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Determinants of energy availability and nutrient intakes among overweight and obese Malaysian adults during COVID-19 lockdown: A cross-sectional study

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ABSTRACT

Introduction: Unhealthy lifestyle, especially during COVID-19, contributed to weight gain. This study investigated energy availability and nutrient intakes in overweight and obese Malaysian adults during lockdown. **Methods:** Fifty participants (overweight: 30.2±0.9 years old, body mass index (BMI) 27.7±0.2 kg.m^{-2}; obese: 27.9±1.9 years old, BMI 30.0±0.2 kg.m^{-2}) recorded their food intake using 24-hour diet recall. Total energy, macronutrient, and micronutrient intakes were analysed with independent *t*-test. **Results:** Energy intake exceeded expenditure across all groups. Overweight males and females consumed 3376±55 kcal/day and 3293±68 kcal/day, while obese males and females consumed 3442±70 kcal/day and 2915±48 kcal/day, respectively. Overweight males expended 2223–2299 kcal/day, while obese males expended 2312–2431 kcal/day. Overweight females expended 1901–1960 kcal/day and obese females expended 1971–2139 kcal/day. Energy availability varied, with overweight males at 24–26 kcal/kg fat-free mass (FFM)/day and obese males at 19–22 kcal/kg FFM/day, while female values ranged from 15 to 31 kcal/kg FFM/day. Fat intake exceeded recommended values, while vitamin D, C, and K intakes were inadequate. Sugar and phosphorus intakes surpassed recommendations. **Conclusion:** During COVID-19 lockdown, overweight and obese Malaysian adults had higher energy intake than energy expenditure, contributing to positive energy balance and potential weight gain. Fat intake exceeded recommendations, while micronutrients, such as vitamins D, C, and K, were deficient. Energy intake (measured) and energy expenditure (calculated) were significant determinants of energy availability.

Keywords: COVID-19, energy availability, nutrients intake, obesity, overweight

INTRODUCTION

As of August 2021, the coronavirus disease 2019 (COVID-19) has infected over 200 million people worldwide. In Malaysia, nearly 1.2 million cases were reported, with the highly transmissible Delta variant driving the surge. Therefore, the Malaysian government

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reimposed the Movement Control Order 3.0 (MCO 3.0) on June 1, 2021, to stop the spread. This was then followed by the Conditional Movement Control Order (CMCO) to allow some economic activities to resume while maintaining safety measures. COVID-19-related isolation has changed dietary habits and food intake patterns. Emotional eating and physical inactivity during lockdown may have potentially caused Malaysia's growing post-pandemic overweight and obesity crisis (Tan *et al.*, 2022).

Global projections suggest that overweight and obesity [body mass index (BMI) ≥25kg/m^2], also referred to as high BMI, could affect over 4 billion people by 2035 compared with over 2.6 billion in 2020. This reflects an increase from 38% of the global population in 2020 to over 50% by 2035 (excluding children under 5). The prevalence of obesity (BMI ≥30kg/m^2) alone is anticipated to rise from 14% to 24% within the same period, affecting nearly 2 billion individuals worldwide. The latest National Health and Morbidity Survey (NHMS 2023) reported that more than half of Malaysian adults (54.4%) were either overweight (32.6%) or obese (21.8%) (IPH, 2024). Overweight and obesity are primarily caused by an imbalance in energy between calories consumed and calories expended (WHO, 2018); individuals who are overweight and obese are at a higher risk of developing non-communicable diseases than those who are physically active.

Although lockdowns were necessary to stop the disease from spreading further, prolonged home confinement raised concerns about significant lifestyle changes that could impact body weight (Drywień *et al.*, 2020). A study has linked home confinement to altered eating habits, decreased physical activity, and increased sedentary behaviour (Sidor & Rzymski, 2020). Furthermore, prolonged confinement can be stressful, leading to overeating or undereating, consequently causing a positive or negative energy balance (Haddad *et al.*, 2020). These lifestyle changes could result in significant changes in body composition and body weight.

Dietary assessment plays a crucial role in obesity management. In this study, the researchers aimed to assess macronutrient and micronutrient intakes, focusing on how energy intake from macronutrients and micronutrients influences energy expenditure, energy availability, and body composition. Energy expenditure is often estimated as total daily energy expenditure (TDEE), which represents the energy expended by the human body. Energy availability refers to the energy available to support body functions after subtracting the energy expended during exercise and expressed relative to fat-free mass (FFM) (Loucks, 2004). Understanding the dysregulation of energy balance and its underlying mechanisms is key to addressing obesity. The relationship between FFM, resting metabolic rate (RMR), and energy intake (EI) reflects the metabolic demands of active tissues.

Regular intake assessment allows for tracking changes in dietary patterns and behaviours. The assessments provide continuous feedback and serve as a foundation for addressing dietary challenges. A previous study by Tan *et al.* (2022) assessed changes in dietary intake patterns during the COVID-19 lockdown in Malaysia but did not estimate macronutrient and micronutrient intakes. Similarly, Zainuddin *et al.* (2019) did not report nutrient intakes during the pandemic. Therefore, this study was conducted to determine energy intake, energy expenditure, and energy availability among overweight and obese Malaysian adults during the COVID-19 lockdown.

MATERIALS AND METHODS

Study design

This was a cross-sectional study. Fifty overweight (*n*=42) and obese (*n*=8) healthy Malaysian adults were recruited in this study by using an opportunistic sampling method. The participants were recruited through advertisements (posters) and flyers distributed on campus and also through social media. Recruitment was conducted among the staffs and students of the Health Campus, Universiti Sains Malaysia. Data collection was conducted from March 2021 to May 2021 during COVID-19 (CMCO). The study was conducted in accordance with the Declaration of Helsinki and the International Committee of Medical Journal Editors guidelines. This study was approved by the Universiti Sains Malaysia's Human Research Ethics Committee (USM/JEPeM/19100617).

Participant recruitment and data collection location

Overweight (males, *n*=13; females, *n*=29) and obese (males, *n*=3; females, *n*=5) Malaysians aged between 18 and 40 years old, with a BMI classification of ≥25.0 kg/m² for overweight and a BMI of ≥30.0 kg/m² for obesity (WHO, 2000) were invited to participate in this study. Other inclusion criteria were being physically inactive, i.e., not exercising more than two times per week. The exclusion criteria were asthma, stroke, diabetes, heart disease, hypertension, and kidney disease. Written consent was obtained from the participants who met the inclusion criteria.

The study was conducted at the Exercise and Sports Science Laboratory, Universiti Sains Malaysia, Kota Bharu, Kelantan. Participants were required to come to the laboratory to fill out the consent form and the World Health Organization STEPwise approach to NCD risk factor surveillance (WHO STEPS). Body composition was measured using bioelectrical impedance analysis (TBF-410, TANITA, Tokyo, Japan), while height was measured using a stadiometer (SECA-217, SECA, Hamburg, Germany). 24-hour diet recall was conducted through an online assessment using a Google link via mobile application. Participants' responses to the questionnaire were supervised by the researcher. Participants were also asked to record their food intake over a three-day period.

Questionnaires and food diary

WHO STEPS instrument

The participants were required to answer a modified and validated questionnaire adopted from the WHO STEPS instrument (core and expanded) to suit the local requirements (Nagendra *et al.*, 2017). The self-administered questionnaire was divided into two parts. Part 1 was about information on socio-demographic variables, smoking, alcohol intake, exercise, and diet. Part 2 pertained to physical measurements such as body height and body weight.

Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and physical activity level (PAL)

Participants were also required to answer general health questions in the PAR-Q+ (Bredin *et al.*, 2013). Researchers used PAR-Q to assess the general health condition of the participants. The questionnaire consisted of seven questions asking about the health conditions of participants before allowing them to be involved in physical activity. In this study, PAL values were adopted from NCCFN (2017), as follows:

PAL 1.4 - Low active
PAL 1.6 - Moderately active
PAL 1.8 - Active
PAL 2.0 - Very active

Based on the inclusion criteria, which required participants to be "physically inactive", a PAL value of 1.4 was used to estimate the TDEE of all participants.

24-hour diet recall

Participants were required to recall the details of the foods and beverages consumed for three days (two days on weekdays and one day on weekends) through an online Google form and were advised not to change their usual eating patterns. The form consisted of a few sections, such as questions regarding food intake for each mealtime (breakfast, lunch, afternoon tea, dinner, and supper), amounts of foods and drinks, and calorie intake. In this study, to monitor the participants' diet throughout the study period, the participants were required to record their daily diet intake on a checklist. Food models and household utensils were used to help the participants estimate the portion sizes of foods and beverages consumed. The recorded food intakes were analysed using licensed Nutritionist Pro software (Version 6.2, Axxya Systems, Stafford, Texas, USA) and the Nutrient Composition of Malaysian Foods (4th Edition) (Tee *et al.*, 1997). For traditional cuisines, the researchers created recipes to estimate total energy intakes in the Nutritionist Pro software. The mean values were compared to Recommended nutrient intake (RNI) values based on NCCFN (2017) recommendations.

Total daily energy expenditure

In this study, basal metabolic rate (BMR) was calculated using formulas by Ismail *et al.* (1998). TDEE was derived by multiplying BMR with a PAL value of 1.4, as recommended by RNI 2017 for physically inactive individuals (NCCFN, 2017).

BMR predictive equations for male and female participants aged 18 to 40 years old (Ismail *et al.*, 1998):

Males
18-30 years (MJ/day) = 0.0550W + 2.480
30-60 years (MJ/day) = 0.0432W + 3.112
Females
18-30 years (MJ/day) = 0.0535W + 1.994
30-60 years (MJ/day) = 0.0539W + 2.147

TDEE = BMR (Ismail *et al.*, 1998) x PAL 1.4 (NCCFN, 2017)

Energy availability prediction

Energy availability is defined as the amount of energy (EI) that is available to support body functions after subtracting the amount of energy that is expended (EE) during exercise and expressed relative to FFM (Loucks, 2004).

Energy availability (EA) = (EI – EE) / FFM (Loucks, 2004)

Anthropometric and body composition measurements

Anthropometric and body composition measurements were conducted in this study. Participants' height (cm) was measured using a body stadiometer (SECA-217, SECA, Hamburg, Germany). Body weight (kg), percentage body fat (%), fat mass (FM), and fat-free mass (FFM) were measured using a body composition analyser (TBF-410, TANITA, Tokyo, Japan).

Statistical analyses

Statistical analyses were performed using the IBM SPSS Statistics for Windows version 26.0 (IBM Corporation, Armonk, New York, USA). The normality of data distribution was determined using the Shapiro-Wilk test. All measured parameters were analysed using Pearson's correlation and stepwise regression analysis. Data were presented as mean and standard deviation (mean±*SD*). A *p*-value of <0.05 indicated statistical significance.

RESULTS

Anthropometry, body composition, energy expenditure, and energy availability of participants

Table 1 exhibits the anthropometry, body composition, energy expenditure, and energy availability of participants during the COVID-19 lockdown. Forty-two participants were overweight (mean age: 30±1 year old) and eight participants were classified as class 1 obesity (mean age of 28 ±2 years old). The heights of overweight and obese participants were 161.7±1.3 cm and 164.8±2.4cm, and their body weights were 72.5±1.3 kg and 82.4±2.4 kg. Their BMIs were 27.7±0.2 $kg.m^{-2}$ and 30.0±0.2 $kg.m^{-2}$, respectively. As for body composition, percentage body fat for overweight was 39.1±1.2% and 40.3±2.4% for obese, with a fat mass of 28.2±0.8 kg and 33.8±1.9 kg, while their FFMs were 44.5±1.4 kg and 50.5±2.7 kg, respectively.

There was no significant difference in all the parameters between both groups. Daily energy expenditure was lower than intake for all participants. Overweight males expended 2223–2299 kcal/day, while obese males expended 2312–2431 kcal/day. Overweight females expended 1901–1960 kcal/day and obese females expended 1971–2139 kcal/day. Energy availability varied, with overweight males at 24–26 kcal/kg FFM/day and obese males at 19–22 kcal/kg FFM/day, while female values ranged from 15 to 31 kcal/kg FFM/day.

Table 1. Anthropometry, body composition, energy expenditure, and energy availability of participants (*N*=50)

Variables	*Overweight (n=42)*	*Obese (n=8)*
Age (years)	30±1	28±2
Body height (cm)	161.7±1.3	164.8±2.4
Body weight (kg)	72.5±1.3	82.4±2.4
Body mass index ($kg.m^{-2}$)	27.7±0.3	30.0±0.2
Percentage body fat (%)	39.1±1.2	40.3±2.4
Fat mass (kg)	28.2±0.8	33.8±1.9
Fat-free mass (FFM) (kg)	44.5±1.5	50.5±2.7
Total daily energy expenditure (TDEE) (kcal/day)		
Male		
18-30 years old	2299±117	2431±0.0
30-60 years old	2223±87	2312±54
Female		
18-30 years old	1901±117	2139±59
30-60 years old	1960±80	1971±96
Energy availability (kcal/kg FFM/day)		
Male		
18-30 years old	24.4±5.1	19.8±0.1
30-60 years old	25.6±9.4	22.2±2.6
Female		
18-30 years old	30.9±7.6	15.2±3.7
30-60 years old	29.6±5.1	18.5±0.3

Values are expressed as mean±*SD*

Table 2. Daily energy and nutrient intakes of overweight and obese participants (by gender category) compared to recommended nutrient intakes (RNIs)

Macro and micronutrients	*Overweight (n=42)*	*Obese (n=8)*	*RNI values (per day)*	*% Adequacy (overweight)*	*% Adequacy (obese)*
Total calories (kcal/day)					
Male	3376±55*	3442±70*	2140		
Female	3293±68 *	2915±48*	1900		
Carbohydrate (g)					
Male	380.3±113.2*	357.2±157.1	400		
Female	388.0±123.4	358.3±72.3	400		
Protein (g)					
Male	122.3±41.0*	136.2±19.5*	62		
Female	120.4±33.6*	98.3±38.7*	53		
Fat (g)					
Male	151.8±11.2*	163.1±32.3*	62-75		
Female	140.0±47.7*	120.9±32.9*	51-61		
Sugar (g)	71.1±12.8	74.6±11.5*	<50	142.2 (Exceed)	149.2 (Exceed)
Vitamin C (mg)	63.8±10.1	28.4±9.8*	65	91.1 (Below)	40.6 (Below)
Vitamin D (µg)	0.9±0.2*	0.3±0.3*	15	6.0 (Very low)	2.0 (Very low)
Vitamin K (µg)	7.4±1.4*	40.4±27.1*	70	10.6 (Very low)	57.7 (Below)
Calcium (mg)	1067.2±100.7*	915.9±151.9*	1000	106.7 (Slightly exceed)	91.6 (Below)
Potassium (mg)	2176±142*	2087±321*	4700	46.3 (Below)	44.4 (Below)
Phosphorus (mg)	2097±144*	1795±185*	700	299.5 (Exceed)	256.4 (Exceed)
Energy from carbohydrate (%)			45-65		
Male	45.1±1.2	41.5±2.2			
Female	47.1±1.3	49.2±2.5			
Energy from protein (%)			10-15		
Male	14.5±0.5	15.8±1.3			
Female	14.6±0.2	13.5±1.1			
Energy from fat (%)			15-30		
Male	40.5±1.3*	42.7±2.3*			
Female	38.3±1.5	37.3±2.4			

RNI: Recommended Nutrient Intake (NCCFN, 2017)
Values are expressed as mean±*SD*, *N*=50; male (*n*=19), female (*n*=31)
*Significantly different from RNI values, $p<0.05$

Total energy, macronutrient, and micronutrient intakes of participants
Table 2 presents the mean energy, macronutrient, and micronutrient intakes during the COVID-19 lockdown. Mean total energy intake was 3376±55 kcal/day for overweight males. Overweight females consumed 3293±68 kcal/day. Obese males had 3441±69 kcal/day, while obese females

Table 3. Ranking of the most commonly consumed and least preferred foods and drinks among overweight and obese males and females

Gender	*Overweight (1 most to 5 least liked)*	*Obese (1 most to 5 least liked)*
Male	1. Coffee 2. Carbonated soft drink 3. French Fries 4. Snack 5. Bread	1. Coffee 2. Carbonated soft drink 3. Fast food 4. Rice 5. Cheese and dairy products
Female	1. Coffee 2. Sweetened beverages 3. Cake and pastries 4. Milk 5. Chicken	1. Sweetened beverages 2. Sweet and dessert 3. Fried chicken 4. Processed meat 5. Juices

had 2915±48 kcal/day. Macronutrient intakes for overweight males were 45.1±1.2% carbohydrates, 14.6±0.5% protein, and 40.5±1.3% fat. Overweight females: 47.1±1.3% carbohydrates, 14.6±0.2% protein, 38.3±1.5% fat. Obese males: 41.5±2.2% carbohydrates, 15.8±1.3% protein, 42.7±2.3% fat. Obese females: 49.2±2.5% carbohydrates, 13.5±1.1% protein, 37.3±2.4% fat. Fat intake in males was significantly higher than RNI. Micronutrient intakes for vitamins D, C, and K were below RNI, while sugar and phosphorus intakes exceeded RNI in both overweight and obese participants.

Table 3 shows the ranking of commonly consumed to least preferred foods and drinks among overweight and obese males and females. Coffee ranked highest for overweight and obese males, followed by carbonated soft drinks. Overweight males also reported high consumption of French fries, snacks, and bread, while obese males consumed more fast food, rice, and dairy products. Among females, coffee and sweetened beverages were frequently consumed, along with cakes, milk, and chicken. Obese females consumed more sweets, fried chicken, processed meat, and juices.

Correlations of energy intake with energy expenditure, energy availability, anthropometry, and body composition

Table 4 shows the correlations of energy intake with energy expenditure, energy availability, anthropometry,

Table 4. Correlations of energy intake with energy expenditure and energy availability, body weight, body mass index, body fat, fat mass, and fat-free mass

Variables	*Energy intake*	
	Pearson Correlation (r)	*p-values*
Energy expenditure	0.205	0.153
Energy availability	0.798*	<0.001
Body weight	0.477*	<0.001
Body mass index	0.956*	<0.001
Body fat percentage	- 0.052	0.994
Fat mass	0.035	0.810
Fat-free mass	0.892*	<0.001

Pearson's correlation *(r)* was performed to explore the relationship between measured parameters.
*Statistically significant correlation; $p<0.05$

and body composition of participants during the COVID-19 lockdown. The correlation between energy intake and energy availability was considerably favourable (r=0.798, p<0.001). However, this study revealed that there was no substantial correlation between energy intake and energy expenditure. Body weight demonstrated a significant positive correlation with energy intake (r=0.477, p<0.001). Furthermore, BMI had a significant positive correlation with energy intake (r=0.956, p<0.001). Similarly, FFM demonstrated a positive correlation with energy intake (r=0.892, p<0.001).

Stepwise regression analysis

By using stepwise regression analysis (Table 5), the variables energy intake (β=0.023, p<0.001) and energy expenditure (β=-0.053, p<0.001) were revealed to be significant predictors of energy availability (R=0.943, R^2=0.888, F=187.236, p<0.001). The R-square of 0.888 implied that 88.8% of the variances in energy availability could be explained by energy intake and energy expenditure. The single best predictor of energy availability was energy intake, which accounted for 62.4% of the factors in energy availability. Meanwhile, with the inclusion of energy expenditure, an additional 37.6% of the variation in energy availability was accounted for, and the adjusted R^2 was set at 0.884. Energy intake showed a significant association with energy availability (r=0.798, p<0.001). Low energy expenditure and high energy intake both contributed significantly to high energy availability.

DISCUSSION

This study assessed the dietary intakes of overweight and obese Malaysians during the COVID-19 lockdown and compared them to existing guidelines. The main findings indicated that carbohydrate, protein, and fat intakes exceeded RNI values. Micronutrients were lower than RNI values for vitamin C, vitamin D, vitamin K, and potassium, whereas sugar, phosphorus, and calcium intakes were above RNI values. Additionally, mean energy expenditure for all participants was lower than their daily energy intake, with stepwise regression analysis identifying energy intake and energy expenditure as the primary factors affecting energy availability.

Findings showed that the mean total energy intake exceeded the requirement. These findings align with well-established evidence suggesting that excessive caloric intake is a major contributor to weight gain. Energy intake patterns were similar across genders, contradicting studies that indicated lower energy requirements for women due to metabolic rate and lean body mass differences (Lee & Wan Muda, 2019). Lifestyle factors, including reduced physical activity, may explain this increase in older females.

Obesity results from an imbalance between energy intake and expenditure, often associated with sedentary

Table 5. Stepwise regression analysis prediction models for the associations of energy availability with energy intake and energy expenditure

Variables	*Unstandardised β*	*Standardised β*	*SE*	*t*	*p*
(Constant)	62.376		10.580	5.895	<0.001***
Energy intake	0.023	0.903	0.001	18.150	<0.001***
Energy expenditure	-0.053	-0.512	0.005	-10.287	<0.001***

Adjusted R^2=0.884
***p<0.001

lifestyles. This study observed that participants' mean energy expenditure was lower than their daily energy intake, indicating a positive energy balance. Energy availability was assessed in overweight and obese participants. For male participants, energy availability was lower in the 30–60 years age group compared to the 18–30 years age group. Similarly, for female participants, energy availability was lower in the older age group (30–60 years) compared to the younger age group (18–30 years). These findings indicate a trend of reduced energy availability with increasing age, particularly in males.

Obese individuals generally have higher RMR than lean individuals, leading to increased energy consumption. Weight gain often results from insufficient energy expenditure, contributing to bodily energy stores (Hill, Wyatt & Peters, 2021). However, insufficient energy expenditure leads to weight gain. While obese adults tend to be less physically active, activity thermogenesis is similar to lean individuals when adjusted for body size (Szwiega *et al.,* 2021).

Energy availability is defined as total energy intake minus energy expenditure relative to FFM (Loucks, 2004). This study found positive correlations between energy intake, body weight, BMI, fat mass, and FFM. Additionally, in this study, energy intake was the single best predictor of energy availability. This implies that the participants were consuming more energy than needed relative to their activity level, potentially leading to weight gain or maintaining an inactive lifestyle. This can occur due to overeating or reduced physical activity, which might explain the energy excess despite a lower level of physical activity. In individuals with excess body weight, high energy availability from energy-dense foods and sedentary lifestyles exacerbates weight gain (Hall *et al.,* 2019).

Macronutrients intake

Carbohydrate intake was within acceptable ranges (45.1±1.2% and 47.1±1.3% for overweight males and females, 41.5±2.2% and 49.2±2.5% for obese males and females), aligning with dietary guidelines recommending 45–65% of total daily energy intake from carbohydrates (NCCFN, 2017). However, refined carbohydrates and added sugars increase obesity risk, insulin resistance, and metabolic disorders (Ludwig *et al.,* 2021). Conversely, consuming complex carbohydrates from whole grains, legumes, vegetables, and fruits can improve satiety, glycaemic control, and overall health outcomes (Schlesinger *et al.,* 2019). Carbohydrate timing, distribution, and glycaemic index impact metabolic responses and weight regulation (Kahleova *et al.,* 2024).

Protein intake met RNI values, contributing 15.8±1.3% and 13.5±1.1% of total energy intake for obese individuals and 14.5%±0.5% and 14.6±0.2% for overweight individuals. Dietary guidelines recommend 10%–15% of total daily energy intake from protein, depending on individual needs, physical activity level, and metabolic health (NCCFN, 2017). The reported values fell within this range, suggesting adequate protein consumption among participants. Higher protein intake improves satiety, increases thermogenesis, and aids weight regulation while preserving lean body mass (Verreijen *et al.,* 2015). Furthermore, consuming high-quality protein sources such as lean meat, fish, dairy, legumes, and plant-based proteins can positively influence body composition and metabolic health.

Excessive fat intake contributes to total energy intake because increased dietary fat intake provides more energy. Many participants were university students and staffs, likely preferring ready-to-eat food or fast food due to academic and work constraints. Cooking restrictions in dormitories and high workloads may have led to increased fast food consumption. Stress, anxiety, and boredom during MCO and CMCO also encouraged reliance on high-fat, high-calorie comfort foods.

Micronutrients intake

Micronutrient analysis revealed deficiencies in vitamin C, vitamin D, vitamin K, and potassium. Low vitamin C intake resulted from inadequate fruit and vegetable consumption among all participants in their diets. It is speculated that the poor vitamin C status of obese or overweight people could be attributable to a shortage of vitamin C in their diets (Kobylińska *et al.*, 2022). However, the number of servings for fruits and vegetables was not measured in this study. Hence, it may not be used to determine the amount of fruit and vegetable intake among participants.

Vitamin D is also essential for optimal health. Fish oil in salmon and mackerel, eggs, mushrooms, and fortified meals are high in vitamin D. In this study, it was found that the participants' vitamin D levels were less than their daily requirement. Vitamin D deficiency was attributed to limited dietary sources and reduced sun exposure during MCO and CMCO. Overweight and obese individuals may also have lower vitamin D bioavailability due to adipose tissue sequestration.

Low vitamin K and potassium intakes reflected inadequate consumption of green leafy vegetables (such as cabbage, spinach, and broccoli), some fruits (including avocados, kiwis, and green grapes), some herbs (parsley, coriander, and green tea), and vegetable oils (soybean, canola, and olive oil).

Malaysia's MCO restrictions limited access to fresh fruits and vegetables, leading to micronutrient deficiencies (Chen *et al.,* 2021). The pandemic also caused economic hardships, pushing people to cheaper, calorie-dense but nutrient-poor food options (Husaini & Lean, 2022). Increased consumption of processed foods further reduced micronutrient intakes (Chew *et al.,* 2020). Therefore, the above explanations are reasons these micronutrients were expected to be consumed less among the participants.

Conversely, sugar, phosphorus, and calcium intakes were higher than the recommended RNI values. Study findings showed that higher sugar intake may have resulted in excess energy intake. High sugar intake is believed to stem from sugar-sweetened beverages (SSB) and processed foods, which leads to increased calorie intake, unhealthy weight gain, and eventually contributes to obesity risk (Cheng & Lau, 2022). Stress-induced eating during MCO and CMCO may have further increased sugar intake. However, in this study, we did not measure stress levels among participants. Hence, in future studies, these parameters could be included.

As for phosphorus intake, it was found that the average amount of phosphorus was higher than the recommended RNI value for both overweight and obese participants. Foods with protein, dairy products, and whole grains are high in phosphorus (Takeda *et al.*, 2012). Furthermore, these consumptions have been linked to a lower risk of various components of the metabolic syndrome, including body weight and adiposity; however, the mechanism behind this benefit is unknown.

The calcium intake guideline for Malaysian adults is 800 mg per day, sourced primarily from dairy products, almonds, green leafy vegetables, fortified meals, and milk (Goh *et al.,* 2020). In this study, we found that the majority of participants consumed more calcium than the recommended reference value. While an adequate calcium intake is essential for bone health, insufficient levels can lead to decreased bone mineral density and a higher risk of osteoporosis (Chan *et al.,* 2021). Sufficient calcium intake plays a critical role in maintaining bone strength and may contribute to weight management by reducing fat absorption and influencing energy metabolism. However, despite participants in this study exceeding the calcium intake recommendations, many still faced issues with overweight and obesity. This finding suggests that factors beyond calcium intake, such as overall dietary patterns and physical activity, may be contributing to their weight challenges. Further research is needed to explore the complex relationship between calcium intake, body weight, and other lifestyle factors.

The strength of this study is the detailed assessment of macronutrient and micronutrient intakes among overweight and obese participants. Also, correlation analysis was performed to determine how dietary intake influences energy balance, anthropometry, and body composition among overweight and obese Malaysian adults. Dietary evaluation could offer insightful data about eating patterns, which is crucial for weight management strategies. Total calorie intake data are useful for tracking macronutrient contribution of a diet to evaluate its overall health and the degree to which an individual achieves the RNIs for fat, protein, and carbohydrate, while micronutrient consumption may be useful in assessing the nutritional adequacy of a diet.

The method of filling out the 24-hour diet recall form does not report the appropriate amount of food intake, which caused limitations in our study. Due to CMCO conditions, this study was conducted online using a self-reporting method. Also, the low sample size and non-adjustment of confounding factors contributed to the limitations of this study. Food and nutrient intakes were frequently underestimated, which is a flaw in self-reported dietary intakes that cannot be neglected. In this study, well-trained nutritionists used interactive techniques to skilfully probe the participants to help them recall as accurately as possible all the foods and beverages consumed in the last 24 hours. Adjustment of confounding factors and an increase in sample size may contribute to more reliable results in future studies.

CONCLUSION

This study found that overweight and obese Malaysians consumed more energy than they expended during the COVID-19 lockdown, leading to weight gain. Macronutrient intakes, especially fat and carbohydrates, exceeded recommended levels, while key micronutrients like vitamin C, vitamin D, and potassium were insufficient. High sugar and processed food consumption contributed to excessive calorie intake. Physical inactivity further worsens energy imbalance. Despite its strengths, the study faced limitations such as self-reported data and a small sample size. Future research should focus on using a more reliable dietary assessment technique to enhance the accuracy of energy intake measurements. Additionally, direct measurement of participants' 24-hour physical activity levels, rather than relying on adopted PAL values, would provide more reliable PAL estimates for calculating TDEE. This improved approach to assessing energy balance could offer better insights into obesity prevention strategies.

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Authors' contributions

Samsudin N, principal investigator, acquisition of data, data analysis and interpretation; Ahmad NS, corresponding author, study conception and design; Samsudin N and Ahmad NS, drafting of manuscript; Ooi FK, Abdul Kadir A & Kassim NK, study conception and design, and critical revision of the manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest.

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