

Design a T2DM-Meal Plan by Enhancing Current Practice using Linear Programming

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Abstract

Changing lifestyles, ignorance of nutritional knowledge and low health consciousness among Malaysians have promoted the alarming increase of diabetes cases today. Currently, an optimal palatable meal for T2DM-affected individuals is not achievable because dietitians have to perform tedious manual calculations; differentiated views on meal plan; and limited consultation time. In addition, none of the few researches on T2DM-meal planning have applied exchange lists currently practiced by dietitians. To provide a mathematical solution to the problem, this research has used linear programming to develop a meal plan as it has the ability to find the best optimal solution when all the constraints are satisfied, and also as an alternative to the current practices. A Malaysian food exchange list for T2DM-affected individuals based on available information in the *Atlas* was created for this purpose. Adapting the current standard dietitian practice and available guidelines has also made design of T2DM-meals more direct and logical with the production of two different models, Exchange Planner and Meal Planner. These models can translate dietary recommendations into actual food exchange plans as well as suggest the amount of food intakes for each meal or snack. In conclusion, the resultant meal plans have successfully minimized energy intakes and satisfied specified restrictions which may simultaneously improve glycaemic control and lessen risk of complications for individuals with T2DM.

Keywords: Atlas, exchange list, Exchange Planner, Meal Planner, T2DM

Introduction

When beta (β) cells in the pancreas fails to produce sufficient insulin to transmit sugar to body cells for energy and abnormally high levels of sugar arise, a metabolic disease called diabetes mellitus (or diabetes) takes place (Coates & Flannery, 2010; MedicineNet, 2013). Recent 2013 statistics estimated doubling of current world diabetic population of 382 million people to 592 million before 2038 (International Diabetes Federation, 2013). The incidence of diabetes has exhibited an alarming rate of increase over the years. In Malaysia, an increase in number of diabetics from 11.6% in 2006 to 15.2% in 2011 has been reported in the *National Health and Morbidity Survey (NHMS)* and a further increase to 21.6% by 2020 have been estimated (Mustapha & Azmi, 2013).

Meal planning for diabetics in Malaysia are affected by: poor nutritional understanding and low health consciousness among diabetics (Lim et al., 2010); public not only unaware of the existence of *Malaysian Dietary Guidelines* (MDG) but also not able to understand key words and key messages (Norimah et

al., 2010); older adults face difficulty understanding the food pyramid (Shahar et al., 2012); experts differ in opinion on meal plans (Sharkawi et al., 2014); and dietitians lack of time to build proper meal plans for patients (Bader et al., 2013). In addition, diabetics are not able to determine their own meal (Swift, 2012); difficult to balance food intakes because food selections are based on habits, preferences, ethnics and traditions (Bawadi & Al-Sahawneh, 2008; Brown et al., 2001); and individuals are incapable of translating conflicting nutrition guidelines (Dotson, 2011; Swift, 2012). Besides, meal planning should focus on both calories and intakes of nutrients (Dotson, 2011; Maillot et al., 2010).

Currently, Malaysian dietitians plan a meal for type 2 diabetes mellitus (T2DM) patients manually using the Malaysian food exchange lists from Shahar et al. (2009). Food-based guidelines are more effective over nutrient-based approach in conveying the messages of nutrition and health (Shahar et al., 2012), but trial and error methods used today are unable to consider the infinitely many possible solutions, thus concluding diets are not optimal (Soden & Fletcher, 1992).

Mathematical modelling may be an excellent approach to translate dietary recommendations into actual food plans and to develop food-based dietary guidelines (Masset et al., 2009).

Thus far, none of the few researches focused on meal planning problems for T2DM-affected individuals have applied the exchange lists currently practiced by dietitians. By using linear programming (LP), the current research has enhanced the current standard dietitian practice to design meals for T2DM-affected individuals in a more straightforward and understandable manner. In particular, it aimed at creating a database on exchange lists of Malaysian food with corresponding nutrient and energy contents for T2DM patients; and formulating LP model that will minimize the energy intakes while satisfying all specified requirement for them.

Methodology

Focus of Research

Four categories of diabetes mellitus exist: type 1 diabetes mellitus (T1DM), type 2 diabetes mellitus (T2DM), gestational diabetes mellitus and other specific types of diabetes. (American Diabetes Association, 2013, 2014). T2DM, most common type of diabetes, develops gradually most often among overweight individuals or obese and thin elderly. 99.3% of the 657 839 registered patients from 2009 to 2012 currently receiving diabetes care at healthcare clinics operated by Malaysian Ministry of Health (MOH) are diagnosed with T2DM. Figure 1 displays three highly populated groups of T2DM patients: age 45-54 (32.6%), age 55-64 (28.7%) and age 30-44 (20.1%) (Mustapha & Azmi, 2013).

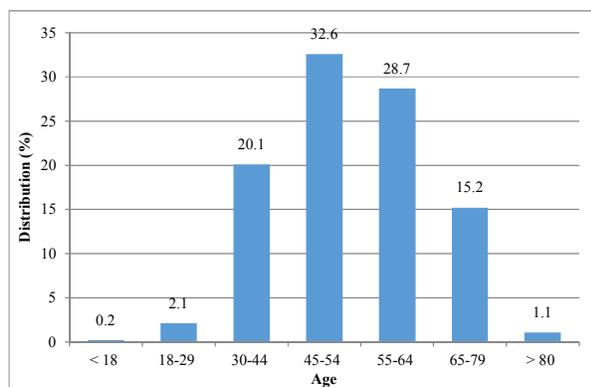


Figure 1: Distribution of T2DM Patients in Malaysia. Retrieved from National diabetes registry report, p. 14, by Mustapha & Azmi, 2013, Kuala Lumpur: Ministry of Health.

T2DM is not prevalent in patients aged less than 18 years old. In addition, cognitive and physical

impairments of individuals aged 65 years and older increase with age (American Association of Diabetes Educators, 2009). Therefore, focus group for this research was T2DM adults aged 18 to 64 years old only but, with normal body weight and more importantly not treated with insulin.

Data used in research

Three lists referred in this research included: list of food items for meal planning; list of nutrient requirements for T2DM-affected individuals; and list of food group requirements for T2DM-affected individuals. The first list was extracted from the exchange lists of commonly consumed foods by Malaysians compiled by Shahar et al. (2009) from the *Malaysian Food Composition Table in the Atlas of Food Exchanges and Portion Sizes (Atlas)*. By filtering items unsuitable for T2DM-affected individuals from the original exchange list of 109 food items from different food groups, a database of Malaysian food exchange list for T2DM-affected individuals was created. Final list containing 173 foods from different food groups and different meals and snacks along with types of food items (cooked or raw); household measurements (cup, bowl, spoon, etc.); weight of food per item; food energy; macronutrient (carbohydrate, protein and fat) contents; and sodium contents were compiled in a spreadsheet using Microsoft Excel 2010. The second list was sourced from *Medical Nutrition Therapy: Guidelines for Type 2 Diabetes Mellitus (2nd ed.)* (Malaysian Dietitian's Association, 2013); *Clinical Practice Guidelines: Management of Type 2 Diabetes Mellitus (4th ed.)* (MOH, 2009); and *Clinical Practice Guidelines: Management of Type 2 Diabetes Mellitus (5th ed.)* (MOH, 2015). The last list used information from the Malaysian food pyramid (MOH, 2010).

Model development

This research has adopted the four stages in the *Atlas* by Shahar et al. (2009) and the model formulation by Hamzah et al. (2011) with some suggested modifications.

Stage 1 - Determine the Body Mass Index (BMI)

BMI was determined using the following equation (MOH, 2010):

$$\text{BMI (kg/m}^2\text{)} = \frac{\text{weight (kg)}}{\text{height (m)}^2} \quad (1)$$

Classifying individual's weight according to the *Atlas*, the BMI for normal weight should be 18.5 to 24.9.

Stage 2 - Determine energy needs

The research has adopted the quick method equation from Shahar et al. (2009)

$$\begin{aligned} & \text{Energy requirement, } E \\ & = \text{weight (kg) x quick method factor (kcal/kg)} \end{aligned} \quad (2)$$

The quick method factor (QMF) differs by an individual's activity level based on his weight status, thus only column 3 of Table 1 was applicable in calculating energy requirements for an individual with normal weight.

Table 1: QMF for Individual Based on Weight Status

| Physical activity level ^a | Factor (kcal/kg) | | |
|--------------------------------------|------------------|--------|------------|
| | Underweight | Normal | Overweight |
| Sedentary ^b | 35 | 30 | |
| Moderate | 40 | 35 | 20-25 |
| Marked | 45 | 40 | |

Notes. Retrieved from *Atlas of food exchanges and portions sizes (2nd ed.)*, p. 109, by Shahar et.al, 2009, Kuala Lumpur: MDC Publisher Sdn.Bhd.

^a Categorized physical activity according to type, frequency, duration and intensity

^b Minimal body movement (reading, working at computer, watching television)

Energy distribution of carbohydrate, protein and fat in gram units were calculated using general factors 4,4, and 9 and the following equations (Shahar et al., 2009):

$$\begin{aligned} & \text{Grams of carbohydrate} \\ & = \frac{\text{total energy allowed (kcal)} \times \% \text{ carbohydrate}}{4 \text{ kcal/g}} \end{aligned} \quad (3)$$

$$\begin{aligned} & \text{Grams of protein} \\ & = \frac{\text{total energy allowed (kcal)} \times \% \text{ protein}}{4 \text{ kcal/g}} \end{aligned} \quad (4)$$

$$\begin{aligned} & \text{Grams of fat} \\ & = \frac{\text{total energy allowed (kcal)} \times \% \text{ fat}}{9 \text{ kcal/g}} \end{aligned} \quad (5)$$

Stage 3: Development of linear programming model for exchange planner (LPMEP) — Convert Calories Allowances into Exchanges

Modifications were made to suit T2DM-affected individuals, thus energy was the main objective considered subject to all requirements of specific individual. Notations used were:

- z = energy level, $z = 1, 2, \text{ or } 3$; $z = 1$ (1500 kcal); $z = 2$ (2000 kcal); and $z = 3$ (2500 kcal)
- i = exchange group, $i = 1, 2 \text{ or } 3$; $i = 1$ (carbohydrate); $i = 2$ (protein); and $i = 3$ (fat)
- j = food group, $j = 1, 2, \dots, 7$; $j = 1$ (rice, cereal, grain products and starchy vegetables, Rc); $j = 2$ (fruits, Fr); $j = 3$ (non-fat milk, Mk); $j = 4$ (lean meat, poultry and meat substitute, Mt); $j = 5$ (fish, Fs); $j = 6$ (legumes, Lg); and $j = 7$ (fat, Ft)

- k = nutrient, $k = 1, 2, \text{ and } 3$; $k = 1$ (carbohydrate); $k = 2$ (protein); and $k = 3$ (fat)
- E_z = minimum energy intakes at z energy level

- e_{ij} = energy content for each j food group in i exchange group
- x_{ij} = exchange portion for each j food group in i exchange group
- y_{ijk} = nutrient k content for each j food group in i exchange group
- $LL_{z,k}$ = lower limit of nutrient k at z energy level
- $UL_{z,k}$ = upper limit of nutrient k at z energy level
- $LL_{z,i,j}$ = lower limit of exchange portion requirement for each of j food group in i exchange group at z energy level
- $UL_{z,i,j}$ = upper limit of exchange portion requirement for each of j food group in i exchange group at z energy level

Table 2 shows the summary of the proposed constraints in LPMEP based on guidelines from the second and third list mentioned earlier on.

Table 2: Summary of Constraints in LPMEP (in Stage 3)

| Constraints | Recommended |
|---|---------------------------------|
| Food group requirements ^a | |
| Rice, cereal, grain products and starchy vegetables | ≥ 8 and ≤ 16 |
| Fruits | $= 2$ |
| Non-fat milk | ≥ 1 and ≤ 3 |
| Lean meat, poultry and meat substitute | ≥ 1 and ≤ 4 |
| Fish | $= 2$ |
| Legumes | $\geq \frac{1}{2}$ and ≤ 1 |
| Macronutrient requirements ^b | |
| Carbohydrate | ≥ 45 and ≤ 60 |
| Protein | ≥ 15 and ≤ 20 |
| Fat | ≥ 25 and ≤ 35 |
| Exchange group requirements ^c | |
| Carbohydrate | ≥ 45 and ≤ 60 |

^a Varies according to energy level (i.e. 1500 kcal/d; 2000 kcal and 2500 kcal/d)

^{b, c} In percentage of energy

Table 3 shows macronutrients (carbohydrate, protein and fat) with a revised set of energy contents for each food group used to design the LPMEP.

Table 3: Food Exchange List with Macronutrient Content

| Exchange group | Food group | Carbohydrate (g) | Protein (g) | Fat (g) | Energy (kcal) ^a |
|----------------|--|------------------|-------------|---------|----------------------------|
| Carbohydrate | Rice, cereal, grain products and starch vegetables | 15.00 | 2.00 | 0.50 | 72.50 |
| | Fruits | 15.00 | 0.00 | 0.00 | 60.00 |
| | Non-fat milk (1% fat) ^b | 15.00 | 8.00 | 0.00 | 92.00 |
| Protein | Lean meat, poultry and meat substitute | 0.00 | 7.00 | 4.00 | 64.00 |
| | Fish, shellfish and legumes | 0.00 | 7.00 | 1.00 | 37.00 |
| | Legumes | 21.00 | 6.00 | 0.20 | 109.80 |
| Fat | Fat | 0.00 | 0.00 | 5.00 | 45.00 |

Notes. Retrieved from *Atlas of Food Exchanges and Portions Sizes (2nd ed.)*, p. xiii, by Shahar et.al, 2009, Kuala Lumpur: MDC Publisher Sdn.Bhd.

^a Energy was calculated using general factors of 4, 4 and 9.

^b Non-fat milk has been considered as part of carbohydrate exchange group as it fits the criteria by containing similar amount of carbohydrate

The complete formulation for LPMEP is given below:

For each energy level, z ($z = 1, 2$, or 3):

$$\begin{aligned} &\text{minimize } E_z \\ &= \sum_{i=1}^3 \sum_{j=1}^7 e_{i,j} x_{i,j} \\ &= \sum_{j=1}^3 e_{1,j} x_{1,j} + \sum_{j=4}^6 e_{2,j} x_{2,j} + e_{3,7} x_{3,7} \end{aligned} \quad (6)$$

subject to:

Macronutrient constraints

(Carbohydrate)

$$LL_{z,1} \leq \sum_{j=1}^3 y_{1,j1} x_{1,j} + \sum_{j=4}^6 y_{2,j1} x_{2,j} + y_{3,71} x_{3,7} \leq UL_{z,1} \quad (7)$$

(Protein)

$$LL_{z,2} \leq \sum_{j=1}^3 y_{1,j2} x_{1,j} + \sum_{j=4}^6 y_{2,j2} x_{2,j} + y_{3,72} x_{3,7} \leq UL_{z,2} \quad (8)$$

(Fat)

$$LL_{z,3} \leq \sum_{j=1}^3 y_{1,j3} x_{1,j} + \sum_{j=4}^6 y_{2,j3} x_{2,j} + y_{3,73} x_{3,7} \leq UL_{z,3} \quad (9)$$

Exchange group constraint

(Carbohydrate exchange group)

$$LL_{z,1} \leq \sum_{j=1}^3 y_{1,j1} x_{1,j} \leq UL_{z,1} \quad (10)$$

Food group constraints

$$LL_{z,i,j} \leq x_{i,j} \leq UL_{z,i,j} \quad \text{if } z = 1 \text{ or } 2; j = 1, 3, 4 \text{ and } 6 \quad (11)$$

$$x_{i,j} = LL_{z,i,j} \quad \text{for } j = 2 \text{ and } 5; \text{ and if } z = 3; j = 1, 2, 3, \dots, 6 \quad (12)$$

Non-negativity constraint

$$x_{i,j} \geq 0 \quad \text{for } i = 1, 2 \text{ and } 3; j = 1, 2, \dots, 7 \quad (13)$$

Stage 4: Development of linear programming model for meal planner (LPMMP)—Convert the Exchanges into a Meal Plan

Different objectives were considered and applied to six different meals (breakfast, morning tea, lunch, evening tea, dinner, and supper). The overall 173 selected food items from different food groups, and different meals and snacks along with food energy; the macronutrient (carbohydrate, protein and fat) contents; and sodium contents were used to design the LPMMP. The notations used in stage 4 are presented below:

- p = type of meal, $p = 1, 2, \dots, 6$; $p = 1$ (breakfast); $p = 2$ (morning tea); $p = 3$ (lunch); $p = 4$ (evening tea); $p = 5$ (dinner); and $p = 6$ (supper)
- q = food code, $q = 1, 2, \dots, 173$; $q = 1, 2, \dots, 26$ for breakfast; $q = 27, 28, \dots, 36$ for morning tea; $q = 37, 38, \dots, 94$ for lunch; $q = 95, 96, \dots, 105$ for

- evening tea; $q = 106, 107, \dots, 163$ for dinner; and $q = 164, 165, \dots, 173$ for supper
- r = nutrient, $r = 1, 2, \dots, 4$; $r = 1$ (carbohydrate); $r = 2$ (protein); $r = 3$ (fat); and $r = 4$ (sodium)
- E = minimum energy intakes
- $e_{p,q}$ = energy content for each q food item in p type of meal
- $x_{p,q}$ = exchange portions for each q food item in p type of meal
- $y_{p,q,r}$ = nutrient r contents for each q food item in p type of meal
- L_r = recommended requirements for nutrient
- $L_{p,q}$ = recommended exchange portion for respective q food item in p type of meal

The LPMMP has been mathematically formulated to achieve a palatable meal with realistic solutions as follows:

$$\begin{aligned} &\text{minimize } E \\ &= \sum_{p=1}^6 \sum_{q=1}^{173} e_{p,q} x_{p,q} \\ &= \sum_{q=1}^{26} e_{1,q} x_{1,q} + \sum_{q=27}^{36} e_{2,q} x_{2,q} + \sum_{q=37}^{94} e_{3,q} x_{3,q} \\ &+ \sum_{q=95}^{105} e_{4,q} x_{4,q} + \sum_{q=106}^{163} e_{5,q} x_{5,q} + \sum_{q=164}^{173} e_{6,q} x_{6,q} \end{aligned} \quad (14)$$

subject to:

Macronutrient constraints

(Carbohydrate)

$$\begin{aligned} &\sum_{q=1}^{26} y_{1,q1} x_{1,q} + \sum_{q=27}^{36} y_{2,q1} x_{2,q} + \sum_{q=37}^{94} y_{3,q1} x_{3,q} \\ &+ \sum_{q=95}^{105} y_{4,q1} x_{4,q} + \sum_{q=106}^{163} y_{5,q1} x_{5,q} + \sum_{q=164}^{173} y_{6,q1} x_{6,q} \\ &\geq L_1 \end{aligned} \quad (15)$$

(Protein)

$$\begin{aligned} &\sum_{q=1}^{26} y_{1,q2} x_{1,q} + \sum_{q=27}^{36} y_{2,q2} x_{2,q} + \sum_{q=37}^{94} y_{3,q2} x_{3,q} \\ &+ \sum_{q=95}^{105} y_{4,q2} x_{4,q} + \sum_{q=106}^{163} y_{5,q2} x_{5,q} + \sum_{q=164}^{173} y_{6,q2} x_{6,q} \\ &\geq L_2 \end{aligned} \quad (16)$$

(Fat)

$$\begin{aligned} &\sum_{q=1}^{26} y_{1,q3} x_{1,q} + \sum_{q=27}^{36} y_{2,q3} x_{2,q} + \sum_{q=37}^{94} y_{3,q3} x_{3,q} \\ &+ \sum_{q=95}^{105} y_{4,q3} x_{4,q} + \sum_{q=106}^{163} y_{5,q3} x_{5,q} + \sum_{q=164}^{173} y_{6,q3} x_{6,q} \\ &\geq L_3 \end{aligned} \quad (17)$$

Sodium constraint

$$\sum_{q=1}^{26} y_{1,q4}x_{1,q} + \sum_{q=27}^{36} y_{2,q4}x_{2,q} + \sum_{q=37}^{94} y_{3,q4}x_{3,q} + \sum_{q=95}^{105} y_{4,q4}x_{4,q} + \sum_{q=106}^{163} y_{5,q4}x_{5,q} + \sum_{q=164}^{173} y_{6,q4}x_{6,q} \leq L_4 \tag{18}$$

Food group constraint

$$\sum_{q \in Q} x_{p,q} = L_{p,q} \quad \text{for } p = 1, 2, \dots, 6; \quad Q = \{q | q = 1, 2, \dots, n_j\} \tag{19}$$

Repetition constraint

$$\sum_{q=41}^{89} (x_{3,q} + x_{5,q+69}) \leq 1 \tag{20}$$

Non-negativity constraint

$$x_{p,q} \geq 0 \quad \text{for } p = 1, 2, \dots, 6; \quad q = 1, 2, \dots, 173 \tag{21}$$

Results and Discussion

Verification and validation of both LP models were done based on the analysis of results solved using the Solver Add-in function in Microsoft Excel 2010.

Investigating the outcomes of LPMEP

Different requirements of exchange portions comply with different levels of energy, z : 1500, 2000 and 2500 calories per day. Therefore, a sample data of three different individuals were used to investigate the outcomes of the model based on three different levels of energy allowances of respective individuals (see Table 4).

Table 4: Data of Three Different Individuals

| | Individual A | Individual B | Individual C |
|---|--------------|--------------|--------------|
| Height (m) | 1.50 | 1.50 | 1.60 |
| Weight (kg) | 50.00 | 50.00 | 62.50 |
| Physical activity level | Sedentary | Marked | Marked |
| Energy allowances (kcal/d) ^a | 1500 | 2000 | 2500 |

^a Calculated using quick method formula based on weight and activity level of an individual

Table 5 shows the optimal solution of the exchange portions for each food group according to each level of energy which corresponds to the imposed constraints. Since the solution has demonstrated minimal differences from the actual recommendations in MDG and the suggested exchanges portions of the model have almost satisfied the minimum recommended requirements for each food group, the optimal solution of the exchange portions (in stage 3) have succeeded at different energy level.

Table 5: Comparison of Optimal Solution of the Model Based on Three Different Individuals to the Recommended Requirements as in MDG

| Results | 1500 kcal/d | | 2000 kcal/d | | 2500 kcal/d | |
|---|-------------|-------|-------------|-------|-------------|-------|
| | MDG | Model | MDG | Model | MDG | Model |
| Rice, cereal, grain products and starchy vegetables | 8.00 | 8.13 | 12.00 | 12.00 | 16.00 | 16.00 |
| Fruits | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Non-fat milk | 1.00 | 1.13 | 2.00 | 2.00 | 3.00 | 3.00 |
| Lean meat, poultry and meat substitute | 1.00 | 2.00 | 2.00 | 2.14 | 4.00 | 4.00 |
| Fish | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Legumes | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 1.00 |
| Fat | - | 5.50 | - | 7.76 | - | 8.65 |

Based on the suggested exchange portions for each food group of the respective individuals, the optimal solution for macronutrient and energy intakes per day is presented in Table 6. Here, the energy intakes at each energy level were lower than the energy requirements of the respective individuals. Therefore, the objective of the model to obtain the solution at the least combination of energy contents for each food group has been achieved.

Table 6: Optimal Solution of the Macronutrient and Energy Intakes (in Stage 3)

| Results | Energy Allowances (kcal/d) | | |
|-------------------------------|----------------------------|--------|--------|
| | 1500 | 2000 | 2500 |
| Carbohydrate (g/d) | 179.25 | 261.00 | 336.00 |
| Protein (g/d) | 56.25 | 75.00 | 104.00 |
| Fat (g/d) | 41.67 | 55.56 | 69.44 |
| Total Energy Intakes (kcal/d) | 1317 | 1844 | 2385 |

Table 7 presents a detailed distribution of energy intakes (carbohydrate, protein and fat) at each different level of energy. Results indicate that LPMEP has achieved the recommended requirements of the macronutrient with all percentage values complying with the recommended proportions for T2DM-affected individuals at the least intakes of energy and has reached 100% of the energy requirements for those individuals.

Table 7: Contribution of the Macronutrient to the Total Energy Intakes

| Results | Recommended | Energy Allowances (kcal/d) | | |
|--------------------------|-------------|----------------------------|-------|-------|
| | | 1500 | 2000 | 2500 |
| Carbohydrate (%) | ≥45 and ≤60 | 54.44 | 56.62 | 56.35 |
| Protein (%) | ≥15 and ≤20 | 17.08 | 16.27 | 17.44 |
| Fat (%) | ≥25 and ≤35 | 28.47 | 27.11 | 26.21 |
| Total Energy Intakes (%) | 100 | 100 | 100 | 100 |

Investigating the outcomes of LPMMP

The LPMMP has developed a meal plan for T2DM patients based on the optimal solution achieved in stage 3. Table 8 shows the optimal solution of LPMMP for the consumption of nutrients and energy per day. Interestingly, values obtained were identical to the

advised requirements in LPMEP with the exception of sodium which was introduced as one of the constraint for LPMMP. The solution for sodium intakes was possible to be found even when it was constrained below the maximum of 2400 milligrams per day as recommended requirements for diabetic patients.

Table 8: Optimal Solution of Nutrients and Energy Intakes of Model (in Stage 4)

| Results | Energy Allowances (kcal/d) | | |
|-------------------------------|----------------------------|---------|---------|
| | 1500 | 2000 | 2500 |
| Carbohydrate (g/d) | 179.25 | 261.00 | 336.00 |
| Protein (g/d) | 56.25 | 75.00 | 104.00 |
| Fat (g/d) | 41.67 | 55.56 | 69.44 |
| Sodium (mg/d) | 510.74 | 1460.00 | 2177.98 |
| Total energy intakes (kcal/d) | 1317 | 1844 | 2385 |

The above discussions have concluded that daily intakes of food were feasible at the lowest intakes of energy, while also satisfying specified nutrients requirements and other restrictions on the model. Therefore, LPMMP has succeeded at fulfilling the objective of finding an optimal solution on food intakes for different meals and snacks at the minimum intakes of energy mainly for individuals with T2DM.

Conclusions

In general, this research has successfully used LP approach to mathematically formulate the current practices by dietitians in Malaysia. Both LPMEP and LPMMP have produced significant results that have satisfied the aim of this research to plan food intakes for T2DM patients at the least intakes of energy while fulfilling all prescribed requirements of respective individuals. The models are able to maintain consistency of meals or snacks consumptions, and appropriate choices of food and amounts; as well as observe intakes of energy and nutrients of a variety of food selection, thus the developed models may be helpful to individuals with T2DM. More importantly, research findings have enhanced the current slow iterative process and tedious manual calculations to plan meals for T2DM-affected individuals, thus dietitians can spend more time on educating, and relaying health messages to patients.

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