



## Original article

# Dietary assessment of pre-diabetic patients by using food frequency questionnaire. A systematic review of study quality, study outcome, study questionnaire and their relative validity and reliability



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## SUMMARY

**Background:** The contribution of dietary factors in the development and progression of pre-diabetes has been increasingly recognized. However, due to high variability in dietary habits measurement of dietary intake remains one of the most challenging tasks in this population. Food frequency questionnaire (FFQ) which investigates usual dietary intake can be used to identify frequent consumption of foods such as dietary fat, fiber, grains that are linked to the risk of pre-diabetes.

**Method:** This systematic review was conducted to identify and describe FFQs that measure dietary intake of pre-diabetic patients and to examine their relative validity and reliability. The systematic search was done through electronic databases such as PubMed, CINAHL, PsycINFO, ProQuest and Scopus. Methodological quality of included studies and results of study outcome was also summarized in this review.

**Result:** The search identified 445 papers, of which 18 studies reported 15 FFQs, met inclusion criteria. Most of the FFQs ( $n = 12$ ) were semi-quantitative while three were frequency measures with portion size estimation of selected food items. Test-retest reliability of FFQ was reported in 7 (38.3%) studies with the correlation coefficient of 0.33–0.92. Relative validity of FFQ was reported in 16 (88.8%) studies with the range of correlation coefficient of 0.08–0.83. Dietary patterns rich in carbohydrate, fat, animal protein and n-3 fatty acids were associated with increased risk of pre-diabetes.

**Conclusion:** No well-established disease-specific FFQ identified in the literature. Development of a valid, practical and reliable tool is needed for better understanding of the impact of diet in pre-diabetic population.

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## 1. Introduction

Pre-diabetes is a condition of abnormal blood glucose homeostasis [1]. It is characterized as either by the presence of impaired fasting glucose (IFG), impaired glucose tolerance (IGT) or in a combination of both. Individuals having Fasting plasma glucose (FPG) levels between 5.6 and 6.9 mmol/l or 2-h post-load plasma glucose level of 7.8–11 mmol/l is categorized as pre-diabetes [2]. The prevalence of pre-diabetes is increasing globally and expected to affect 472 million adults by the end of 2030 [3]. Increase in prevalence of pre-diabetes contributes a significant parallel increase in the

prevalence of type 2 diabetes (T2DM) [4]. According to the American Diabetes Association panel of experts, up to 70% of individuals having pre-diabetes progressed to diabetes [1]. However, it is evident that modification in diet and lifestyle can reduce this figure [5].

In epidemiological studies, long-term dietary assessment is considered sufficient in identifying the etiological role of nutrients with chronic disease [6]. Traditional dietary assessment methods such as 24-h dietary recall and food records can provide detailed information of consumed foods and beverages, however unable to capture habitual long-term dietary intake unless multiple assessments are performed. Multiple measurements are time-consuming, expensive and place a substantial burden on both respondent and research staffs [6]. Given that, Food frequency questionnaire (FFQ) is the most commonly used method to estimate dietary intake in large nutritional epidemiologic studies because it is less expensive, less burdensome and can capture long-term dietary intake [7]. It can

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categorize individuals according to their dietary intake and thus, helps the researchers to examine the relationship between dietary factors and disease-specific markers [8]. However, to categorize individuals accurately according to their nutrient intake, validity and reliability of FFQ should be known before it is used as a dietary assessment tool in the study [6]. Typically, FFQs are validated against 24-h recall, record and recovery biomarkers of the studied disease by using correlation statistics [9]. Nevertheless, the use of the correlation coefficient has been criticized in literature and recommended to use in conjunction with the *Bland Altman* method [10], which measures correct agreements between two dietary assessment methods. Use of kappa statistics is also recommended for categorical data for the assessment of relative validity [10]. Furthermore, validity and the quality of dietary data may also be affected by the accuracy in estimation of frequency, portion sizes of consumed food and data collection procedure [7]. This can be overcome by the organization of food items into food groups, inclusion of close-ended frequency responses and food portion size estimation by using food models and photographs, that helps individuals to report accurately and reduce cognitive challenges in recalling long-term dietary intake [10].

Dietary habits of pre-diabetic patients might differ from the general population [11]. The use of FFQ which is sensitive enough to capture differences in the intake of a specific nutrient, is needed

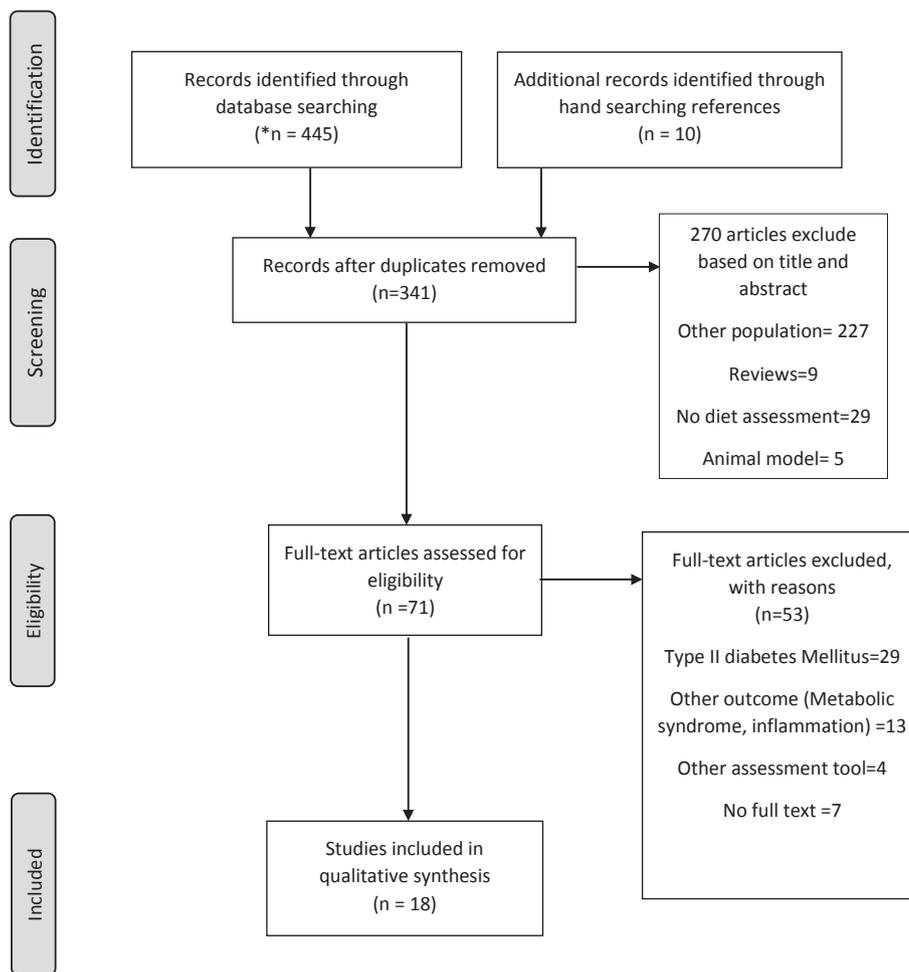
[10]. Several FFQs to date have been developed for use in epidemiological studies [6], but the awareness about their use, reliability and relative validity among the pre-diabetic population is still limited. Therefore, we aimed i) to identify FFQs that were used among the pre-diabetic population and examine their relative validity and reliability ii) to evaluate methodological quality, and to determine the association of diet with pre-diabetes from reviewed studies that were using FFQ as a main dietary assessment tool.

## 2. Method

This systematic literature search was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [12] to identify potentially relevant articles.

### 2.1. Data source and search strategy

A computerized search strategy was implemented by using electronic databases i.e. PubMed (1966–13th April 2018), CINAHL (1937–13th April 2018), PsycINFO (1937 – 13th April 2018), ProQuest (EBSCOhost 1937–13th April 2018) and Scopus (1970–13th April 2018). Medical subject heading (MeSH) terms of major topic and



\*n= number of study

Fig. 1. Flow diagram of study selection process contributing to this review.

**Table 1**  
Study and FFQ characteristics of reviewed articles.

Author, Year, Country	Study objectives	Study design	FFQ type (name if given) SQ: semi-quantitative Q: quantitative	FFQ item	Findings
Bagheri, F, 2016, Iran [11]	Relationship of dietary patterns with pre-diabetes	Case control	SQ	168	VFL inversely, SSMM positively associated with pre-diabetes
Cathrine Lau, 2005, Denmark [22]	Relationship between GI, GL, simple sugar and fiber with HOMA-IR	Cross-sectional	Q	198	lactose associated positively while GL, dietary fiber glucose carbohydrate shows a negative association with HOMA-IR
Eussen, S. J., 2016, Netherland [23]	Relationship between dairy products with IGM (IFG, IGT)	Cross-sectional	Q (Maastricht FFQ)	253	high consumption of skimmed and fermented products has lower odds of IGM. High intake of full fat product not associated with IGM
Jennifer M. KOLB, 2014, USA [21]	Dietary behaviors of pre-diabetic patients	RCT	Q (REAP-S)	16	Poorer scores on diet quality were inversely correlated with BMI.
Jeppesen, C., 2014, Green Land [24]	Association between dietary patterns with IFG, IGT	Cross-sectional	SQ	68 (25 traditional, 43 imported energy contributing food item)	traditional food was positively associated with higher FPG, lower insulin and HOMA- $\beta$ compared with the standard diet.
Jiantao MA, 2016, US [17]	Consumption of SSBs associated with pre-diabetes	Longitudinal cohort	SQ	126	SSBs was associated with insulin resistance and development of pre-diabetes.
Liese, 2003, US [27]	Association of whole grain intake with insulin sensitivity (Si), fasting insulin	Cross-sectional	SQ (IRAS FFQ)	114 items	higher intake of whole grain associated with increase insulin sensitivity
Liese, 2004, US [26]	Dietary patterns association with insulin sensitivity	Cross-sectional	same as IRAS FFQ		dietary patterns associated significantly with insulin sensitivity
Liese, 2005, US [34]	association of carbohydrate, fiber GI, GL with insulin sensitivity, fasting insulin, and adiposity	Cross-sectional	same as IRAS FFQ		fiber positively associated with insulin sensitivity, carbohydrate with fasting insulin. GI not associated, while GL associated significantly with all outcomes
Maryam Safabakhsh, 2017, Iran [20]	fruits and vegetable consumption among pre-diabetic group	Case-control	SQ	168	fruit and vegetable intake were associated with lower odds of pre-diabetes.
Matthew Little, 2016, Canada [28]	Factors associated with prediabetes development	Cross-sectional	SQ	222	dietary fatty acids intake was associated with pre-diabetes cases (P < 0.05)
Meilin Zhang, 2015, China [29]	Dietary pattern association with IFG	Cross-sectional	SQ	81	vegetables-fruits dietary pattern was inversely associated with IFG, animal offal-dessert pattern was associated with an increased risk of IFG.
Sartorelli, D. S., 2009, Brazil [30]	Association between carbohydrate intake and $\beta$ - cell dysfunction in IGT	Cross-sectional	SQ	122	GI, GL, refined grain inversely associated with HOMA- $\beta$ function, reduced $\beta$ cell functioning.
Sridevi Krishnan, 2017, USA [18]	Dietary fatty acids intake association with the IFG, IGT	Longitudinal cohort	SQ (willett FFQ)	66	High intake (10–15% of TE) of MUFA reduced I-IFG risk by 10%, higher intake (0.15% of TE) n-3 FA increase I-IFG risk by 10%, n-6 PUFA (4–5% of TE) reduced IFG and IGT risk.
Tetsuya Mizoue, 2006, Japan [31]	Association between dietary pattern and glucose tolerance abnormality (IFG/IGT/T2DM)	Cross-sectional	Q	74	Japanese dietary pattern positively associated with glucose tolerance abnormality (p for trend 0.048)
Tina Wirström, 2013, Sweden [19]	Wholegrain intake and development and progression of pre-diabetes	Longitudinal cohort	SQ	29	Higher intake of whole grain decreases the risk of progression from normal glucose tolerance to prediabetes
Yuna He, 2009, China [32]	Association of dietary patterns with glucose intolerance	Cross-sectional	SQ	NR	Dietary patterns associated with the presence of glucose tolerance abnormalities in China

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**Table 1** (continued)

Author, Year, Country	Study objectives	Study design	FFQ type (name if given) SQ: semi-quantitative Q: quantitative	FFQ item	Findings
Woo, J., 2002, Hong Kong [33]	Association of dietary pattern with glucose intolerance	Cross-sectional	SQ	266	Diet is not a risk factor for development of IGT in Chinese population.

MOA = Mode of administration; NR = not reported; VFL = vegetable, fruit and legume; SSMM = sweet, solid fat, meat and mayonnaise; GI = glycemic index; GL = glycemic load HOMA-IR = Homeostatic Model Assessment of Insulin Resistant; HOMA- $\beta$  = Homeostatic Model Assessment of  $\beta$ -cell function; IGM = impaired glucose metabolism; IFG = impaired fasting glucose; IGT = impaired glucose tolerance; NR = not reported; RCT = randomized control trial; FPG = fasting plasma glucose; SSBS = sugar sweetened beverages; IRAS FFQ = Insulin resistant Atherosclerosis Study food frequency questionnaire; TE = total daily energy MUFA = Mono unsaturated fatty acids; PUFA = poly unsaturated fatty acids; I-IFG = isolated impaired fasting glucose.

free text terms were used which were categorized under four groups. 1) food frequency questionnaire: FFQ 2) nutrition assessment: diet survey, diet evaluation, energy intake 3) diet: nutrition, dietary pattern, diet quality, nutrition status 4) pre-diabetes (age  $\geq$  18 years): pre-diabetic state, glucose intolerance, insulin resistance. Search was conducted either by entering search terms separately or in combination with Boolean terms such as “AND,” OR “. Keywords and search terms were identified in titles and abstracts (the complete search protocol is available in [supplementary material](#)). Studies that were not in the English language, using animal models, not having full text were excluded. All the retrieved articles were then send to Endnote X7.7.1 where duplicates were removed.

## 2.2. Study selection and data extraction

Studies that evaluate the association of dietary factors or dietary pattern among pre-diabetic patients of  $\geq$ 18 years older by using FFQ were included in this review. Narrative reviews or editorial papers were excluded as contain no methods section that can be critically appraised.

Studies with primary or secondary outcomes of (1) evaluating the relationship of diet with glycemic indices of pre-diabetes such as IFG, IGT and homeostasis model assessments, (Homeostatic Model Assessment of Insulin Resistant (HOMA-IR) and Homeostatic Model Assessment of  $\beta$ -cell function (HOMA- $\beta$ )) or (2) assessing odds of pre-diabetes with dietary pattern intake or (3) assessing diet as a risk factor for the development of pre-diabetes were included. However, studies assessing the relationship of diet with markers of inflammation, metabolic syndromes and obesity, cardiovascular disease (CVD), oxidative stress among pre-diabetes were excluded.

Title and abstract of included studies were reviewed to examine whether they met inclusion and exclusion criteria for full text review. In second round of screening, full-text articles that met all inclusion and exclusion criteria were included in review for data extraction. Data on FFQs characteristics, relative validity and reliability of identified FFQ and association of diet with pre-diabetes risks were extracted and summarized. Each reviewed study ranked according to its methodological quality using summary score by Dennis et al. [13]. This quality score assessed the quality of nutritional information in epidemiological studies from FFQ. The score scale range is 0–15. Studies that had summary score  $\geq$ 7 were categorized as high quality, while studies scored  $<$ 7 were categorized as low quality (the details of the methodological quality are available in [supplementary information](#)). Nutrients of identified FFQs were considered as reliable and/or accurate if i) adequate association with Pearson or Spearman rank correlation coefficient correlation  $>$ 0.50 [14] or ii) if agreement demonstrated by Intra-class correlation coefficient (ICC)  $>$  0.50 [15] or Kappa coefficient  $>$ 0.60 [16]. Bland Altman method also reported as a test of agreement between two measurements if it is reported in studies. No critique criteria available for its statistics in literature.

## 3. Result

The initial search strategy identified 445 potentially relevant citations of which 341 remained after removal of duplicates and review type articles (Fig. 1). After abstract and title scanning, 71 articles were retained for final evaluation whereby a total of 18 articles were included in this review.

Out of 18 reviewed studies, 3 (16.66%) were cohort studies [17–19], 2 (11.1%) were case–control [11,20], 1 (5.55%) was a randomized controlled trial [21] and remaining 12 (66.6%) were cross-sectional studies [22–33]. The sample size (number of subjects included in statistical analysis) varied in between a range of 270–20,210 among studies with the median of 1087 individuals.

### 3.1. FFQs characteristics

The final 18 articles reported dietary assessment using 15 FFQs (Table 1). Eleven (73.3%) questionnaires were semi-quantitative, except for 4 (26.66%) FFQs which were frequency measures, with portion size estimation of selected food items only [21–23,31]. Length of FFQs varied among studies. Shortest length FFQ was short rapid eating and activity assessment (REAP-S) which is food frequency and behavioral questionnaire with 16 items, developed and validated among US medical students [21], while the longest FFQ was developed and validated among Chinese population with 266 items [33].

Among reviewed studies, 4 (22.22%) FFQs were self-administered [19,21,22,31] while 12 FFQs (66.66%) were administered by trained interviewer. Two studies (11.11%) does not report mode of administration of their FFQ [17,30]. The number of frequency choices may vary according to the intended use of the questionnaire. Most of the identified FFQ used pre-coded frequency responses ranging from six to nine categories. For example, “ $\geq$ 4 to seldom or never”. Out of 15 identified FFQs, 5 (33.33%) FFQs asked individuals to report their frequency of consumption of individual food item as per daily, weekly monthly or yearly responses. Recall time also varied among studies, with a minimum stated recall of 1 week [33], while the maximum was one year which was reported in 9 studies (50%). Two (13.33%) FFQs used standard portion sizes for estimation of daily intake [11,19], 2 (13.3%) FFQs used household utensils such as cups and glass [24,28]. One (6.66%) FFQ used the common unit for estimation of portion sizes such as one bread slice, one egg etc. [18]. Three (20%) FFQs were given along with the visual aid of portion estimation for better accuracy [24,28,33]. Regarding portion size, 2 (13.33%) FFQs asked participants to report their intake of food portion according to the standard “small, medium, large” pre-defined portion sizes [25,30].

### 3.2. Evaluation of reliability and relative validity

Repeatability is assessed by administration of same FFQ to the same study group at the different time point to assess the association between the two responses. The repeatability of dietary

**Table 2**  
Relative validity and Reliability of identified FFQ used in Reviewed studies.

Validity			Reliability			
Name of FFQ or country using FFQ among reviewed studies	Reference measure/ Statistic used	Validity coefficients	<sup>a</sup> some relative validity coefficients <sup>b</sup> r > 0.5 or kappa > 0.60	Statistic used	Reliability coefficients	<sup>a</sup> some reliability coefficients <sup>b</sup> r > 0.5 or <sup>c</sup> ICC > 0.5
Iran FFQ [35]	Twelve 24-HR/CC	Energy adjusted r = 0.69 for dietary fiber, 0.63 for white breads and 0.71 for dark breads	✓	Pearson CC	r = 0.81 for dietary fiber, 0.85 for white bread, and 0.89 for dark bread,	✓
Denmark FFQ [36,47]	4- day DR/Pearson CC	r = 0.36 for protein, 0.62 for total fat, 0.64 for total carbohydrate, 0.54 for fiber	✓	Pearson CC	Energy adjusted r = 0.65 for fat, 0.66 for protein, and 0.64 for carbohydrate and for dietary fiber	✓
Maastricht FFQ [23]	NR	NR		NR	NR	
REAP-S [41]	Study 1: 3day DR, study 2: FFQ/Pearson CC	Study 1: (REAP and HEI): total score r = 0.49 p = 0.007, sub scores r = -0.47 (meat) to 0.55 (for fat), 0.50 for fruit p < 0.001. study 2 subscales of FFQ and REAP: r = 0.32 for fiber p < 0.002, fruit 0.30 p < 0.003, 0.45 for vegetable p < 0.001	✓	Pearson CC	r = 0.86, for sub scores r = 0.79 for type of ice cream to 0.33 for vegetable P < 0.0001.	✓
Green land FFQ [24]	NR	NR		NR	NR	
US FFQ [37]	2 one-week DR/ Pearson CC	r = 0.66 for low energy drinks, 0.51 for high energy drinks, 0.83 for coffee, 0.74 for fruit juices, 0.59 for red meat, 0.27 for whole grains. For dietary patterns 0.45–0.74 for prudent and western pattern respectively	✓	Pearson CC	r = 0.40 for leafy vegetables, 0.92 for coffee, 0.88 for red meat, 0.71 for fruit and 0.83 for fruit juice, 0.54 for high energy drinks. For dietary patterns: r = 0.70 for prudent, 0.67 for western pattern	✓
IRAS FFQ [40]	Eight 24-HR/CC (nutrient intake between different ethnic of IRAS population)	mean r = 0.62 urban non-Hispanic white, 0.61 rural non-Hispanic whites, 0.50 African American, 0.41 Hispanic, median correlation coefficient for the total sample was 0.49	✓	CC (nutrient intake between different ethnic of IRAS population)	mean r = 0.62 (median r = 0.63)	✓
Canadian FFQ [38]	Six 24-HR/Pearson CC, Bland Altman LOA	Energy adjusted r = 0.60 for carbohydrate, 0.51 for MUFA and for dietary fiber 0.37 for protein, 0.51 for dietary fiber. LOA for energy intake between two methods was (ranged 768 –1358 ± 2SD)	✓	ICC, person CC	ICC = 0.72 for carbohydrates, 0.56 for PUFA, 0.45 for folate r = 0.78 for carbohydrate and 0.54 for PUFA between FFQ1 and FFQ3 spaced 1 year apart.	✓
Chinese FFQ [29]	Four 24-HR/ Pearson CC	r = 0.52–0.64 for macronutrient and 0.29–0.76 for micronutrient	✓	NR	NR	
Brazil FFQ [39]	Four 3-day DR/ Pearson CC	Energy adjusted mean r = 0.27 for sodium to 0.68 for dietary fiber.	✓	Pearson CC	Energy adjusted r = 0.52 for protein to 0.75 for retinol	✓
Willett FFQ [46]	Four 1-week DR, 116 item FFQ/ Pearson CC	Energy adjusted r = 0.53 (range 0.44 –0.62), between DR and FFQ, r = 0.44 (range 0.28–0.61) between two FFQs	✓	NR	NR	
Japan FFQ [43]	7- day DR/ spearman CC (r <sub>s</sub> ), weighted kappa (food and beverages), Pearson CC (nutrient),	r <sub>s</sub> = 0.56 for rice, 0.48 for meat, 0.58 for dairy. kappa = 0.54 for rice, 0.44 for meat and 0.56 for dairy. Energy adjusted (correlation for nutrients) r = 0.41 (range 0.19–0.63), 0.44 for protien, 0.45 for carbohydrate, 0.56 for fiber	✓	NR	NR	
Sweden FFQ [44]	7-day DR/Pearson, mean daily intake	r = 0.29 for fiber and 0.30 for fat after adjusted for age, mean estimated intake of fiber and fat from FFQ was lower than food records i.e. 18.3 and 19.0 for fiber 44.9 and 88.6 g/day for fat between FFQ and food records respectively	r < 0.5 for fiber and fat indicate poor correlations between two methods	NR	NR	

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Table 2 (continued)

Validity		Reliability				
Name of FFQ or country using FFQ among reviewed studies	Reference measure/ Statistic used	Validity coefficients	<sup>a</sup> some relative validity coefficients <sup>b</sup> r > 0.5 or kappa > 0.60	Statistic used	Reliability coefficients	<sup>a</sup> some reliability coefficients <sup>b</sup> r > 0.5 or <sup>c</sup> ICC > 0.5
Chinese FFQ [45]	3-day DR/ correlation coefficient	r = 0.42 (range 0.08–0.76)	✓	NR	NR	
Hong Kong FFQ [42]	Recovery biomarker of energy, NA, K and concentration biomarker for plasma lipid/paired s-test, partial correlation coefficient	No significant difference in energy. Intake of NA, K was significantly lower than estimated values p ≤ 0.05. Energy adjusted r = 0.10 (fat and HDL cholesterol), p ≤ 0.05	✓	NR	NR	

ICC = intraclass correlation coefficient; r = correlation coefficient; BMI = Body mass index; CC = correlation coefficient; 24HR = 24 h recall; DR = diet record; SD = standard deviation; VFL = vegetable, fruit, legume; SSMM = sweet, solid fat, meat and mayonnaise pattern, GI = glycemic index; GL = glycemic load; NR = not reported; REAP-S = short rapid eating activity participant questionnaire, NA = sodium, K = potassium.

<sup>a</sup> Validity and reliability coefficients of some nutrients of FFQ in acceptable limit as given in literature [14–16].

<sup>b</sup> r = icorrelation coefficient.

<sup>c</sup> ICC = intraclass correlation coefficient.

intake was reported for 7 (46.6%) FFQs [35–41]. The retest time between two FFQ administration was 1 year in 3 studies [35–37]. The shortest repeatable administration of FFQ for the reproducibility measure was one week [42], with different statistical tests. Seven studies (38.88%) employed correlation coefficient for reliability testing, the correlation coefficient among studies was 0.33–0.92 [37,43] which is an indicator of reasonable reliability.

Out of 18 studies, sixteen (88.8%) studies reported relative validity of FFQ except two (11.1%) [23,24]. One study used non-validated FFQ with providing no valid reason [24]. No reference provided for tracking validity of identified FFQ in one study [23]. Wide variety of reference measures such as 24-h recall, food record, previously developed FFQ, and recovery and concentration biomarkers were used in validation studies. Four FFQs (26.6%) were validated against 24-h recalls [29,35,38,40], six (40%) against food records [36,37,39,43–45]. One (6.6%) instrument validated against previously validated FFQ [41] and one (6.6%) was tested against recovery biomarker [42]. Two (13.33%) FFQs were tested against combination of more than one reference measure [45,46]. The reported validity coefficient was in range of 0.08–0.83 [37,46] among reviewed studies. One validation study gives poor agreement between two methods when tested against 7-day dietary record by using correlation coefficient. The estimated Pearson correlation coefficient for fat and fiber intake was  $r < 0.50$ . However, mean consumption intake of fiber was not significantly differ in between two methods i.e. 18.3 g/day intake from FFQ and 19.0 g/day intake from dietary records. Thus, this questionnaire can be used to assess absolute fiber intake with good precision [44]. One validation study demonstrate agreement between two methods by using Bland Altman plot. Limit of agreement for energy intake between two methods was in range of 768–1358 cal/day ( $\pm 2SD$ ), this wide variation in mean reflects under reporting of energy from 24-hour recall by study participants [38]. Summary of relative validity and reliability of FFQs are described in Table 2.

### 3.3. Methodological quality assessment

Out of 18 studies, 3 (16.66%) studies attained low methodological quality score [19,21,32], 15 studies (83.33%) were categorized as high-quality with the score range of 7–12 (Table 3). The maximum score that one study can obtain was 15 [13]. No study met all the

requirements for a maximum methodological quality score. The main reasons were lack of information provided about number of food items, mode of administration, survey completion time required, pre-testing of FFQ and database used for daily nutrient calculation among studies. However, one study which attained a high score failed to report the association of dietary pattern with glucose intolerance [33].

### 3.4. Association of dietary factors with pre-diabetes

This review found that fruits, vegetables [11,20], whole grain [22,29,34], skimmed and fermented dairy [23] and intake of monounsaturated fatty acids (MUFA) [18] reduced risk of pre-diabetes.

In contrast SSMM (sweet, solid fat, meat and mayonnaise) [11], traditional dietary pattern (Japanese and Green land) [24,31], sugar-sweetened beverages [17], western dietary pattern [29], refined grain with high glycemic index, glycemic load [30], dietary pattern rich in carbohydrate [32], fat [28], lactose [22] and n-3 fatty acid [18] intake were reported to be associated with increased risk of pre-diabetes.

Two studies did not show any association of diet with pre-diabetes [21,33]. Jennifer M. Kolb et al. [21] used disease-specific tool (REAP-S) for the estimation of diet quality in accordance to the US recommended dietary guideline. REAP-S is a 16-item questionnaire with the combined aspects of behavioral and frequency questions developed and validated among US medical students with the aim to assess nutrition and physical assessment of study participants in clinical setting. The findings of dietary assessment among pre-diabetes by Jennifer M. Kolb et al. [21] showed an inverse association of poor score on diet quality with lower BMI, i.e. Individuals with healthy eating habits had higher BMI in comparison to those having poor eating habits ( $r = -0.42$ ,  $p = 0.0017$ ). This inverse association were suggested to be due to improper estimation of self-reported dietary intake by study participants [21]. Woo. J et al. [33] estimated dietary pattern association among the Chinese population, found that dietary patterns such as rice noodle, pasta, vegetables, fruit and fat were not a risk factor for the development of glucose intolerance in Chinese population even after adjusted for confounding variables [33]. Table 3 summarizes the association of diet with pre-diabetes.

**Table 3**

Association of diet with pre-diabetes and methodological quality score of reviewed articles.

Author, Year, Country	Sample size (n), Target population,/(Ethnicity)	Sample characteristic (mean age, BMI Kg/m <sup>2</sup> )	Dietary pattern/Factor	Reduced risk of pre-diabetes	High risk of pre-diabetes	Methodological Quality score (Dennis et al.) <sup>a</sup> . [13] ≥7 High <7 Low
Bagheri, F, 2016, Iran [11]	n = 300, pre-diabetic, normal group,/(NR)	Pre-diabetic: age = 47.4 BMI = 29.4 control: age = 47.7, BMI = 27.1	VFL, SSMM	VFL pattern negatively associated with pre-diabetes (OR 0.16; 95% CI 0.10, 0.26), p < 0.001	SSMM positive association (OR 5.45; 95% CI 3.22, 9.23) p < 0.001	10/High
Cathrine Lau, 2005, Denmark [22]	n = 5675, NGT, IFG, IGT patients/(NR)	Age = 45.1, BMI 25.8	daily GI, GL, simple sugar and dietary fiber	dietary fiber intake inversely associated with HOMA-IR (OR = 0.97 (0.96–0.99) (P < 0.05)	Intake of lactose positively associated with HOMA-IR (OR = 1.02 (1.01–1.02) (P < 0.0001)	8/High
Eussen, S. J., 2016, Netherland [23]	n = 2391, IGM = 470 (IFG, IGT), NDD = 125, NGT = 1796/NR	age = 59.9 ± 8.2, BMI = 27.26	full fat, semi skimmed, fermented, non- fermented dairy	High consumption of skimmed and fermented products has lower odds of IGM i.e. OR = 0.73 (95% CI 0.55, 0.96), 0.74 (95% CI 0.54, 0.99) p for trend 0.04		10/High
Jennifer M. Kolb, 2014, USA [21]	n = 54, prediabetic/(white, Hispanic, black, Asian)	age = 45.7yrs, BMI = 35.7	poorer diet score indication of poor nutrition	No association observed		5/low
Jeppesen, C., 2014, Green Land [24]	N = 2374, IGT, IFG and newly diagnosed T2DM/(Inuit of Greenland)	age = 55.25 y, BMI = NR	imported meat, traditional food, un-healthy and balanced dietary pattern		Highest percentage of IFG people was found in traditional dietary pattern p < 0.001).	8/High
Jiantao MA, 2016, US [17]	n = 1685 individuals from Framingham offspring study free of pre-diabetes/(NR)	age: 51.9 ± 9.2 y (BMI; kg/m <sup>2</sup> ): 26.3 ± 4.4	SSBs, diet soda	No association between diet soda and pre-diabetes (p-trend = 0.24)	highest SSBs consumers had a 46% higher risk of developing prediabetes (HR: 1.46; 95% CI: 1.16, 1.83), higher SSBs intake increase HOMA-IR (p < 0.05)	8/High
Liese, 2003, US [27]	n = 978, 67% normal, 33% IGT/ (African American, Hispanic, and non-Hispanic white),	age = 54.8 ± 8.5, BMI = 28.4 ± 5.6	whole grain (dark bread, high fiber cereal, hot cereal)	Higher consumption of whole grain increases insulin sensitivity SI (β = 0.082, P = 0.0005) and insulin (β = - 0.0646, P = 0.019)		10/High
Liese, 2004, US [26]	n = 980, 67% normal, 33% IGT/ (African American, Hispanic, and non-Hispanic white)	age = 55 ± 8.5, BMI = 27.68	six patterns i) fries ii) White bread iii) Low-frequency eaters iv) Fruits, v) Wine, mixed drinks vi) Dark bread		all dietary patterns were significantly correlated with fasting insulin p < 0.004 after adjusted for confounders	10/High
Liese, 2005, US [34]	n = 979, 67% normal, 33% IGT/ (African American, Hispanic, and non-Hispanic white)	54.8 ± 8.5, BMI = 28.4	carbohydrate, fiber, GI, GL	fiber intake has beneficial effect on insulin sensitivity Si (β = 0.1250 p < 0.001).		10/High
Maryam Safabakhsh, 2017, Iran [20]	n = 300, prediabetic, normal group (NR)	age = 50 y, BMI = 28.2	fruits and vegetable	High intake of cruciferous vegetables, other vegetables, and berries reduce risk of pre-diabetes (p < 0.05)	Lower intake of fruit vegetable has higher odds of pre-diabetes p trend < 0.007. Higher intake of dark yellow vegetables has higher chance of pre-diabetes (p trend = 0.006)	11/High
Matthew Little, 2016, Canada [28]	n = 753, pre-diabetic, newly diagnosed T2DM, T2DM/(rural south Indian community)	age = 47 ± 14.7 BMI = 23.1 (Pre-diabetic patients)	dietary intake (carbohydrate, fat, dairy, fiber meat fruit, legume)		fat intake was associated with pre-diabetes (IFG, IGT) [OR = 0.92, 95% CI 0.86, 0.99], p < 0.01	11/High
Meilin Zhang, 2015, China [29]	n = 1459, IFG (n = 132), NGT (n = 1327)/(Chinese)	age = 48 y, BMI = 26.3	i) vegetable- fruit pattern, ii) Animal- offal dessert, iii) white rice -red meat pattern	inverse association between vegetable dietary pattern score (highest tertile and IFG status (OR:0.57,95% CI:0.34–0.95) p = 0.013	positive association shown between animal offal dessert pattern score (in highest tertile) and IFG status i.e. (OR:3.15, 95% CI 1.87–5.30) p = 0.035	9/High

(continued on next page)

Table 3 (continued)

Author, Year, Country	Sample size (n), Target population,/(Ethnicity)	Sample characteristic (mean age, BMI Kg/m <sup>2</sup> )	Dietary pattern/Factor	Reduced risk of pre-diabetes	High risk of pre-diabetes	Methodological Quality score (Dennis et al.) <sup>a</sup> [13] ≥7 High <7 Low
Sartorelli, D. S., 2009, Brazil [30]	n = 270, IGT/(Japanese Brazilian patients)	Age = 58 y, BMI = 25	total carbohydrate, fiber, refined-grain, glycemic index (GI) and glycemic load (GL)		GL, refined grains intakes, GI were inversely associated with HOMA-β: (-0.140 (95% CI = -1.044; -0.078), p = 0.023), (-0.186 (95% CI = -0.4862; -0.058), p = 0.012), (-0.1246 (95% CI = -2.2482, -0.0257), p < 0.001) respectively.	9/High
Sridevi Krishnan, 2017, USA [18]	n = 5288, individuals free from diabetes/(84% Caucasian and 26% African American)	age = 53.5 ± 5.7, BMI = 26.2 ± 4.6	dietary SFA, MUFA, PUFA, n-3 FA and n-6 FA intakes	MUFA intake reduced the risk of IFG by 10% p = 0.03, 6-PUFA reduced risk of IFG, IGT by 12%	n-3 FA intake increase risk of isolated IFG by 10% HR = 1.10; 95% CI 1.00, 1.121; P = 0.05. SFA shows no association. Japanese dietary pattern was positively associated with IGT (P = 0.048).	9/High
Tetsuya Mizoue, 2006, Japan [31]	n = 2106, Japanese defense officials without known diabetes/(Japanese)	age = 52.4 years BMI = 23.8	dietary pattern 1) high dairy, fruit, vegetable, starch and low alcohol 2) animal food pattern 3) Japanese dietary pattern			7/High
Tina Wirström, 2013, Sweden [19]	n = 3180 men, 2297 women/ individuals without known diabetes at baseline followed for 8–10 years/(NR)	Age = 47.5 y BMI = 27.5	whole grain intake	Higher intake (>59.1 g/d) of whole grain was significantly associated with 27% reduced risk of pre-diabetes (all, OR: 0.73; 95% CI: 0.56, 0.94; men, OR: 0.57; 95% CI: 0.40, 0.80) p for trend = 0.017		6/low
Yuna He, 2009, China [32]	n = 20, 210, IFG, IGT, T2DM/ (Chinese)	age = 45–69 years, BMI <18.5- ≥ 28 kg/m <sup>2</sup>	green water (rich in rice, vegetable), New affluence (western diet rich in animal food, fat), yellow earth (rich in carbohydrate), and western adopter (rich in animal food, drinks)		New Affluence cluster (2.05 [1.76–2.37]) had higher prevalence rates for glucose intolerance abnormality. Highest % of IFG was found with new affluence dietary pattern i.e.2.7% compared to reference green water pattern.	6/low
Woo, J., 2002, Hong Kong [33]	n = 988, IGT, NGT and T2DM/ (Chinese)	Mean age = 45.6 years SD 11.7, BMI = 24.1 SD 3.6		No association of dietary pattern observed with IGT.		12/High

VFL = vegetable fruit legume; SSMM = sweet, solid fat, meat mayonnaise; GI = glycemic index; GL = glycemic load; NR = not reported; HOMA-IR = Homeostatic Model Assessment of Insulin Resistant; ND = newly diagnosed diabetes; NGT = normal glucose tolerance; T2DM = type 2 diabetes mellitus; SSBs = sugar sweetened beverages; HR = Hazard Ratio; OR = Odds Ratio; wk = week; HEI = Healthy Eating Index; IFG = impaired fasting glucose; IGT = impaired glucose tolerance; SFA = saturated fatty acid; FA = fatty acid; WHR = Waist to Hip Ratio.

<sup>a</sup> Dennis et al. [13] quality level high ≥ 7, low <7.

#### 4. Discussion

Wide variety of dietary assessment studies that assess dietary intake of pre-diabetic patients were reviewed. Total 15 questionnaires were identified and reviewed for their design and relative validity and reliability. Among this, half of the tools were assessed for dietary pattern associated with glycemic indices among pre-diabetic patients while rest were identified the relationship of dietary factors with pre-diabetes. Overall, reported validity and reliability of the measures were fair to good. No significant difference noted between the validity coefficients of FFQ when tested against a different reference method. Correlation coefficient and the intraclass correlation coefficient was used as a measure of reliability testing mainly in reviewed studies. However, both tests were criticized previously [10], as correlation coefficient does not provide absolute intake instead it is a measure of relative intake to evaluate how an individual is categorized relative to other participants. Similarly, instruments with low absolute agreement still can achieve high correlation coefficient [48] leading to false estimates. It is recommended to use the *Bland Altman* method in conjunction with above-defined test for validity and reliability testing [10].

Among the reviewed articles, REAP-S questionnaire was the only disease-specific questionnaire but with combine aspect of frequency and behavioral questions. This questionnaire provides a quick assessment of dietary intake of vegetables, milk and fat in primary care setting but failed to provide evidence of its reliability and validity testing among pre-diabetic patients in the literature [21]. Despite the fact that FFQ has been validated previously but its applicability cannot be assumed in all situations [10]. Only one identified FFQ was used previously among T2DM [18,46] before the commencement of its use for dietary assessment among pre-diabetic patients.

Another aspect of this review was to provide an understanding of diet association with pre-diabetes. This review revealed that high consumption of fruits, vegetables [11,20], whole grain [22,29,34], skimmed and fermented dairy [23] protect individuals from developing pre-diabetes. In contrast, western type dietary patterns (categorized by higher consumption of red and processed meat, refined grain, high fat) [11,28–30,32], traditional dietary pattern (Japanese and Green land) [24,31], sugar-sweetened beverages [17], lactose [22] and n-3 fatty acid [18] intake were associated with increased risk of pre-diabetes.

Methodological quality of dietary assessment showed that most of the reviewed studies were ranked high quality according to summary score proposed by Dennis et al. [13] except three [19,21,32]. The reason for lower quality score was related to lack in reporting information about number of food items in FFQ, pre-testing of FFQ, database used for nutrient calculation and time required to complete survey questionnaire. Inconsistency was also observed between methodological quality and association of diet with pre-diabetes. One low-quality study showed an association of dietary pattern that was rich in carbohydrate with an increased risk of pre-diabetes [32]. In contrast, one high-quality study reported no association of diet with glucose intolerance [33]. The likely reason of inaccurate association between diet and glucose intolerance described by the studies was the cross-sectional nature of study design, inaccurate estimation of dietary habits as it was measured only once, correlated with glucose intolerance using single measurement [33], and effect of preparation method on food consumed such as effect of frying on dark yellow vegetables. For this reason, higher consumption of dark yellow vegetables was reported to be associated with high risk of pre-diabetes ( $p < 0.001$ ) [20].

Summary score proposed by Dennis et al. [13] used in this review was used to identify the methodological issues in the studies identified. Poor reporting of dietary assessment details is might be

due to the limited length of the articles. However, many studies did not even report the critical characteristics of FFQ such as questionnaire length [32] and the mode of administration [17,30]. Above limitations made it challenging to understand the effect of these aspects of FFQ on their study outcome.

Particular attention to methodological issues should be given to provide consistent information in future studies. FFQ used should always be validated and pre-tested for the clarification of food and portion sizes before the commencement of a study. The original purpose of FFQ should always be reported and if the FFQ has been used previously, it is necessary to report the reference of the referred studies. A brief description of the validation study, sample size, reference method used, and validation results of specific food or nutrients of interest also needs to be reported. A brief description of the critical characteristics of FFQ regarding food items, portion size estimation and frequency responses should always be described. In addition, it is also necessary to provide the statement regarding the administration method of FFQ and database used for the calculation of daily nutrient intake [10]. It is essential to explain the reason if the validation was not done.

##### 4.1. Strengths and limitations

To our knowledge, this is the first systematic review which provides the insight of dietary assessment studies conducted among the pre-diabetic population using FFQ as provided by the study authors. The overall purpose is to highlight the issues regarding methodological quality using summary score by Dennis et al. [13], relative validity and reliability of FFQ which need to be focused on when using FFQ as a primary dietary assessment tool to increase the quality of data collected. Descriptive details and relative validity and reliability of FFQs were highlighted wherever available. The given review also provides evidence of association of diet with pre-diabetes.

However, there are some limitations associated with this review. A copy of the original instrument of FFQs cannot be identified and the description provided may be limited as a result discussed in published studies. Validity and reliability of identified FFQ were directly retrieved from the reference provided for tracking psychometric properties, which is not an actual validation study reported in some papers [11,20,22]. The search was limited to the pre-diabetic population and FFQs that were developed for T2DM and can be used among pre-diabetic populations may not be identified [49]. This review is limited to studies that were published in English, therefore, some relevant disease-specific FFQ developed in other languages were not included.

#### 5. Conclusion

The present review has identified a range of FFQ that could be used among the pre-diabetic population with adequate reliability and/or relative validity. Further validity and reliability testing of identified FFQs is required to determine their suitability of measurement in this context. If FFQs were used in the different population, they should be adapted and evaluated locally to check their acceptance and reliability among the evaluation sample. Our review indicated the need of new applicable, reliable and valid disease-specific tool that identifies target food and habits important in prevention and prognosis of pre-diabetes. Attention should be given to methodological issues when assessing dietary assessment among pre-diabetic patients. More observational and interventional studies are required to further explain the role of dietary patterns and pre-diabetes risk across the population using FFQ.

## Statement of authorship

Sania Siddiqui performed systematic literature review and drafted manuscript. Sania Siddiqui, Hadzliana Zainal contribute to the concept and design of the work. Sabariah Noor Harun and Siti Maisharah Sheikh Ghadzi critically reviewed manuscript. All authors read and approved the final manuscript.

## Conflict of interest

No conflict of interest declared by all study authors.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clnesp.2018.10.002>.

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