A practical solution to improve the nutritional balance of Korean dine-out menus using linear programming

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Abstract

Objective: We analysed optimal nutrient levels using linear programming (LP) to reveal nutritional shortcomings of Korean dine-out meals and to stress the importance of fruits and dairy products for maintaining a healthy diet.
Design: LP models that minimize deviation from recommended nutrient values were formulated to analyse deficiency or excess of nutrients under the best situation.
Setting: Korean dine-out menus and nutritional information were taken from the nutrient composition tables for dine-out menus developed by the Ministry of Food and Drug Safety and the nutrient database from Computerized Analysis Program. Acceptable macronutrient distribution ranges of macronutrients such as carbohydrate, protein and fat, and recommended intake levels for energy, vitamins, minerals and cholesterol, by sex, were based on the Dietary Reference Intake for Koreans aged 30–49 years.
Participants: Optimization was performed on selecting the optimal Korean meal combination.
Results: LP optimization models showed that it is unlikely to satisfy all nutrient recommendations with any combination of dine-out menus. Specifically, meal combinations of Korean dine-out menus had high levels of Na and cholesterol and low levels of vitamins and minerals. Four formulations were considered to compare the effects of controlling Na and including fruit and dairy products. The unbalanced diet was resolved with extra consumption of fruits and dairy products.
Conclusions: The best meal combination in dine-out menus, even though the proportion and pairing of menus may be unrealistic, is not healthy, and thus one should consume fruits and dairy products to maintain a balanced diet.

Keywords
Dining out
Linear programming
Diet optimization
Korean meals

Demographic changes are affecting our meal patterns such as when we eat, where we eat and who we eat with[1,2]. Even though a healthy diet is an important aspect of a healthy life, maintaining a healthy diet is not an easy task in today's society. An increase in dual-income households and long work hours are attracting individuals and families to dine out, take out or order in from restaurants[3]. Likewise, the proportion of one-person households and dual-income households is expanding and an increasing number of individuals are enjoying eating out rather than cooking their own meals in South Korea[4]. While the variety of menus and convenience of eating out or ordering in have been improving, it is still generally difficult to maintain a well-balanced diet from available restaurant menus.

In fact, dining out alone has become popular in recent years, especially among the younger generation, and many restaurants nowadays have customized menus and special seating for customers who come alone[5]. Moreover, delivery service for restaurants has improved significantly; some companies specialize in delivering takeout meals where individuals can order food from any restaurant and even have meals delivered to an outdoor location such as a public park[6].

The popularity in eating out is due to its convenience, mainly because it is the best option for saving time. However, the general guideline is to avoid dining out frequently because it is difficult to consume all the necessary nutrients that are recommended for a healthy diet.

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The dine-out culture of Korea is unique because Korean restaurants do not serve full-course meals and most restaurants that serve main dishes do not offer dessert. A main menu is usually served with several side menus, but dessert menus are often skipped because they cannot be consumed in one seating. While Korean meals use various grains, meats and vegetables, it is very rare for fruit and dairy products to be used as ingredients. Hence, a critical concern with the Korean dine-out culture is the shortage of fruit and dairy products that results in imbalance of nutritional intake.

Several studies have reported dine-out patterns and nutritional adequacy or health outcomes. A systematic review described that eating out of home was associated with a higher total energy intake and energy contribution from fat in the daily diet, as well as with a lower intake of micronutrients, particularly vitamin C, Ca and Fe(7). Watts *et al.* have shown that more frequent dinner meals prepared away from home and eating out with friends were associated with lower scores on the Healthy Eating Index adapted to the Canadian context among adolescents with overweight or obesity(8). Korean dine-out meals are known to be high in Na and low in vitamins and minerals(9). National survey data showed that individuals in the non-homemade meal group had higher energy intakes, with higher percentages of energy from protein and fat and lower intakes of dietary fibre, P, K, niacin and vitamin C, than those in the homemade meal group among Korean adults(10). Dining out on a regular basis might have long-term effects on one's health if one is not carefully selecting what to eat each day.

Therefore, the present study was conducted to discuss the nutritional shortcomings in Korean dine-out menus using linear programming (LP) and to suggest solutions to meet the recommended nutritional intake for people who habitually dine out using optimization models. Additionally, the study examined the possibility of application of LP as an approach for selecting a healthy diet plan.

Methods

Database for dine-out menu extraction

Korean dine-out menus and the nutritional information were taken from the nutrient composition tables for dine-out menus developed by the Ministry of Food and Drug Safety(11–14) and the nutrient database from Computerized Analysis Program (CanPro 5.0)(15). Acceptable macronutrient distribution ranges of macronutrients such as carbohydrate, protein and fat, and recommended intake levels for energy, vitamins, minerals and cholesterol, by sex, were based on the Dietary Reference Intake for Koreans(16). We focused our analysis to the age group from 30 to 49 years.

The distribution of dine-out menus used in the analysis is summarized in Fig. 1, where a total of 331 menus are included. Most menus categorized as rice, noodle or soup (with rice) are generally served as the main dish and other foods are often served together as side dishes. Since the number and type of side dishes depend mostly on the restaurant and not the menu ordered, it is common to eat from many menus on the list for a single meal. Fruit and dairy products are normally not included in Korean dine-out menus, but the nutrition data are used in our analysis as discussed further in the 'Menu optimization: additional model' subsection below.

Menu optimization: formulation

We first present the formulation of the mathematical program used in the present study in this subsection and then include intuitive descriptions of various models that were analysed in the next two subsections. It should be noted that the proposed formulation does not find a dine-out menu combination relative to another plan (i.e. improve an existing plan) and, thus, the solution is the absolute optimal decision that provides the best possible nutrient combination. The dine-out menu optimization problem can be formally expressed as:

$$\text{Minimize } \frac{\sum_{i \in L} \max(l_i - x_i, 0) + \sum_{i \in U} \max(x_i - u_i, 0)}{N} \quad (1)$$

$$\begin{aligned} \text{Subject to } & l_{cal} \le x_{cal} \le u_{cal} \\ & 0 \le w_j \le 1 \text{ for each menu } j \\ & x_i = \sum_j n_{i,j} w_j \text{ for each nutrient } i \end{aligned}$$

where the decision variable x_i represents the total consumption level of the ith nutrient and w_j represents the consumption of the jth menu expressed as a proportion of a single serving. The sets L and U represent nutrients that have recommended lower and upper levels, respectively. Furthermore, the constant l_i represents lower limits for nutrients in L, and u_i represents upper recommended levels for nutrients in U. Since bounds on total energy (calories) are included as a strict restriction, x_{cal} is constrained to be within l_{cal} and u_{cal}. Finally, $n_{i,j}$ represents the amount of the ith nutrient that can be consumed from eating the jth menu. The objective value computes the average deviation by dividing the total deviation by N, which is the number of nutrients optimized.

The optimization problem given by equation (1) can also be written as below without the maximization in the objective function as:

$$\text{Minimize } \frac{\sum_{i \in L} \frac{d_i}{l_i} + \sum_{i \in U} \frac{e_i}{u_i}}{N} \quad (2)$$

$$\begin{aligned} \text{Subject to } & l_{cal} \le x_{cal} \le u_{cal} \\ & 0 \le w_j \le 1 \text{ for each menu } j \\ & x_i = \sum_j n_{i,j} w_j \text{ for each nutrient } i \\ & y_i = x_i - e_i + d_i \text{ for each nutrient } i \\ & y_i \le u_i \text{ for } i \in U \end{aligned}$$

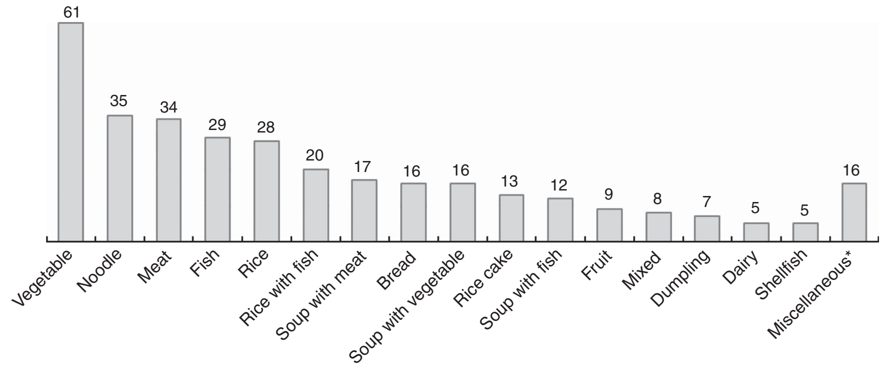

Fig. 1 Summary of Korean dine-out menu data[11–14], showing the number of menus analysed by category (total, *n* 331). *Miscellaneous includes legume, soup with legume, rice with meat, rice with vegetable, grain, egg, and soup with egg

$$y_i \geq l_i \text{ for } i \in L$$
$$e_i \geq 0, d_i \geq 0 \text{ for all } i$$

where slack variables e_i and d_i represent the excessive consumption and the deficient amount of the *i*th nutrient, respectively. The use of slack variables and additional dummy variables y_i formulates the original problem (1) into a problem (2) that is more solver-friendly. Solving the optimization problem (1) or (2) provides the optimal choice of dine-out menu that satisfies all constraints while minimizing the proportion of nutrients that do not fall within guidelines.

Menu optimization: base model

In our analysis, we formulated the dine-out menu optimization problem as below for finding a complete diet that attempts to satisfy recommended daily nutrition levels.* We refer to this formulation as Case A.

Case A	Base model
Decision variables:	Amount of each menu to consume (expressed as a proportion of a single serving)
Objective function:	Minimize deviation from recommended level for each nutrient
Constraint 1:	Total daily energy consumption must be within recommended range
Constraint 2:	Each menu can only be consumed up to a single serving

There is one decision variable for every dine-out menu considered in the problem. If a menu is not chosen, the corresponding decision variable will have a value of 0. If a decision variable has a value of 0·5, it shows that half a serving of the corresponding menu should be consumed.

* The basic components of optimization problems are further discussed in the 'Optimization models' subsection.

As shown above, in Case A the objective function is to minimize deviation from the recommended nutrition levels. Since some nutrients have recommended lower bounds while others have suggested upper bounds, the objective function measures deficiency of nutrients with lower bounds and excess of nutrients with upper bounds. Furthermore, since the recommended levels are different for different nutrients, we measured the percentage of deficiency or excess instead of the actual value.

Energy consumption is most critical for maintaining one's health. It is known that energy restriction improves metabolic efficiency and reduces oxidative damage markers, which may decrease incidence and progression of chronic diseases such as obesity, metabolic syndrome and cancer[17]. Therefore, the first constraint of the menu optimization problem in Case A forces total daily energy to be within a recommended range. This constraint makes sure one consumes at least the minimum energy necessary for an average lifestyle and also avoids consuming too much food that will eventually lead to weight gain and reduced health conditions. The second constraint limits the consumption of each dine-out menu to a maximum of 1 serving/d and this reflects the unlikelihood of eating the same menu more than once on the same day. Together with the definition of the decision variables, each menu will have a value between 0 and 1.

The recommended nutrition levels are summarized in Table 1. We focused the analysis on nutritional recommendations for ages 30–49 years because this is the age group with the most frequent dine-outs in South Korea. The limits for energy are used in the first constraint and the other suggested levels are used for computing the objective function value.

Menu optimization: additional model

In addition to the base model given by Case A, we compared a few variations to analyse how changes in allowed

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Table 1 Lower and upper limits and recommended level of daily nutrient intakes for Korean adults aged 30–49 years, by sex[16]

	Males			Females		
Nutrient	Lower limit	Upper limit	Recommended intake level	Lower limit	Upper limit	Recommended intake level
Energy (kJ; strict lower/upper limits)	9832	10 251	10 042	7740	8159	7950
Energy (kcal; strict lower/upper limits)	2350	2450	2400	1850	1950	1900
Carbohydrate (g)	–	398	55–65 %E	–	317	55–65 %E
Protein (g)	–	123	7–20 %E	–	98	7–20 %E
Total fat (g)	–	82	15–30 %E	–	65	15–30 %E
Thiamin (mg)	1·2	–	1·2	1·1	–	1·1
Riboflavin (mg)	1·5	–	1·5	1·2	–	1·2
Vitamin C (mg)	100	–	100	100	–	100
Niacin (mg)	16	–	16	14	–	14
Folate (mg)	0·4	–	0·4	0·4	–	0·4
Cholesterol (mg)	–	300	300	–	300	300
Na (mg)	–	2000	2000	–	2000	2000
K (mg)	3500	–	3500	3500	–	3500
Ca (mg)	800	–	800	700	–	700
Fe (mg)	10	–	10	14	–	14
P (mg)	700	–	700	700	–	700
Mg (mg)	370	–	370	280	–	280
Mn (mg)	4	–	4	3·5	–	3·5
Se (mg)	60	–	60	60	–	60
Cu (mg)	800	–	800	800	–	800
Zn (mg)	10	–	10	8	–	8

%E, percentage of energy.

menu choices and constraints affect the optimal decision. The four cases are summarized below.

Case A Base model
Case B Case A + upper bound constraint on total Na consumption
Case C Case B + fruit and dairy products added to menu data
Case D Case C + constraints to limit total fruit consumption between 100 and 300 % and total dairy product consumption between 100 and 200 %

The first case is the base model introduced in the previous subsection. As shown in the 'Results' section, the base case revealed significant overconsumption of Na, which is a widely known concern in Korean meals[4]. Thus, the second case, referred to as Case B, added a strict upper limit on total Na consumption. This second case will demonstrate how the optimal menus change when one is forced not to exceed the Na limit when excess use of salt is common in Korean meals. Case C solved the same optimization model as Case B, but it selected from more menus. More specifically, Case C will find the optimal diet when fruit and dairy products are included as shown in Table 2. This third case is important because fruit and dairy products are difficult to find in dine-out menus even though they are excellent choices for intake of vitamins and minerals. Finally, Case D restricted the total selection of fruits and dairy products to be at least 1 serving/d but less than 2 or 3 servings/d. The upper limit of 3 servings/d (300 %) for fruit and 2 servings/d (200 %) for dairy products reflects the recommended daily amount for adults aged 30–49 years whose recommended energy level is 10 042 kJ/d (2400 kcal/d)[16]. This last constraint portrays a more realistic situation since people usually do not eat excess amounts of fruit or dairy products, especially when one eats out regularly. In Cases C and D we included only fruit and dairy products but no other food groups such as grains or vegetables because, while most food groups including vegetables are commonly used as ingredients of Korean dine-out menus, fruit and dairy products cannot be consumed unless eaten separately (e.g. as dessert).

Although the Cases B, C and D are variations of the base model (Case A), the additional cases do not change the overall structure of the optimization problem because the extra constraints are all expressed as linear functions. In the 'Results' section, results of the four models are compared to analyse optimal dine-out decisions under various conditions.

Optimization models

The menu optimization problems presented above allow the selection of any single menu in any proportion between 0 and 1; 0 represents not selecting the menu and 1 represents selecting one serving of the menu. Nevertheless, since fractions are also possible, it is possible to select, for example, half a serving (0·5) or a tenth of a serving (0·1).

Table 2 List of fruit and dairy products included in menu data

	Serving size (g)	Energy (kJ)	Energy (kcal)	Carbohydrate (g)	Protein (g)	Total fat (g)
Dairy products						
Milk	200	502	120	9·4	6·4	6·4
Low-fat milk	200	301	72	9·2	5·8	1·2
Coffee milk	200	527	126	21·0	5·4	2·4
Yoghurt	100	431	103	16·8	3·5	2·4
Ice cream	100	607	145	22·7	3·8	4·3
Fruit						
Banana	100	335	80	21·2	1·0	0·0
Tangerine	100	167	40	10·5	0·5	0·1
Orange	100	184	44	11·2	0·9	0·1
Grape	100	251	60	14·1	0·4	0·8
Strawberry	200	243	58	14·4	1·6	0·2
Kiwi	100	268	64	14·8	0·8	1·0
Peach	100	201	48	10·0	1·8	0·7
Watermelon	200	268	64	16·2	1·6	0·0
Apple	100	205	49	13·1	0·2	0·1

The model is purposely designed this way because we are interested in observing the healthiest choice of dine-out menus under a situation that is not too restrictive. If a healthy diet is not possible under a non-restrictive condition, it will certainly be impossible under more restrictions. Limiting selections to be only either zero or one serving, or a choice among a few portions (e.g. quarter, half or full serving), becomes a more restrictive model.

Linear programming for nutrient analysis

Optimization methods compute the optimal solution under specified conditions and LP (or linear optimization) is the simplest form of optimization problems where the problem settings are described by linear functions[18,19]. More specifically, LP finds the best solution for achieving the decision maker's objective, where the objective function could be to either maximize or minimize.

There have been studies that employ LP methods for analysing nutrients and recommending diet guidelines. One of the most popular approaches for utilizing linear optimization is to find a healthy diet (or food combination) that satisfies given nutrient recommendations but requires minimum change from the current diet pattern[20–22].

In contrast to previous studies, we introduce a new formulation that finds the optimal dine-out menu combination without reference to any previous pattern. Since the formulation in our analysis is expressed as a linear program, the solution is the absolute optimal decision that provides the true optimum and best possible nutrient combination.

Results

Findings from the four cases were compared and we begin by discussing results for males before mentioning those for females. The results from our optimization analyses are presented by gender in Tables 3–8.*

Males

First, Case (A), which is the base case that restricts only total energy consumption and the amount of serving per menu, could not satisfy all recommended nutrient levels and even the optimal choice showed 3·03 % average deviation from recommendation. The most noticeable issue is a 56 % excess in Na. This shows that the optimal combination of dine out-menus can satisfy the guideline levels of most nutrients except for Na (deficiency in K is only about 1 %). In other words, it will be possible to find a healthy menu combination if Korean meals contained less Na. This observation on Case A confirms, through optimization, that the main concern in Korean meals is the excessive amount of Na (Table 3).

When the level of Na is restricted to a maximum of 2000 mg in Case B, the optimal decision became worse with an increased average deviation of 5·84 %. Even though no nutrients had excessive levels, minerals such as niacin, folate, K and Mg could not reach their recommended minimum levels of consumption. This illustrates that simply limiting the consumption of Na is not the solution to reaching a balanced diet (Table 3).

Cases C and D, that add fruits and dairy products to the list of candidate menus, support how additional sources of vitamins and minerals are critical. Case C clearly showed the most efficient selection with less than 1 % average deviation and only Mg being below recommended levels. Moreover, Case D, which is a more realistic situation, formed a meal plan that is more ideal than Cases A and B. In comparison to Case B, Case D reduced the deficiency levels of folate, K and Mg, and satisfied the recommended level for niacin (Table 3).

* Results presented were optimized using OpenSolver, which is an Excel add-in that uses COIN-OR branch-and-cut solver (CBC) for solving optimization problems.

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Table 3 Results on optimal nutrition levels for Korean males aged 30–49 years from the dine-out menu optimization

	Average deviation from recommended levels (%)	Excessive nutrients (%)	Deficient nutrients (%)
Case A	3·03	Na (+56·3)	K (−1·2)
Case B	5·84	None	Niacin (−22·1) Folate (−15·5) K (−45·9) Mg (−27·6)
Case C	0·77	None	Mg (−14·6)
Case D	2·05	None	Folate (−1·6) K (−9·8) Mg (−27·5)

Table 4 List of menus selected by dine-out menu optimization in Case D for Korean males aged 30–49 years (sorted by decreasing optimal amount)

Menu	Food group	Optimal amount (%)	Serving size (g)	Energy (kJ)	Energy (kcal)	Carbohydrate (g)	Protein (g)	Total fat (g)
Fried sweet potato with syrup (*mat-tang*)	Grain	100	200·00	2054·34	491·00	94·60	3·30	11·00
Yoghurt	Dairy	100	100·00	430·95	103·00	16·80	3·50	2·40
Grape	Fruit	100	100·00	251·04	60·00	14·10	0·40	0·80
Peach	Fruit	100	100·00	200·83	48·00	10·00	1·80	0·70
Starch jelly (*acorn muk*)	Grain, vegetables	100	100·00	192·46	46·00	10·40	0·30	0·30
Milk	Dairy	99	197·31	495·30	118·38	9·27	6·31	6·31
Beef cutlet	Meat	79	158·23	2965·60	493·69	30·46	26·11	29·67
Watermelon	Fruit	74	148·34	198·61	47·47	12·02	1·19	0·00
Rice with curry	Rice	67	333·65	1876·23	448·43	84·08	9·01	8·47
Stir-fried dried shrimp	Fish, vegetables	53	10·69	147·57	35·27	3·05	2·51	1·44
Potato fries	Grain	42	62·71	804·67	192·32	23·58	2·30	9·87
Strawberry	Fruit	26	51·66	62·68	14·98	3·72	0·41	0·05
White rice	Rice	25	22·56	333·21	79·64	17·71	1·29	0·02
Ox bone soup (with rice)	Meat	20	162·00	617·31	147·54	16·65	12·95	2·94
Roasted pork ribs	Meat	13	44·44	499·86	119·47	3·69	9·23	7·54
Low-fat milk	Dairy	1	2·69	4·06	0·97	0·12	0·08	0·02
Oyster rice soup	Grain, shellfish	0·5	3·15	13·85	3·31	0·43	0·21	0·09
Boiled pork	Meat	0·04	0·13	2·16	0·52	0·00	0·03	0·04
Total	–	999·4	1797·57	10 205·80	2450·00	350·69	80·92	81·67

The optimal menu combination for Case D is presented in Tables 4 and 5. The optimal meal for one day included portions of beef cutlet with rice, rice with curry, and ox bone soup with rice as main dishes, with several sides including sweet potatoes, starch jelly and stir-fried dried shrimps. More importantly, the meal showed that it is optimal to meet the recommended levels of fruit and dairy product consumption (3 servings/d for fruit and 2 servings/d for dairy products) through yoghurt, milk and some fruits. Our observations stress that one should not restrict one's diet to dine-out menus and should consciously add fruits and dairy products to his/her diet.

Females

The results for females, as shown in Table 6, were consistent with our findings for males above. Case A, the base case, again exhibited very high levels of Na and slight deficiency in a few minerals. When Na was controlled to not exceed the maximum allowed amount, the degree of deficiency in minerals increased and the average deviation from recommendations also rose. More importantly, adding fruits and dairy products found a perfect meal plan with no excessive or deficient nutrients. Even Case D, which limited the maximum consumption of fruits and dairy products, showed minimal insufficiency. Overall, the cases for females displayed a healthier diet in each case, but the key issues with dine-out menus were consistently observed. The list of menus selected for Case D are presented in Tables 7 and 8.

Discussion

The results of the present nutrient analysis for dine-out menus in Korea demonstrated issues in dining out and the

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Table 5 Food categories selected by dine-out menu optimization in Case D for Korean males aged 30–49 years

Food group	Optimal amount (%)	Serving size (g)	Energy (kJ)	Energy (kcal)	Carbohydrate (g)	Protein (g)	Total fat (g)
Grain	283·9	670·50	5171·63	1236·05	225·39	16·15	29·56
Meat, fish, shellfish	138·8	371·72	3265·65	780·51	52·55	49·67	40·96
Vegetables	76·7	55·34	170·00	40·63	6·72	1·41	0·87
Fruit	300·0	400·00	713·16	170·45	39·84	3·80	1·55
Dairy	200·0	300·00	930·31	222·35	26·20	9·89	8·73
Total	999·4	1797·57	10 250·80	2450·00	350·69	80·92	81·67

Table 6 Results on optimal nutrition levels for Korean females aged 30–49 years from the dine-out menu optimization

	Average deviation from recommended levels (%)	Excessive nutrients (%)	Deficient nutrients (%)
Case A	2·72	Na (+42·5)	Folate (–1·8) K (–7·3)
Case B	3·88	None	Folate (–20·3) K (–41·5) Mg (–11·9)
Case C	0·00	None	None
Case D	0·74	None	K (–14·1)

Table 7 List of menus selected by dine-out menu optimization in Case D for Korean females aged 30–49 years (sorted by decreasing optimal amount)

Menu	Food group	Optimal amount (%)	Serving size (g)	Energy (kJ)	Energy (kcal)	Carbohydrate (g)	Protein (g)	Total fat (g)
Fried sweet potato with syrup (*mat-tang*)	Grain	100·0	200·00	2054·34	491·00	94·60	3·30	11·00
Grape	Fruit	100·0	100·00	251·04	60·00	14·10	0·40	0·80
Peach	Fruit	100·0	100·00	200·83	48·00	10·00	1·80	0·70
Starch jelly (*acorn muk*)	Grain, vegetables	100·0	100·00	192·46	46·00	10·40	0·30	0·30
Watermelon	Fruit	98·2	196·42	262·96	62·85	15·91	1·57	0·00
Yoghurt	Dairy	87·5	87·49	337·02	90·11	14·70	3·06	2·10
Low-fat milk	Dairy	79·7	159·31	239·95	57·35	7·33	4·62	0·96
Rice with curry	Grain	79·5	397·33	2234·30	534·01	100·13	10·73	10·09
Milk	Dairy	32·9	65·71	164·98	39·43	3·09	2·10	2·10
Stir-fried dried shrimp	Fish, vegetables	30·0	6·00	82·80	19·79	1·71	1·41	0·81
Steamed skate	Fish, vegetables	27·4	125·81	595·89	142·42	19·65	14·29	0·30
Potato fries	Grain	27·2	40·85	524·13	125·27	15·36	1·50	6·43
Roasted pork ribs	Meat	14·1	49·51	556·97	133·12	4·12	10·28	8·40
Seasoned skate	Fish, vegetables	11·4	22·89	95·27	22·77	2·98	2·05	0·30
Roasted mackerel	Fish	8·7	21·85	244·18	58·39	0·17	5·17	4·13
Oyster rice soup	Grain, shellfish	2·7	17·56	77·19	18·45	2·39	1·15	0·48
Strawberry	Fruit	1·8	3·58	4·35	1·04	0·26	0·03	0·00
Total	–	901·1	1694·31	8158·80	1950·00	316·88	63·76	48·90

need for consuming vitamins and minerals from additional sources for both males and females. The high usage of Na in Korean dine-out menus was found to be the biggest concern and this had broad effect because limiting the intake of Na resulted in dine-out plans with low content of minerals.

The model used in our analysis allowed investigating nutrient information in the most optimal combination among all possible combinations of dine-out menus because it was formulated as an LP problem. Formulating a diet optimization problem as a linear program is a major advantage because the problem can be efficiently solved

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Table 8 Food categories selected by dine-out menu optimization in Case D for Korean females aged 30–49 years

Food group	Optimal amount (%)	Serving size (g)	Energy (kJ)	Energy (kcal)	Carbohydrate (g)	Protein (g)	Total fat (g)
Grain	258·0	696·96	4947·58	1182·50	216·48	16·25	27·91
Meat, fish, shellfish	58·6	157·50	1226·83	293·22	17·64	24·90	13·47
Vegetables	84·4	127·35	483·21	115·49	17·37	9·02	0·85
Fruit	300·0	400·00	719·19	171·89	40·27	3·80	1·50
Dairy	200·0	312·51	781·95	186·89	25·11	9·78	5·16
Total	901·1	1694·31	8158·80	1950·00	316·88	63·76	48·90

and include various restrictions on nutrients or eating habits.

Linear optimization models have been applied to nutrient analysis under various settings. Most of the studies have focused on improving one's diet in order to meet certain health goals. Soden and Fletcher[20] formulated a linear program that computes the optimal food quantities of an observed diet and demonstrated the case for a 50-year-old overweight female with nutrient targets for energy, fibre, Na and fat. Masset *et al.*[21] also concentrated on improving one's original diet with minimum change but they applied constraints based on guidelines for cancer prevention. The model was further explored in Okubo *et al.*[24] as they designed a diet model optimized for the food intake patterns in Japan by considering twenty-eight nutrients. The case for developing countries was illustrated in Ferguson *et al.*[22], who also discussed testing the robustness of their model using a second LP model; and the nutritional quality of food aid delivered by food banks in France was analysed by Rambeloson *et al.*[25]. Moreover, there are studies that have incorporated cost into the model to analyse the effect of having a budget on healthy food choices[26,27] and extensions for revising over-restricted or unrealistic diet choices using goal programming[28,29].

The most relevant to the present study is the work by Asano[30] that focused on nutrient optimization in Korean meals. Asano studied the food intake patterns of Koreans and formed a healthy Korean diet based on the widely used formulation given by equation (1). As discussed in the 'Methods' section, our approach is distinct from previous studies because the goal here is not to improve an existing diet pattern but to analyse the nutritional deficiency of the most optimal choice. Furthermore, we examined a comprehensive list of dine-out menus in Korea that provide detailed information rather than observing food groups or categories.

First, we found that a healthy diet cannot be achieved with any combination among Korean dine-out menus; it is impossible to meet all recommended nutrient guidelines regardless of which combination of dine-out menus is selected. Second, our results confirmed that excessive intake of Na is the major concern for Korean menus. Finally, we showed that dine-out meals require additional consumption of fruits and dairy products in order to achieve a balanced diet. It is also noteworthy to mention that additional consumption of fruits and dairy products was necessary to meet daily requirements of vitamins and minerals. The addition of fruits and dairy products in optimization models to solve the deficiency of vitamins and minerals is due to the characteristics of Koreans' diet. Unlike the Western diet, the traditional Korean diet is composed of rice and various side dishes such as meat, fish, legumes and vegetables[31], but it does not include fruits and dairy foods. Thus, people should consume those foods separately from meals as a dessert or snack in order to achieve a balanced diet. However, it is hard to eat them when eating out unless people go to a café or dessert shop because Korean restaurants usually do not provide a dessert menu with meals. Given that, it is meaningful to add fruits and dairy products, not other food groups, in dine-out menus for the optimized diet among Koreans. This result emphasizes the importance of a balance diet comprised of various food groups for nutritional adequacy. Dine-out menus lack variety because the menu is mainly single dish not like a meal at home. Therefore, the optimization proves that the additional supplements are needed to secure the balance and variety in food choice for nutritional adequacy in dining out.

The optimization formulation tested here is less restricted than real-world dine-out decisions. In reality, individuals will also take price, taste, restaurant location and time constraint into consideration when deciding where to eat out. Since our optimization problem could not find a well-balanced dine-out menu combination, this shows that excess of Na and deficiency of minerals are more critical and it is impossible to maintain a healthy diet from eating out in real life in South Korea.

While the less restricted analysis provides meaningful findings, we note that there are a few limitations that can be improved in future work. It will be possible to analyse more intuitive diet plans if common dining patterns were reflected in the model. For example, it is less likely that one would eat pizza with kimchi, and these could be avoided if we add constraints to the model. Moreover, current analysis found the optimal menu combination for daily consumption without making distinction among breakfast, lunch and dinner. Incorporating eating patterns will help prepare an optimal meal plan for a day. Nevertheless, this task requires much observation, data and careful modelling because common dining patterns do not represent everyone's eating habits. In addition, the analysis can be improved by expanding the data on dine-out menus. The analysis presented herein includes 317 dine-out items, nine fruits and five dairy products, which covers a wide range of dining options, but it will be interesting to observe the results when further extending the list of menus.

Conclusion

In conclusion, our findings revealed that it is unlikely to satisfy all nutrient recommendations with any combination of dine-out menus. Specifically, high levels of Na must be resolved with extra consumption of fruits and dairy products. Our results showed that the best meal combination, even though the proportion and pairing of menus may be unrealistic, is not healthy and thus one should not fully depend on eating out.

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