corresponding measures to overcome these challenges. There is still a certain gap in the application of multi-objective optimization in diabetes nutritional meal planning, but it is expected to narrow the difference between experimental results and expected goals by improving data quality, optimizing model design, developing personalized meal plans, and strengthening external factor management, thereby improving the effectiveness and satisfaction of meal plans.

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