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A Modified Integer Programming Model for Hypertension Patients Diet Plan

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ABSTRACT

Hypertension is commonly called a silent killer that could affects people all over the world. Unbalanced diets are one of the risk factors for hypertension. Therefore, hypertension patients must put high concern on their health by taking the right quality and quantity of nutrient foods. Having a good diet plan could reduce their medical expenditure. The objectives of this study are to modify an integer programming model which can create a diet menu that meets the nutritional needs of hypertension patients with minimum calories intakes. The proposed menu of nutrients is based on the solution of the model, which is solved by using Microsoft Excel and MATLAB. This study helps the hypertension patients in choosing the optimum nutrition menu. It also helps researchers and dieticians as they work together with healthcare specialists. This study only focuses on female hypertension patients between the ages of 40 and 60 who do not have any other illnesses or allergies and non-pregnant. The result of the six-meal per day produced by the mathematical model has satisfied the nutrients necessary for hypertension patients with a minimum of 1417 kcal calories intake and two servings of banana during lunch and dinner.

Keywords: Diet Plan, Integer Programming Model, Hypertension Patients

INTRODUCTION

Hypertension is a serious public health issue that affects people in many countries. Hypertension is the medical term for elevated blood pressure (Hui et al., 2021). It is the biggest preventable illness, affecting 26.4% of the world's adult population. In addition, it is a global risk factor for premature death and disability, except for patients with primary or essential arterial hypertension. In primary hypertension, 10% of patients have secondary high blood pressure.

It is estimated that 1.28 billion adults aged 30-79 years worldwide suffer from hypertension (WHO, 2023). High blood pressure is a problem in the United States, affecting over a quarter of the population which is 75 million adults (Mensah, 2018). However, only half of them attain the desired therapeutic blood pressure control. It is a fact that many people with high blood pressure

also have additional diseases or conditions that elevate their chances of developing cardiovascular disease, attack or organ failure which also contributes to their adverse health effects.

Varas-Doval et al. (2020) stated that more than half of patients with hypertension which is 720 million patients were not receiving the proper medicine. Other than medicine, hypertension patients with a healthy lifestyle will prevent and treat chronic diseases. A well-balanced diet is also essential in the treatment of hypertension. Many hypertensive patients are generally uninformed of their dietary requirements, which have now become one of the causes of hypertension (Hui et al., 2021). Hypertension patients must put high concern on their health. They need sufficient nutrients to live along with the disease. They should eat the right quality and quantity of nutrient foods. Practicing a healthy lifestyle with a good daily diet plan which contains the most optimum amount of nutrients will be a very good solution to their problem. Treatment of hypertension patients requires large expenditures in terms of the travelling and medication costs. Therefore, if they opt for any alternatives other than long-term medication treatment, then it would be a huge cost saving for them. Having a good diet plan could reduce their medical expenditures.

A diet plan is normally developed for people based on their health, weight, age and lifestyle, as well as their weight reduction and health objectives. The diet plan serves as a personalized guide to help manage eating habits, body exercise, and lifestyle to achieve maximum health and quality of life. Dietary planning also intends to consume diets that have a low probability of being insufficient or excess in nutrients (Wadden et al., 2020). A-day meal is a good start for hypertension patients to have a healthy lifestyle. Meal planning helps to have a variety of different foods including fruit and vegetables, which reduce the risk of chronic diseases.

Dietary problems of hypertension patients have long been a source of concern in the field of operation research. A diet that includes restrictions on nutrient types is an optimization problem and can be presented as a mathematical model. The advantage of the model is it allows us to maximize or minimize the real function, while ensuring that nutrient requirements are satisfied by choosing the available food provided in the menu. There are variety of mathematical models that are widely used in achieving desired goals in preparing for patients' diet. Among them are linear programming (LP), goal programming (GP) and integer programming (IP).

Khalid et al. (2024) proposed an LP model to produce an optimal diet menu from a fast food restaurant that able to fulfil the daily requirements of calories, protein, carbohydrates and fats for both men and women. Alaini et al. (2019) used LP model to develop a low-cost cancer-preventive diet plan for selected individuals for preparing balanced meals in Kuala Lumpur, Malaysia. A balanced diet is essential to reduce the risk of cancer and a good diet for cancer prevention must include sufficient macronutrients and micronutrients. The study focused on these required nutrients for cancer patients and Excel Solver was used to solve the LP model. Based on local market pricing, the LP model has effectively produced the balanced diet for the cancer-preventive diet plan at minimal cost.

A study for diabetes mellitus patients menu was done by Paidipati et al. (2021) who produced effective approaches for determining the optimal menu plan using GP. The study essentially generating pre-emptive and non-preemptive GP focusing on maximizing energy or calories levels by evaluating the maximum distribution of the amount of food in a recipe. The result has produced recipes for diabetic patients which strived to be low in carbohydrates, lipids and other essential nutrients.

In the context of nutrient requirement for hypertension patients, Kumar et al. (2012) has stated that the blood pressure can be reduced by 10% by taking bananas every day for a week. This finding is significant and very helpful for the hypertension patients. However, as far as it is concerned, the existing mathematical models do not specify the valuable benefits of bananas to hypertension patients. A practical mathematical model should include the impact of the banana potassium content in the diet plan. Therefore, this study is intended to produce a diet plan that include banana intakes for the hypertension patients.

Another concern of the nutrients for hypertension patients lies on the fact that large body weight can lead to a rise in blood pressure. Wilkinson et al. (2020) stated in the United States, about 70% of adults are overweight. Stern et al. (2021) has mentioned that weight loss has a significant effect on preventing and treating high blood pressure. This is true as calorie consumption is closely related to weight loss. It was also stated that the intake of daily calorie consumption of less than 1500 kcal will reduce high blood pressure. From the gap analysis on past studies, this constraint of calories intake for hypertension patients is not mathematically addressed. Therefore, this study has the intention to modify a mathematical model which limits this daily calorie intake.

Having said these, the objective of this study is to propose a day menu for hypertension patients with optimum amount of nutrients. This is done by modifying a mathematical model that can minimize the calories intake, and include the nutrition required by hypertension patients. The proposed menu of nutrients is based on the solution of the modified mathematical model.

This study only focuses on diet plan for female hypertension patients who aged 40-60 in Malaysia, non-pregnant and free from any other diseases or allergies. This is due to the prevalence of chronic diseases such as diabetes, hypertension, stroke and heart disease among Malaysian which commonly occurs between the ages of 40 and 60 (Oo et al., 2020). The data on food and nutrient requirements are the limitation of this study. They are varieties of food types being considered in research over the world. However, this study only uses ten types of food in the model construction. They are drinks, cereal flour-based, rice flour-based, cereal-based meal, meat dishes, vegetables, fruits, wheat flour-based, seafood and miscellaneous. In addition, this study only selects ten nutrients which are carbohydrate, protein, fibre, fats, calcium, magnesium, potassium, sodium, vitamin B2 and vitamin C. Other nutrients are not considered in this study.

METHODOLOGY

This paper is the extension of the study done by Fuazee et al. (2023) which has presented the preliminary development of the IP model. The modified IP model is chosen to be the tool for finding the optimal solution for nutrient recommendations for hypertension patients. The paper has investigated the elements that constitute the mathematical model, which are the model objective functions, constraints, sets and parameters. There are lists of food groups, food items and meals being considered in the model construction. From the gap analysis done, a model objective function which minimizes calories intake is developed. The novelties are the inclusion of bananas as a source of potassium and the minimum calorie intake, which is strongly recommended for hypertension patients. This paper is intended to utilize the modified model obtained from the previous study and implement the experiment to achieve the desired research objectives.

The data of food items consists of 41 foods and drinks with 10 types of food groups. Each of the item is grouped into food categories that include cereal flour-based, rice flour-based, cereal-based meal, meat, seafood, vegetables, fruits, wheat flour-based, miscellaneous and drinks. This

study also included 10 nutrients which are carbohydrate, protein, fibre, fats, calcium, magnesium, potassium, sodium, vitamin B2 and vitamin C. Having the good diet plan helps to reduce high blood pressure. Data is collected from the Recommended Nutrients Intake (RNI) (2017) and Malaysian Food Composition Database (MyFCD) (2023). Food requirement and menu planning per day are obtained from a previous study by Lee et al. (2020). The menu is classified into six meals with 10 food groups and 18 total dishes per day as shown in Table 1. The meals are consisting of breakfast, morning tea, lunch, evening tea, dinner and supper.

This study considers macronutrients of carbohydrate requirements by Dunkley (2021). It has stated that a consumption of carbohydrate within 130 g to 260 g daily can help to regulate blood pressure and lose weight. Beside this, protein intake at a minimum of 52 g is necessary for hypertension to lower BP (Hui et al., 2021). There is also a statement which mentioned that a consistent daily intake of 5.5 g of fibre for women will decrease the SBP and DBP by 7.5 mmHg and 5.5 mmHg, respectively (Aleixandre and Miguel, 2016). In addition to this, Waksmańska et al. (2020) has stated that fats intake of 115 g is essential for female hypertension patients.

Table 1: Menu Planning of Food Item per Day

Meal	Type of Food Group	Amount
Breakfast	Drinks	1
	Cereal Flour-based	1
Morning Tea	Drinks	1
	Rice Flour-based	1
Lunch	Drinks	1
	Cereal Flour-based	1
	Vegetables	1
	Fruits	1
	Meat Dishes	1
Evening Tea	Drinks	1
	Wheat Flour-based	1
Dinner	Drinks	1
	Cereal-based meal	1
	Vegetables	1
	Fruits	1
	Seafood	1
Supper	Drinks	1
	Miscellaneous	1
	Total Dishes Per Day	18

Source: *Lee et al. [16]*

Table 2 shows the range of nutritional values required for the female hypertension patients. The nutrients that are categorised under macronutrients are carbohydrates, protein, fiber, fat and calcium. On the other hand, micronutrients consist of magnesium, potassium, sodium, vitamin B2 and Vitamin C. The recommended lower and upper bound of the nutrient intakes are taken from various sources as stated in the right-hand column.

Table 2: The Lower and Upper Bound of Nutrition Values for Female Hypertension Patients

Type of Nutrients	Nutrients	Lower Bound	Upper Bound	References
Macronutrients	Carbohydrate (g)	130	260	Dunkley (2021)

	Protein (g)	52	-	Hui et al. (2021)
	Fiber (g)	-	5.5	Aleixandre and Miguel (2016)
	Fat (g)	-	115	Waksmańska et al. (2020)
	Calcium (mg)	1000	1500	Cormick and Belizán (2019)
Micronutrients	Magnesium (g)	-	350	Houston (2011)
	Potassium (mg)	-	4700	Staruschenko (2018)
	Sodium (mg)	1000	2300	Aronow (2017)
	Vitamin B2 (mg)	1.1	-	Ben et al. (2019)
	Vitamin C (mg)	-	500	Guan et al. (2020)

There are three types of drinks which are refreshing, stimulating and nourishing (Rathinasamy et al., 2022). This study only considers stimulating beverages that stimulate the body fluids which are tea, coffee, milk and plain water. These are the common drinks consumed by the people. This study considers five food items namely cereal flour-based, four food items of rice flour-based, six food items of cereal based-meal and three food items of wheat flour-based. Wheat flour usage contains high in fibre which necessary for hypertension patients. Food items such as cereal, cookies, muffin and oat able reduce caloric value and also reduce the risk of cancer, obesity, hypertension and diabetes (Arshad and Ahmad, 2021).

The red meat dishes consist of beef, chicken, pork, lamb and maw dishes (Shafiee et al., 2022). This study only considers three meat dishes which are beef, chicken and lamb. High concentrations of glutamic acid and non-essential amino acids found in the silver pomfret. Its incorporation of antioxidants is good to treat hypertension patients (Ahmed et al., 2021). Thus, this study includes silver pomfret as food items. A diet which is rich in fruits and vegetables is effective in preventing cardiovascular disease, blood pressure and other diseases (Mattiolli et al., 2018). In the context, Kumar et al. (2012) has stated that the blood pressure can be reduced by 10% by taking bananas every day for a week. Therefore, this study considers bananas as food groups of fruits, and it should be taken twice a day. The food items adopted for this study are commonly consumed by Malaysian and suitable for hypertension patients. Table 3 shows the information on the selected food items i, food groups j and meals k.

Table 3: List of Food Items, Food Groups and Meals

Food items, i		Food groups, j	Meals, k
Plain water, i=1	White Bread, i=21	Drinks, j=1	Breakfast, k=1
Coffee, i=2	Beef Soup, i=22	Cereal Flour-Based, j=2	Morning Tea, k=2
Milo, i=3	Chicken Curry, i=23	Rice Flour-Based, j=3	Lunch, k=3
Tea, i=4	Coconut Milk Gravy, i=24	Cereal-Based Meal, j=4	Evening Tea, k=4
Milk, i=5	Clam Cooked Chilli, i=25	Meat Dishes, j=5	Dinner, k=5
Apple Juice, i=6	Shrimp Cooked Chilli, i=26	Seafood Dishes, j=6	Supper, k=6
Instant Cereal, i=7	Silver Pomfret, i=27	Vegetables, j=7	
Kaya Bun, i=8	Fried Cuttlefish, i=28	Fruits, j=8	
Oat Cookies, i=9	Broccoli Stir Fried, i=29	Wheat Flour-Based, j=9	
Banana Muffin, i=10	Fried Cabbage, i=30	Miscellaneous, j=10	
Kaya Dumpling, i=11	Stir Fried Vegetable, i=31		
Kuih Lapis, i=12	Kailan Oyster Sauce, i=32		
Kuih Bom, i=13	Coconut Milk, i=33		
Pancake, i=14	Salad, i=34; Banana, i=35		
Kuih Sri Muka, i=15	Currypuff Potato, i=36		
Plain Rice, i=16	Sandwich Sardine, i=37		
Instant Oat, i=17	Doughnut, i=38		

Keow Teow Soup, *i*=18	Kerepek, *i*=39
Fried Mee Hoon, *i*=19	Banana Pengat, *i*=40
Chicken Porridge, *i*=20	Cream Crackers, *i*=41

Source: *Malaysian Food Composition (2023)*

The IP model by Lee et al.(2020) is modified to accommodate the speciality of this study which focus on the diet planning for hypertension patients. Existing mathematical models on diet planning do not consider designated nutrients for hypertension patients. Beside integrating this aspect, this study also considers including bananas in the daily menu with a calorie consumption of 1500 kcal per day. The indices, parameters, decision variables, objective function, model constraints are defined as follows.

Indices:

i : Index for food items
j : Index for food groups
k : Index for meals

Parameters:

I : Set of food items
J : Set of food groups
K : Set of meals
c_i : Calories intake for each food items, i

Decision Variables:

$x_{ijk} = 1$ if the food item i in food group j and meal k is included; 0, otherwise.

Objective Function:

$$\text{Minimize } \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_i x_{ijk} \tag{1}$$

Subject to model constraints:

$$w_L \le \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_i x_{ijk} \le w_U \tag{2}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} x_{ijk} = n_j, \qquad \forall j \tag{3}$$

$$\sum_{i=1}^{I} c_i x_{ijk} \le w_U \tag{4}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} x_{ijk} = 2 \qquad \forall i = 3, \forall j = 8, \forall k = 3,5 \tag{5}$$

where,

$w_L =$ Lower bound for each nutrient content for a day
$w_U =$ Upper bound for each nutrient content for a day
$n_j =$ Required amount of serving for each food group j for a day

Objective function (1) refers to general nutritional requirements. The aim is to minimize the total calories intake in a daily diet of hypertension patients. Constraint (2) refers to general nutritional requirements. It can be expanded into ten constraints of nutrients that include the lower bound and upper bound values based on Table 2. Constraint (3) represents the specification of ten food group requirements which is specified in Table 1. Constraint (4) refers to the maximum calories' intake for hypertension patients in Malaysia as 1500 kcal per day. Constraint (5) ensures that hypertension patients must take exactly 2 servings of bananas per day. Constraint (4) and (5) are the novelty of this study

3. Result

The integer programming model for the optimum diet menu for hypertension patients was solved using Microsoft Excel and MATLAB software. Table 4 shows the optimal result on the total nutrients for a day meal based on the IP model solution. The solution shows that the result has satisfied the lower and upper bound of the nutrient values as stated in Table 2. These nutrients include carbohydrate, protein, fibre, fat, calcium and all other nutrients. Hence, the output results satisfied the model Constraint (2).

Table 4: The Total Nutrient for a Day Meal Based on Model Solution

Food items, *i*	Calori-es	Carbo-hydrate	Protein	Fats	Calci-um	Magn-esium	Fiber	Potas-sium	Sod-ium	Vit. B2	Vit. C
Unit	*kcal*	*g*	*g*	*g*	*mg*	*mg*	*g*	*mg*	*mg*	*mg*	*mg*
Plain Water	0	0	0	0	144	30	0	6	66	0	0
Choc Drink	408	66	10.2	11.4	360	0	0	0	300	0.6	30
Milk	25	4.51	0.81	0.44	24	1	0	43	9	0.12	4.2
Oat Cookies	67	8.07	0.96	3.39	17	2.38	0	12	44	0.1	0
Pancake	71	14.72	0.64	1.03	9	0.79	0	8	2	0.04	0.4
Plain Rice	206	47.64	3.65	0.16	5	0.32	0	10	10	0.02	0
White Bread	96	19.55	3.65	0.38	15	1.13	0.1	22	128	0.12	0.7
Chicken Curry	110	1.35	11.4	6.53	27	1.2	0	60	183	0.24	0
Shrimp Chili	71	0.39	5.77	5.16	196	1	0.1	168	114	0.01	0
Fried Cabbage	28	2.78	3.3	0.34	142	1.56	1	386	30	0.44	105.6
Banana	206	47.2	2.6	0.8	22	1.2	0.8	482	58	0.16	34.6
Sandwich Sardine	71	11.93	2.07	1.62	26	0.45	0.2	26	128	0.02	0.3
Cream Crackers	58	8.62	7.95	1.35	4	0.44	0.2	32	6	0.05	0
Total	1417	232.7	53	31.6	991	41.47	2.4	1255	1078	1.92	175.8
Lower Bound	-	130	52	-	1000	-	-	-	1000	1.1	-
Upper Bound	1500	260	-	115	1500	350	5.5	4700	2300	-	500

Due to the large number of constraints on nutrients and food groups, the modified IP model only provides a one-day diet menu for female hypertension patients. Table 5 shows the menu plan for hypertension patients with the optimum amount of nutrition in a day. From the MATLAB results, hypertension patients should take plain water, milk and oat cookies for breakfast, plain water and pancake for morning tea, plain water, plain rice with chicken curry, fried cabbage and banana for lunch, plain water, milo and sandwich sardine for evening tea, plain water, milo, white bread, shrimp cooked in chili, fried cabbage and banana for dinner and plain water, chocolate drink and cream crackers biscuits for supper. This satisfies the research objective which is to propose a day menu for hypertension patients based on the solution of the modified model with six meals per day.

From previous research, Lee et al. (2020) presented 18 dishes for menu planning per day according to specific food group, which include drinks and dishes. These specifications are enforced by Constraint (3). In terms of drinks, MATLAB result has successfully produced the total number of drinks as four drinks per day, excluding plain water. The model in this study does not consider plain water as a beverage because it makes up 60% of the human body which makes the body hydrated. It also aids the body in obtaining essential minerals and eliminating toxins. Drinking six to ten 8-ounce glasses of water per day will provide health benefits by treating high BP (Rodger et al., 2023). From five drinks considered in this study, the result has established that hypertension patients should take milk for breakfast and milo for evening tea, dinner and supper.

The result in Table 5 also indicates the amount of food items and calories intakes per day. The result shows the calorie intake of food item per day is 1417 kcal which is less than 1500 kcal per day. These observations have satisfied Constraint (4). Besides this, it was also found that the banana intakes are two servings of bananas a day during lunch and dinner. All these observations have satisfied Constraint (5). With these findings, the generated menu meets the nutrient requirements of hypertension patients.

Hypertension patients should take a small portion and frequent meals per day. There should be a gap of two to three hours per meal (Stergiou et al., 2021). Taking three meals per day will double the portion of meals which is not suitable for hypertension patients. This is the reason why this study considers six meals per day for hypertension patients.

Table 5: Optimal Menu Plan for a Day for Hypertension Patients

Meal	Food items	Amount of Serving	Amount of Calories (kcal)
Breakfast	Plain Water	1	0
	Milk	1	25
	Oat Cookies	1	67
Morning Tea	Plain Water	1	0
	Pancake	1	71
Lunch	Plain Water	1	0
	Plain Rice	1	206
	Chicken Curry	1	110
	Fried Cabbage	1	14
	Banana	1	103
Evening Tea	Plain Water	1	0
	Milo	1	136
	Sandwich Sardine	1	71
Dinner	Plain Water	1	0
	Choc Drinks	1	136
	White Bread	1	96
	Shrimp Cooked in Chili	1	71
	Fried Cabbage	1	14
	Banana	1	103
Supper	Plain Water	1	0
	Choc Drinks	1	136
	Cream Crackers	1	58
	Total of Servings/Calories	22	1417

The solution obtained from the modified model is unique. There is no other alternate solution produced by MATLAB. In order to offer other menu for the diet plan, the constraint of the calories intake was adjusted. From the upper bound of 1500 kcal the value was lowered to 1450 kcal. The purpose is to obtain other set of menu for another day. A calorie below 1450 kcal is selected because it remains within the range of optimal calories. The result shows that it takes 2.160 seconds processing time when the calories value was below 1450 kcal, as compared to 2.194 seconds processing time for calories value below 1500 kcal. It shows that the alternate solution is produced in shorter processing time. In terms of the the calories intake, the optimal result obtained was recorded to be 1417 kcal. The decision variables based on model solution produced are the same as before.

For further analysis, the upper bound of calories was then lowered to 1400 kcal. The purpose is to obtain another set of diet plan menu. MATLAB output results shows that there is no feasible solution found. This indicates that there is no menu can be generated for calories intake of less than 1400 kcal. To get a solution with calories below 1400 kcal, then an option is to modify the selection of food items. This is because different food items contain different amount of calories. As for this study, setting a calories intake less than 1400 kcal will not produce any feasible solution.

CONCLUSION

Hypertension patients need to have knowledge about the nutrient requirements which are best for them. This study has successfully modified an IP model and proposed a-day menu for hypertension patients, which minimizes the calories' intakes. The optimal menu plan that was obtained from the experiment includes varieties of food items which are categorized according to food groups, food items, and served in six meals in a day.

The computational experiment produced 22 dishes of food per day. This solution satisfies all the dishes constraints in the IP model. In addition to this, the result shows the optimum calorie intake of food item per day is 1417 kcal, which is below 1500 kcal per day as specified in the model constraint. The solution shows that hypertension patients should take two servings of bananas a day during lunch and dinner. In addition, they need to take bananas every day for a week so that there is a reduction in blood pressure. This study does not only produce a diet plan for hypertension patients but also presented the research novelties. The novelties are the inclusion of banana as a source of potassium and the minimum of calories intake, which is strongly recommended for hypertension patients.

For future research, it is recommended to include a variety types of food items in each food group so that hypertension patients can have more options in a daily meal plan. This research only considered one type of dish for each food item. In addition, it is recommended that future studies produce a weekly-diet menu plan so that there will be longer menu cycle, besides considering minimizing cost in the menu plan. Future research may also use a metaheuristic solution approach for future works in contrast to heuristic approach used in this study. It is because metaheuristic is more powerful and able find a near optimal solution on a large-scale problem with shorter processing time.

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