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Dietary patterns associated with the risk of type 2 diabetes in women with and without a history of gestational diabetes mellitus: A pilot study

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ABSTRACT

Introduction: There is limited evidence on dietary patterns and the risk of type 2 diabetes (T2D) in women with a history of gestational diabetes mellitus (GDM) compared to their non-GDM counterparts, especially in the Asian population. The pilot study investigated dietary patterns in women with a history of GDM (HGDM) and without a history of GDM (non-HGDM), and the association with T2D risk. **Methods:** This comparative cross-sectional study involved 64 women (32 HGDM, 32 non-HGDM). Food intake was assessed using a validated food frequency questionnaire. Principal component analysis derived the dietary patterns. T2D risk score was determined using the Finnish Diabetes Risk Score tool. **Results:** HGDM group had significantly higher proportion of first-degree family history of diabetes; higher risk of T2D and better diabetes knowledge; lower gestational weight gain and postpartum weight retention; and consumed more fast food than non-HGDM. 'Rice-noodle-pasta-meat' dietary pattern was significantly associated with increased T2D risk after adjusting for age (β=0.272, p=0.032). 'Bread-cereals-fast food-meat' dietary pattern was positively and significantly associated with T2D risk after adjusting for confounders, including age, education level, family history of diabetes, diabetes knowledge score, gestational weight gain, and postpartum weight retention (β=0.251, p=0.012). **Conclusion:** Dietary patterns high in bread, cereals and cereal products, fast food and meat, as well as rice, noodle, pasta and meat were associated with an elevated T2D risk. A more extensive study is warranted to establish the association between dietary patterns and risk of T2D, focusing on women with a history of GDM.

Keywords: dietary patterns, gestational diabetes mellitus, type 2 diabetes

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INTRODUCTION

Type 2 diabetes (T2D) accounts for approximately 90% of diabetes cases worldwide (International Diabetes Federation, 2019). Women with pregnancy complicated with gestational diabetes mellitus (GDM) have a 10-fold risk of developing T2D following delivery, compared to those who have normoglycaemic pregnancy (Vounzoulaki *et al.*, 2020). Hence, early detection is critical to reduce the risk of T2D in women with a history of GDM.

The mainstay of GDM treatment is lifestyle interventions, which include medical nutrition therapy (MNT), regular physical activity, and diabetes self-management education (American Diabetes Association, 2022). Dietary interventions during GDM pregnancy have been shown to improve glycaemic control and neonatal outcomes (Yamamoto *et al.,* 2018). However, it is unknown whether these women retain their diabetes knowledge and continue healthy dietary practices after delivery. Women with a history of GDM were reported to have suboptimal physical activity levels and dietary intake despite their knowledge on prevention strategies for T2D (Jones, Roche & Appel, 2009).

A diet relatively low in carbohydrates, but high in animal fat and protein was associated with an increased risk of T2D in women with a history of GDM (D'Arcy *et al.*, 2020). In contrast, dietary patterns characterised by high intakes of vegetables, fruits, nuts, legumes, and fish; and low intakes of red/processed meats and sugar-sweetened beverages were found to reduce the risk of T2D in this population (D'Arcy *et al.*, 2020). However, most studies investigating dietary patterns among women with a history of GDM were conducted in the Western population (D'Arcy *et al.*, 2020). There is little evidence on the association between Malaysian-tailored dietary patterns and the risk of T2D in women with a history of GDM compared to their non-GDM counterparts. Furthermore, the dietary patterns of the Malaysian population might be different compared to the Western population (Norimah *et al.*, 2008), prompting the current investigation. Therefore, this study aimed to determine the dietary patterns of Malaysian women with and without a history of GDM and their association with the risk of T2D.

MATERIALS AND METHODS

Study design and participants

This comparative cross-sectional study was a pilot study for a more extensive study aiming to investigate the dietary patterns, metabolomic profile, and risk of T2D in Malaysian women with a history of GDM (Hasbullah *et al.*, 2022). The study has been registered on ClinicalTrials.gov (NCT04190199). The study was conducted at Universiti Putra Malaysia (UPM), Selangor, Malaysia from February to March 2020. Out of 16 faculties and two research centres in UPM, simple random sampling was used to select half of the faculties (*n*=8) and research centre (*n*=1). The faculties selected were Faculties of Food Science and Technology, Environmental Studies, Sciences, Engineering, Economics and Management, Human Ecology, Educational Studies, and Modern Languages and Communication. The research centre randomly selected was the Family, Adolescent and Child Research Centre of Excellence. The study was approved by the Research Committee of Universiti Putra Malaysia (JKEUPM)(ID: 2019-404).

Participants were Malaysian women aged 18-49 years old who had previously given birth and had no prior diagnosis of type 1 or type 2 diabetes. Women were selected from the staff name list obtained from the selected faculties/

institute and screened for eligibility. Eligible participants were then invited to participate in the study. Participants were divided into two groups: those with a history of GDM (HGDM) and without a history of GDM (non-HGDM). History of GDM was self-reported by the participants; the diagnosis was made by medical doctors based on their oral glucose tolerance test (OGTT) results during pregnancy. All participants provided written consent before enrolment.

Sample size was calculated based on a previous study comparing the prevalence of postpartum T2D between women with and without a history of GDM (6.5% vs. 0%) (Moleda *et al.*, 2015), with 80% power and 95% confidence interval, yielding a total of 270 participants. The sample size for pilot studies is recommended to be 10% from the parent study (Connelly, 2008). Hence, a minimum of 27 participants were required for this pilot study.

Dietary assessment

A trained dietitian administered a 165-item food frequency questionnaire (FFQ) adapted from the nationwide Malaysian Adult Nutrition Survey (MANS) 2014 to determine food consumption in the past one month (IPH, 2014). The FFQ comprised 14 food groups: cereals and cereal products, fast food, meat and poultry, fish and seafood, eggs, legumes, milk and dairy products, vegetables, fruits, beverages, alcoholic drinks, confectionaries, bread spreads, and condiments. Participants reported their consumption frequencies (daily, weekly, monthly, or not consumed) and serving sizes for each food item. The amount of food consumed was converted into g/day for each food item (Norimah *et al.*, 2008). Energy and macronutrient intakes were calculated using Nutritionist Pro software version 5.1.0 (Axxya Systems, WA, USA). The HGDM and non-HGDM groups were compared on their intakes of energy, macronutrients, and the 14 food groups (comprising 165 items) based on MANS FFQ.

Socio-demographic, obstetric and anthropometric assessments

Socio-demographic information on participants' age, ethnicity, education level, household income, family history of diabetes, and smoking habit were collected using a general questionnaire. Obstetric information during their index pregnancy (defined as the most recent GDM pregnancy for HGDM group and most recent pregnancy for the non-HGDM group) was obtained from their antenatal records. These included their parity, weight history, delivery method, and breastfeeding duration. Gestational weight gain was calculated as the difference between weight at the last prenatal visit and pre-pregnancy weight, whereas postpartum weight retention was the difference between weight at six months postpartum and pre-pregnancy weight. Total gestational weight gain cut-offs were based on the Institute of Medicine (2009) guidelines.

Height was measured using a stadiometer (SECA model 206, seca GmbH, Germany), whereas weight was assessed using a body composition monitor (Tanita Health Equipment Ltd., Tokyo, Japan). Body mass index (BMI), calculated from height and weight, was classified according to the World Health Organization (WHO) BMI guidelines for adults (WHO, 1998). Waist circumference was measured using a measuring tape (SECA model 203, seca GmbH, Germany) according to the measurement protocol by WHO (2011). The cut-off point for waist circumference in women was ≥80cm to indicate abdominal obesity (WHO, 2011).

Type 2 diabetes risk and knowledge assessment

Finnish Diabetes Risk Score (FINDRISC) predicted participants' risk of T2D within ten years (Lindström & Tuomilehto, 2003). The risk score cut-offs were low risk (<7), slightly elevated risk (7-11), moderate risk (12-14), high risk (15-20), and very high risk (>20). Meanwhile, the 24-item Diabetes Knowledge Questionnaire (DKQ-24) determined participants' level of diabetes knowledge; the tool was reliable as shown by a Cronbach's alpha value of 0.78 (Garcia *et al.*, 2001).

Statistical analyses

Principal component analysis (PCA) was conducted to obtain dietary patterns. From 165 items in the FFQ, ten food items with no responses were removed (ham, bacon, luncheon meat, herbal/ botanical brewed drinks, all alcoholic beverages). Plain water was also removed as it contained no calories.

The remaining 154 food items were re-categorised into 12 food groups: rice, noodle and pasta; bread, cereals and cereal products; fast food; meat and poultry; fish and seafood; eggs; legumes; milk and dairy products; fruits and vegetables; beverages; confectionaries and bread spreads; and condiments. Food items under the fast food, meat and poultry, fish and seafood, eggs, legumes, milk and dairy products, beverages, and condiments food groups were similar with the MANS FFQ. Confectionaries and bread spreads were combined into one food group, as well as fruits and vegetables (the food items under these categories were also similar with the MANS FFQ). Only cereals and cereal products were divided into two food groups: rice, noodle and pasta; and bread, cereals and cereal products (containing all breads, local flatbread, sago, corn, breakfast cereals, and oats). This categorisation was made based on nutrient profile similarities and data from previous local studies (Shyam *et al.*, 2020; Yong *et al.*, 2020; Nik Mohd Fakhruddin *et al.*, 2019).

Data suitability was determined prior to performing PCA using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (>0.50) and Bartlett's test of sphericity (BTS, $p<0.05$) (Nik Mohd Fakhruddin *et al.*, 2019). KMO value in this study was 0.512, while BTS value was <0.001, indicating that the data were adequate for PCA. Eigenvalue cut-off >1.0 determined the number of factors. Factor scores were orthogonally rotated by varimax transformation to increase loading differences for easier interpretability. Factor loadings of <±0.3 were removed from further analysis. Factor scores for each dietary pattern were the summation of food item intakes weighted by their factor loadings. A high factor loading score for a given dietary pattern indicated a high intake of that food group, and a low score indicated low intake of those foods.

Statistical analyses were performed using SPSS software version 25.0 (IBM Corp, Armonk, NY, USA). Data were expressed as mean±standard deviation (*SD)* for continuous variables; and frequencies and percentages for categorical variables. Characteristics of HGDM and non-HGDM groups were compared using independent *t*-test for continuous variables, or Pearson's chi-square test for categorical variables (Fisher's Exact Test for non-parametric parameters). Pearson's correlation coefficient determined the strength of the association between dietary patterns and intakes of energy and nutrients. Dietary patterns associated with the risk of T2D were determined using multiple linear regression, with T2D risk score as the dependent variable. The dietary patterns were adjusted for significant covariates at the bivariate regression level ($p<0.20$): age, education level, family history of diabetes, gestational weight gain, postpartum weight retention, and diabetes knowledge. Significant value for all statistical tests was set at $p<0.05$.

RESULTS

A total of 64 participants participated in the pilot study (n=32 in each group). Participants were in their mid-thirties

Table 1. Characteristics of participants

Variables	*HGDM (n=32)*	*Non-HGDM (n=32)*	*p-value*
	Mean±SD or n (%)		
Socio-demographic background			
Age (years)	35.8±5.2	37.9±6.3	0.1610.387
≤25	0 (0.0)	1 (3.1)	
26-34	14 (43.8)	10 (31.3)	
≥35	18 (56.3)	21 (65.6)	
Ethnicity			0.500†
Malay	31 (96.9)	32 (100.0)	
Chinese	1 (3.1)	0 (0.0)	
Education level			0.113†
Secondary education	0 (0.0)	4 (12.5)	
Tertiary education	32 (100.0)	28 (87.5)	
Monthly household income (RM)	6625±3628	6877±4574	0.808
Family history of diabetes	23 (71.9)	18 (56.3)	0.193
Degree of family history of diabetes‡			<0.001***
First-degree	23 (71.9)	8 (25.0)	
Second-degree	0 (0.0)	10 (31.3)	
Current smoker	0 (0.0)	2 (6.3)	0.492†
Obstetric history			
Parity	1.8±0.6	1.8±0.6	0.824
Pre-pregnancy weight (kg)	61.3±13.9	57.9±13.7	0.317
Pre-pregnancy BMI (kg/m^2)	24.5±5.1	23.5±5.4	0.262
Underweight (<18.5 kg/m^2)	3 (9.4)	6 (18.8)	0.523
Normal (18.5-24.9 kg/m^2)	14 (43.8)	16 (50.0)	
Overweight (25.0-29.9 kg/m^2)	10 (31.3)	6 (18.8)	
Obese (≥30.0 kg/m^2)	5 (15.6)	4 (12.5)	
Gestational weight gain (kg)	8.4±3.9	12.6±6.8	0.003**
Inadequate	21 (65.6)	10 (31.3)	0.020*
Within recommendation	6 (18.8)	14 (43.8)	
Excessive	5 (15.6)	18 (56.3)	
Postpartum weight retention (kg)	-0.6±5.0	3.1±4.8	0.003**
Delivery method	19 (59.4)	22 (68.8)	0.434
Normal	13 (40.6)	10 (31.2)	
Caesarean section			
Breastfeeding duration			0.453
<6 months	9 (28.1)	13 (40.6)	
6-12 months	3 (9.4)	4 (12.5)	
>1 year	20 (62.5)	15 (46.9)	

Table 1. Characteristics of participants *(continued)*

Variables	*HGDM (n=32)*	*Non-HGDM (n=32)*	*p-value*
	Mean±SD or n (%)		
Anthropometry measurements			
Height (m)	1.56±0.05	1.57±0.05	0.457
Current weight (kg)	63.3±13.3	64.6±13.7	0.709
Current BMI (kg/m²)	25.9±5.3	26.1±5.1	0.879
Underweight (<18.5 kg/m²)	1 (3.1)	0 (0.0)	0.438
Normal (18.5-24.9 kg/m²)	17 (53.1)	15 (46.9)	
Overweight (25.0-29.9 kg/m²)	9 (28.1)	14 (43.8)	
Obese (≥30.0 kg/m²)	5 (15.6)	3 (9.4)	
Waist circumference (cm)	83.9±13.6	80.4±8.5	0.213
Within recommendation (<80cm)	17 (53.1)	16 (50.0)	0.802
Exceeded recommendation (≥80cm)	15 (46.9)	16 (50.0)	
Diabetes risk			
Risk score	13.0±3.4	7.2±4.5	<0.001***
Risk category			
Low risk (<7)	0 (0.0)	13 (40.6)	<0.001***
Slightly elevated risk (7-11)	11 (34.4)	14 (43.8)	
Moderate risk (12-14)	10 (31.3)	4 (12.5)	
High risk (15-20)	10 (31.3)	0 (0.0)	
Very high risk (>20)	1 (3.1)	1 (3.1)	
Diabetes knowledge			
Knowledge score (%)	62.5±15.8	42.1±15.7	<0.001***
Knowledge category			0.001**
Poor (<60%)	13 (40.6)	27 (84.4)	
Acceptable (60-80%)	15 (46.9)	5 (15.6)	
Good knowledge (>80%)	4 (12.5)	0 (0.0)	

BMI: body mass index; HGDM: women with history of gestational diabetes mellitus; non-HGDM: women without history of gestational diabetes mellitus
p-value based on independent *t*-test (continuous variable) or Pearson's chi-square test (categorical); †*p*-value based on Fisher's Exact Test
‡Degree of family history of diabetes: First-degree includes parents and siblings; Second-degree includes grandparents, aunts, uncles, nieces and nephews.
**p*<0.05, ***p*<0.001, ****p*<0.001

(36.8±5.9 years old), predominantly of the Malay ethnicity (98.4%), and most were university graduates (93.8%). On average, participants were currently overweight (26.0±5.1 kg/m²) and their waist circumference exceeded the recommended cut-off value (82.2±11.4 cm). The HGDM group had significantly lesser gestational weight gain and postpartum weight retention (both *p*=0.003), but higher diabetes risk and knowledge (both *p*<0.001) (Table 1). The HGDM group also had a significantly higher prevalence of a first-degree family history of diabetes (*p*<0.001). Other characteristics did not significantly differ between the two groups (Table 1).

The HGDM group significantly consumed more fast food compared to the other group (*p*=0.035). The HGDM group consumed 89.3±82.9 g/day of fast food, which is equivalent to one serving

Table 2. Energy, nutrient, and food group intakes of participants

Energy, nutrient, and food group intakes	*HGDM (n=32)*	*Non-HGDM (n=32)*	*p-value*
	Mean±SD		
Energy (kcal/day)	2090±607	1949±510	0.321
Carbohydrate			
g/day	302.5±109.0	296.7±100.5	0.827
As % of energy	57.3±8.8	60.6±9.6	0.161
Protein			
g/day	84.1±32.3	83.8±29.3	0.962
As % of energy	16.2±4.5	17.3±5.0	0.361
Fat			
g/day	56.9±20.6	48.9±20.9	0.128
As % of energy	24.6±6.3	22.7±6.9	0.256
Total fibre (g/day)	10.7±11.3	9.2±6.5	0.515
Sugar			
g/day	44.5±30.4	42.9±29.5	0.825
As % of energy	8.4±4.8	8.5±4.9	0.918
Cereals and cereal products (g/day)	473.5±260.1	399.0±221.0	0.222
Fast food (g/day)	89.3±82.9	54.5±35.9	0.035*
Meat and poultry (g/day)	53.9±44.7	43.9±36.0	0.329
Fish and seafood (g/day)	79.9±74.7	357.4±1444.8	0.286
Eggs (g/day)	31.9±25.1	28.6±27.2	0.615
Legumes (g/day)	15.1±20.2	22.5±42.0	0.372
Milk and dairy products (g/day)	165.7±367.1	93.5±141.8	0.303
Vegetables (g/day)	58.2±45.9	53.0±54.2	0.683
Fruits (g/day)	234.8±182.1	234.9±209.8	0.998
Beverages (g/day)	336.7±345.7	302.0±289.0	0.664
Alcoholic drinks (g/day)	0.5±3.0	0.0±0.0	0.325
Confectionaries (g/day)	75.3±59.7	61.5±45.6	0.305
Bread spreads (g/day)	1.3±1.1	1.3±1.8	0.951
Condiments (g/day)	29.9±50.6	23.3±28.9	0.525

Food groups are according to food groups in the Malaysian Adult Nutrition Survey 2014 food frequency questionnaire (IPH, 2014)
p-value based on independent *t*-test
$^*p<0.05$

of fried chicken per day (90 g), compared to the non-HGDM group (54.5±35.9 g/day of fast food). Intakes of energy, nutrients, and other food groups did not significantly differ between the two groups ($p>0.05$) (Table 2).

Table 3 presents the factor loading scores for dietary patterns identified by PCA. A total of five *a posteriori* dietary patterns were derived from the food groups. The first dietary pattern, 'Dairy-beverages-confectionaries-condiments', explained 20.4% of the variance and was characterised by high intakes of milk and dairy products, beverages, confectionaries and bread spreads, and condiments. The 'Egg-legume' dietary pattern, explaining 13.7% of the variance, had high intakes of eggs and legumes. The 'Bread-cereals-fruits-vegetables' dietary pattern was characterised by high intakes of bread, cereals and cereal products, and fruits and vegetables (accounted 11.8% of the

Table 3. Factor loading scores for dietary patterns identified by principal component analysis

Food groups	*Dietary patterns and factor loading scores*				
	DP 1 (Dairy-beverages-confectionaries-condiments)	*DP 2 (Eggs-legumes)*	*DP 3 (Bread-cereals-fruits-vegetables)*	*DP 4 (Bread-cereals-fast food-meat)*	*DP 5 (Rice-noodle-pasta-meat)*
Rice, noodle and pasta	0.196	0.015	-0.142	0.107	**0.590**
Bread, cereals and cereal products	-0.116	0.130	**0.727**	**0.308**	0.133
Fast food	-0.030	-0.011	0.107	**0.696**	-0.140
Meat and poultry	0.079	0.029	-0.119	**0.617**	**0.409**
Fish and seafood	0.258	0.010	-0.124	0.135	**-0.730**
Eggs	0.148	**0.781**	0.164	0.165	-0.036
Legumes	0.049	**0.710**	0.101	**-0.394**	0.101
Milk and dairy products	**0.847**	0.048	0.155	-0.053	-0.014
Fruits and vegetables	0.127	-0.023	**0.812**	-0.195	-0.187
Beverages	**0.804**	0.045	-0.089	-0.070	0.212
Confectionaries and bread spreads	**0.371**	**-0.660**	0.228	-0.092	0.031
Condiments	**0.862**	-0.131	-0.061	0.164	-0.233

DP: dietary pattern
Bold indicates factor loading score ≥0.3 (high intake of dietary pattern) or ≤-0.3 (low intake of dietary pattern)

variance). The 'Bread-cereals-fast food-meat' dietary pattern had high intakes of bread, cereals and cereal products, fast food, meat and poultry; and low intake of legumes (accounted 10.6% of the variance). Lastly, the 'Rice-noodle-pasta-meat', which explained 9.0% of the variance, had high intakes of rice, noodle and pasta, meat and poultry; and low intake of fish and seafood.

Table 4 shows the association between dietary patterns and the risk of T2D. The 'Rice-noodle-pasta-meat' dietary pattern was positively and significantly associated with the risk of T2D after adjusting for age (β=0.272, p=0.032). The 'Bread-cereals-fast food-meat' consistently remained positively and significantly associated with T2D after adjusting for confounding variables (β=0.251, p=0.012). The final models (each dietary pattern adjusted for age, education level, family history of diabetes, diabetes knowledge score, gestational weight gain, and postpartum weight retention) contributed towards 43.8-49.8% of the variance.

None of the dietary patterns had a strong correlation with energy or macronutrient intakes (Table 5). The 'Dairy-beverages-confectionaries-condiments' dietary pattern had a moderate, positive association with total fibre intake (p<0.001). The 'Eggs-legumes' dietary pattern was moderately and linearly associated with protein intake (p=0.002). The 'Bread-cereals-fruits-vegetables' dietary pattern showed a moderate and positive association with energy (p=0.003), protein (p<0.001), and sugar intakes (p<0.001). There was a moderate and linear correlation between 'Bread-cereals-fast food-meat' dietary pattern and fat intake (p=0.003), and

Table 4. Linear regressions of dietary patterns associated with risk of type 2 diabetes

Dietary pattern	*Model 1*		*Model 2*		*Model 3*		*Model 4*		*Model 5*	
	Standardised β	*95% CI*	*Standardised β*	*95% CI*	*Standardised β*	*95% CI*	*Standardised β*	*95% CI*	*Standardised β*	*95% CI*
DP 1 (Dairy-beverages-confectionaries-condiments)	-0.022	-1.364, 1.143	-0.022	-1.375, 1.153	0.035	-0.858, 1.204	0.021	-0.933, 1.137	0.028	-0.897, 1.172
DP 2 (Eggs-legumes)	0.05	-1.006, 1.498	0.051	-1.021, 1.521	-0.141	-1.737, 0.344	-0.129	-1.683, 0.406	-0.151	-1.788, 0.297
DP 3 (Bread-cereals-fruits-vegetables)	-0.064	-1.568, 0.935	-0.067	1.614, 0.954	-0.047	-1.323, 0.857	-0.068	-1.433, 0.760	-0.152	-1.932, 0.427
DP 4 (Bread-cereals-fast food-meat)	0.274	0.145, 2.557*	0.276	0.143, 2.585*	0.260	0.324, 2.243*	0.253	0.291, 2.210*	0.251	0.284, 2.198*
DP 5 (Rice-noodle-pasta-meat)	0.269	0.120, 2.535*	0.272	0.121, 2.570*	0.173	-0.147, 1.859	0.172	-0.151, 1.848	0.139	-0.354, 1.731

Model 1: unadjusted
Model 2: adjusted for age
Model 3: adjusted for age, education level, family history of diabetes
Model 4: adjusted for age, education level, family history of diabetes, diabetes knowledge score
Model 5: adjusted for age, education level, family history of diabetes, diabetes knowledge score, gestational weight gain, and postpartum weight retention
DP: dietary pattern
*$p<0.05$

Table 5. Correlation coefficients between intakes of energy and macronutrients with dietary patterns

Energy and macronutrient intakes	*DP 1 (Dairy-beverages-confectionaries-condiments)*	*DP 2 (Eggs-legumes)*	*DP 3 (Bread-cereals-fruits-vegetables)*	*DP 4 (Bread-cereals-fast food-meat)*	*DP 5 (Rice-noodle-pasta-meat)*
Energy intake (kcal/day)	0.215	0.120	**0.363***	0.287*	0.291*
Carbohydrate intake (g/day)	0.133	-0.015	0.257*	0.155	**0.349***
Protein intake (g/day)	0.049	**0.389***	**0.470***	0.287*	0.123
Fat intake (g/day)	0.183	0.202	0.296*	**0.367***	0.028
Fibre intake (g/day)	**0.632***	-0.120	0.272*	-0.193	-0.001
Sugar intake (g/day)	0.187	0.131	**0.502***	-0.078	-0.052

DP: dietary pattern
Bold indicates at least a moderate correlation ($r \geq 0.3$), *$p<0.050$

between 'Rice-noodle-pasta-meat' dietary pattern and carbohydrate intake (p=0.005). The other correlations between dietary patterns and intakes of energy or macronutrients were either weak (r<0.30) or were not statistically significant (Table 5).

DISCUSSION

In this study, women with a history of GDM had increased risk of T2D, which was consistent with current literature (Vounzoulaki *et al.*, 2020). In comparison to non-HGDM, the HGDM group also had significantly higher proportion of first-degree family history of diabetes, higher diabetes knowledge, lower gestational weight gain, and postpartum weight retention. Women with previous GDM and had a family history of diabetes were significantly more likely to develop metabolic syndrome, T2D, and cardiovascular events at a younger age than their non-GDM counterparts (Carr *et al.*, 2006). Hence, women with both a family history of diabetes and a history of GDM are at even greater risk of T2D and its complications; and this warrants immediate intervention to prevent or delay T2D.

The HGDM group was also more knowledgeable on diabetes, possibly because they received diabetes education and dietary counselling during their GDM pregnancies (Malaysian Dietitians' Association, 2013). Women with GDM would receive an individualised MNT delivered by a clinical dietitian, which include education on appropriate weight gain and nutritional strategies to improve their glycaemic control (Malaysian Dietitians' Association, 2013). In this study, women with a history of GDM had lower gestational weight gain and postpartum weight retention at six months, which may indicate the short-term benefits of lifestyle interventions in managing GDM. However, despite a higher level of diabetes knowledge, the HGDM group also consumed significantly higher amount of fast food and had higher T2D risk score. Altogether, this may signify the need for continuous postpartum lifestyle interventions to sustain their nutrition-related diabetes knowledge and healthy dietary patterns.

The HGDM group consumed significantly higher amount of fast food (the equivalent of one fried chicken per day). Based on MANS 2014 findings, a Western dietary pattern (characterised by fast food, meat, and carbonated beverages) was the predominant dietary pattern in Malaysian adults (Shyam *et al.*, 2020). Ready-to-eat fast foods offer accessible, convenient and quick meal solutions for families of working adults (Shyam *et al.,* 2020). Nevertheless, frequent consumption of fast food has been associated with obesity, impaired insulin and glucose homeostasis, dyslipidaemia, systemic inflammation, and oxidative stress, thus increasing the risk of T2D in adult populations (Bahadoran, Mirmiran & Azizi, 2015).

The 'Bread-cereals-fast food-meat' dietary pattern was shown to be positively and significantly associated with increased T2D risk score in women with and without a history of GDM. This dietary pattern was characterised by high intakes of bread, cereals and cereal products, fast food, meat and poultry, and low intake of legumes. A meta-analysis involving adults from several populations reported that refined grains, red and processed meat were strongly correlated with elevated T2D risk, whereas legume intake was inversely correlated with T2D risk (Jannasch, Kro & Schulze, 2017). A possible mechanism leading to the development of T2D is the advanced glycation end (AGE) products in red and processed meat. AGE products are produced via the glycation and oxidation of proteins and lipids (Dariya & Nagaraju 2020). AGE product accumulation in the body generates reactive oxygen species (ROS), increases oxidative stress and inflammation, which plays a pivotal role in the development of T2D and its complications (Dariya & Nagaraju 2020). Furthermore, this dietary pattern was also shown to be moderately correlated with total fat intake. In the PREvención con DIeta MEDiterránea (PREDIMED) cohort study among Spanish adults, participants who consumed the highest amount of saturated and animal fat had more than two-fold higher risk of T2D compared to the lowest quartile (Guasch-Ferré *et al.*, 2017).

Another dietary pattern had high intakes of bread, cereal and cereal products in addition to fruits and vegetables, but were inversely associated with T2D risk instead (although not statistically significant). We postulated that the healthy components of fruits and vegetables in this dietary pattern may have offset the influence on T2D risk, suggesting the importance of consuming a variety of foods and maintaining a mainly healthy and balanced diet. Although this dietary pattern was moderately correlated with sugar intake, this could be due to the fructose content in the fruits and not because of added sugars. Moderate consumption of fructose (<50g/day) was shown to exert beneficial effects on glycaemic control in individuals with T2D (Cozma *et al.*, 2012).

The 'Rice-noodle-pasta-meat' was also significantly associated with elevated T2D risk. This dietary pattern was moderately correlated with total carbohydrate intake, which was mostly due to the intakes of rice, noodle, and pasta. Carbohydrate intake ≥70% from total energy intake was associated with a higher risk of T2D (Hosseini *et al.*, 2022). In terms of carbohydrate type or quality, consumption of carbohydrates that are high in starch and low in cereal fibre was associated with an elevated risk of T2D (AlEssa *et al.*, 2015). High fibre intake from whole grain cereals have been consistently correlated with lower risk of T2D (Weickert & Pfeiffer 2018). The soluble fibre component in whole grain cereals delays the digestion and absorption of carbohydrates, thus lowering postprandial glucose responses and insulin excursions (Weickert & Pfeiffer 2018). On the other hand, the consumption of refined grains may elevate the risk of T2D due to their high glycaemic index and glycaemic load, and lower fibre and nutrient contents (Aune *et al.*, 2013).

The study has a few limitations. Firstly, the cross-sectional nature of this study did not enable the causal relationship between dietary patterns and risk of T2D. There was also a lack of participants from various socio-demographic (ethnicities, education, and age); hence, findings from this study may not be generalisable to the target population at large. Secondly, some analyses were not adequately powered due to the small sample size. Results from this small-scale pilot study are promising and further explorations on dietary patterns will be conducted in a more extensive study (Hasbullah *et al.*, 2022). Metabolomic biomarkers related to dietary patterns will also be investigated to better understand the mechanism involved in T2D development in women with a history of GDM, thus helping to inform on the appropriate nutritional interventions for T2D prevention in women with a history of GDM (Hasbullah *et al.*, 2022).

CONCLUSION

Despite having previous diabetes knowledge, women with a history of GDM had higher risk of T2D and fast food consumption than women with normoglycaemic pregnancy. Dietary patterns with high intakes of bread, cereals and cereal products, fast food and meat; as well as rice, noodle, pasta and meat, were associated with an elevated risk of T2D. This indicates that dietary patterns high in saturated fat and protein from animal sources, and food high in carbohydrates, particularly from refined cereal products, may play a role in the development of T2D in women with and without a history of GDM. A more extensive study considering larger sample size and identification of certain metabolites is needed to explore the association between dietary patterns and the risk of T2D, focusing on women with a history of GDM. Continuous postpartum lifestyle interventions are needed to educate women with a history of GDM on healthy dietary patterns to delay their progression to T2D.

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Authors' contributions

Hasbullah FY, conducted the study, data analysis and interpretation, and prepared the draft of the manuscript; Mohd Yusof BN, principal investigator, conceptualised and designed the study, and assisted in drafting of the manuscript; Abdul Ghani R, Appannah G, Mat Daud ZA, and Abas F, supervised the study, assisted in data analysis and interpretation, and reviewed the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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