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ORIGINAL ARTICLE

Use of a web-based dietary assessment tool in early pregnancy

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Abstract

Background Maternal diet is critical to fetal development and lifelong health outcomes. In this context, dietary quality indices in pregnancy should be explicitly underpinned by data correlating food intake patterns with nutrient intakes known to be important for gestation.

Aims Our aim was to assess the correlation between dietary quality scores derived from a novel online dietary assessment tool (DAT) and nutrient intake data derived from the previously validated Willett Food Frequency Questionnaire (WFFQ).

Methods 524 women completed the validated semi-quantitive WFFQ and online DAT questionnaire in their first trimester. Spearman correlation and Kruskal–Wallis tests were used to test associations between energy-adjusted and energy-unadjusted nutrient intakes derived from the WFFQ, and diet and nutrition scores obtained from the DAT.

Results Positive correlations were observed between respondents' diet and nutrition scores derived from the online DAT, and their folate, vitamin B_{12}, iron, calcium, zinc and iodine intakes/MJ of energy consumed derived from the WFFQ (all $P < 0.001$). Negative correlations were observed between participants' diet and nutrition scores and their total energy intake ($P = 0.02$), and their percentage energy from fat, saturated fat, and non-milk extrinsic sugars (NMES) (all $P \leq 0.001$). Median dietary fibre, beta carotene, folate, vitamin C and vitamin D intakes derived from the WFFQ, generally increased across quartiles of diet and nutrition score (all $P < 0.001$).

Conclusions Scores generated by this web-based DAT correlate with important nutrient intakes in pregnancy, supporting its use in estimating overall dietary quality among obstetric populations.

Keywords Web-based dietary assessment · Pregnancy · Food frequency questionnaire

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Introduction

It has been established that micronutrient deficits in pregnancy are associated with unfavourable neonatal outcomes. For example, low iron status in pregnancy has been linked to low birth weight and impaired cognitive development [1, 2], while low maternal folate status in the first trimester is a critical risk factor for neural tube defect (NTD) births [3]. Maternal vitamin D intakes are also thought to influence fetal growth, while low vitamin C intake has been associated with lower birthweight [4, 5].

Outside pregnancy, dietary assessment is challenging because accurate data are difficult to obtain. Issues which can affect the accuracy of dietary data collected include conscious or inadvertent mis-reporting from the participant, inaccurate estimation of portion sizes and interviewer bias. In pregnancy, the assessment of food and nutrient intakes and the interpretation of their effects on pregnancy outcomes are further complicated. For example, changes in appetite and eating patterns may take place as pregnancy progresses. In addition, complex and sequential physiological changes in nutrient absorption and metabolism, and in energy and nutrient needs, occur throughout gestation [6]. The difficulties associated with accurate quantitative dietary assessment in pregnancy may potentially give rise to misleading conclusions about the influence of maternal diet and specific nutrient intakes on the course and outcome of pregnancy [7].

Several methods for dietary assessment are currently used in clinical and research practice, with new models and technologies also beginning to emerge [8]. Currently there is a lack of research describing the use of online tools in the dietary assessment of pregnant women. It has been recommended however, that more research be undertaken to validate innovative web-based dietary assessment tools (DATs) [8] and intervention tools [9], given the importance of maternal diet in fetal development and in later infant and adult health. In this context, accurate and practical dietary assessment methods are important to support the development of effective, evidence-based nutritional interventions. Our aim was to compare dietary quality scores derived from a newly developed online DAT against nutrient intakes derived from the Willett Food Frequency Questionnaire (WFFQ) which has been previously validated in healthy pregnant women presenting for antenatal care [10].

Methods

The Coombe Women and Infants University Hospital (CWIUH) is one of the largest maternity hospitals in the EU and cares for women from all socioeconomic groups and from across the urban–rural divide. Women were recruited at their convenience at the first antenatal visit between February and August 2013. The women's clinical and socio-demographic details were computerised routinely at the first antenatal visit and updated again immediately after delivery.

To assess habitual food and nutrient intakes, women were asked to complete the previously validated semi-quantitative WFFQ [10–13], and then the online DAT questionnaire. Both questionnaires were completed at the first antenatal visit (~2 h duration), with the WFFQ given to participants ~1 h before the DAT. Socioeconomic, health behavioural, and physical activity data were also collected using the online tool. Height was measured to the nearest centimetre using a Seca wall-mounted digital metre stick with the woman standing in her bare feet. Weight was measured digitally to the nearest 0.1 kg (Tanita MC 180, Tokyo, Japan) and body mass index (BMI) calculated (kg/m^2). Written informed consent was obtained. The study was approved by the Hospital's Research Ethics Committee (Study number 7-2012).

Inclusion and exclusion criteria

The inclusion criteria were attendance for antenatal care and confirmation of a singleton ongoing pregnancy of 18 weeks or less gestation upon ultrasound examination. The exclusion criteria included multiple pregnancies, so as to reduce the number of potential confounding variables; and maternal age of less than 18 years.

Food frequency questionnaire

To determine habitual food and nutrient intakes, women were asked to complete a self-administered, semi-quantitative WFFQ at the first antenatal visit. Women were given the WFFQ at the start of their antenatal visit and asked to complete the questionnaire unsupervised. This WFFQ was originally adapted from the European Prospective Investigation into Cancer and Nutrition (EPIC) study and validated for use in a population of Irish adults [11–13]. This WFFQ has also been recently validated against 3-day food diaries in an Irish obstetric population [10].

Using the WFFQ, the frequency with which a 'standard portion' of each food or beverage item was consumed was reported using nine categories, ranging from 'never or less than once per month' to 'six or more times per day'. A 'standard portion' was quantified using the UK Food Standards Agency's Average Portion Sizes [14]. In this way, food and nutrient intake data reflective of the periconceptional period were captured as the WFFQ protocol focuses on intake over the previous year. These WFFQ data were entered into WISP version 4.0 (Tinuviel Software, Llanfechell, Anglesey, UK) to convert reported food intakes into estimated nutrient intakes. The food composition tables used in WISP are derived from McCance and Widdowson's Food Composition Tables 5th and 6th editions, and all supplemental volumes [15].

Online assessment tool

The online assessment tool was a self-administered computer-based application, which was divided into three parts. Part one collected socio-demographic, attitudinal and health behavioural data, including the participant's name, address, household composition (the number of adults and children in the household), their ethnic or cultural background, their educational and employment status and their estimated weekly income. The clinical, attitudinal and health behavioural data also collected included any medical conditions or medications which applied to the individual; their self-perceived level of psychological stress; their barriers to healthy eating; and their current and habitual health behaviours (smoking, alcohol intake, nutritional supplement usage) [16–18]. Questions collecting socioeconomic data were derived from the EU Survey on Income and Living Conditions (EU-SILC) [19, 20].

Part two of the computer-based tool collected self-assessed habitual physical activity levels (PALs), with individual PALs estimated for each participant from 1.45 metabolic equivalents (METs) (seated work with no option of moving around and no strenuous leisure time activity); up to 2.20 METs [strenuous work or highly active leisure time (e.g. competitive athletes in daily training)] [21].

Part three of the computer-based tool collected the participants' dietary intake data. These dietary data were divided into ten dietary domains (fruit and vegetables, breakfast cereals, milk and dairy foods, meats, alcohol, fatty foods, starchy foods, refined sugars, oily fish and supplements). Data describing the amount and frequency of breakfast cereal consumption were collected, along with the respondent's frequency of oily fish intake. Starchy food intakes (habitual amounts and types of bread, pasta, rice, potatoes and noodles consumed); meat and poultry intakes (serving sizes, frequency of processed meats, cooking methods); and sweet and sugary food and drink intakes (cakes, sweets, chocolate, fizzy drinks, sugar, jam and honey) were also determined. The types and amounts of milk, spread, yoghurt and cheese habitually consumed by participants were also estimated, as well as their intake of fat-rich foods (chips, savoury snacks, rich sauces, desserts and take-away foods). Finally, participants were asked to estimate their alcohol intakes in terms of commonly consumed alcoholic beverages. Images of specific food portion sizes were used to facilitate more accurate estimation of intake by participants, and the number of servings usually consumed per day or week were determined as outlined in Table 1. The estimated dietary intake data was reflective of the previous year, as women were asked to complete the DAT according to their usual intakes over the previous 12 months.

Each of the ten domains was allocated an a priori weighting, based on their respective nutritional importance to the gestational diet. For example, domains describing breakfast cereal, fruit and vegetable, low fat dairy, lean meat and alcohol intakes all received higher weightings due to their better established associations with maternal micronutrient intake and neonatal outcomes [22–24]. Dietary domains with weaker, less developed or less consistent evidence to support their associations with neonatal health outcomes such as fatty foods [25–27], starchy foods [28, 29], refined sugar [30–35] and oily fish [36–39], received lower relative weightings. The domain assessing the use of dietary supplements including vitamin D, multivitamins and omega-3 fatty acids received a modest weighting. This was in recognition of the persisting lack of consensus which still exists regarding the associations between maternal use of these supplements and gestational and neonatal health outcomes [40–45].

Each dietary domain yielded a score which contributed to an overall composite score (%) that reflected the overall quality of the diet. The ten dietary domains with their respective weightings are shown in Table 1. The elements of this dietary scoring system are consistent with the food intake guidelines highlighted in dietary recommendations for pregnancy disseminated by national and international health agencies [46–48]. The system is also consistent with previous efforts to operationalise food-based dietary guidelines for pregnancy using existing dietary quality indices [49–51].

Statistical analysis

Data analysis was carried out using SPSS version 20.0 (IBM Corporation, Armonk, NY). Respondents who either under-reported or over-reported their Energy Intake (EI) were excluded from the final analyses to enhance the integrity of the nutrient intake data [52]. These EIs were calculated using the WFFQ data and WISP v 4.0 software (Tinuviel Software, Llanfechell, Anglesey, UK). Lowest plausible thresholds for Physical Activity Level (PAL) were calculated for each respondent according to their individual self-reported PAL category [53]. Basal metabolic rate (BMR) was calculated using standard equations based on gender, weight and age [54]. Those whose ratio of EI to their calculated BMR (EI/BMR) fell below the calculated plausible threshold for their physical activity category were classified as dietary under-reporters [55]. In all categories, those with an EI/BMR greater than 2.5 were classified as dietary over-reporters [56].

Plausible dietary reporters (i.e. subjects who were not classified as under- or over-reporters) were dichotomised into those meeting and not meeting recommended intake guidelines for dietary fibre, macro- and micro- nutrients (approach one). Median diet and nutrition scores from the DAT were compared between these binary groupings using Mann–Whitney *U* tests. As well as assessing compliance with nutrient intake guidelines at the individual level, thresholds for population compliance with dietary fibre, alcohol, carbohydrate, NMES, fat and saturated fat intake recommendations were also calculated and the study population dichotomised into compliers and non-compliers around these thresholds [57, 58] (approach two).

Nutrient intakes per mega-joule of energy consumed were calculated to evaluate the micronutrient density of the diet. As the nutrient intake data derived from the WFFQ were skewed, Spearman correlation analyses were used to test the associations between energy, dietary fibre, and energy-adjusted and energy-unadjusted nutrient intakes derived from the WFFQ; and diet and nutrition scores

Table 1 Composition and relative weightings of dietary intake domains in the dietary assessment tool (DAT)

Dietary domain	Domain % weighting	Indicative assessment questions
Fruit and vegetables	14.0 (12.5 %)	No. of pieces of fruit/raw vegetables per day
		No. of servings of cooked vegetables or salad per day
Breakfast cereals	14.0 (12.5 %)	No. of days per week with high fibre breakfast cereal
Dairy foods	13.5 (12.1 %)	Type of milk used (full fat/low fat/low fat fortified)
		Amount of milk per day
		Amount of cheese per week
Meats	13.0 (11.6 %)	No. of days with processed red meats at the main meal per week
		Serving size of meat/chicken/fish at the main meal
		Usual cooking method for meat, poultry or fish
Alcohol	12.0 (10.7 %)	Usual no. of units per week
Fatty foods	11.0 (9.8 %)	No. of servings of chips per week
		No. of packets of crisps/savoury snacks per week
Starchy carbohydrates	11.0 (9.8 %)	Type of bread eaten (wholemeal/white/pitta)
		Serving size of cooked potatoes/rice/pasta at main meal
Sugary foods and drinks	10.0 (8.9 %)	No. of sweet cakes/biscuits per week
		No. of teaspoons of sugar, honey or jam per day
		No. of sugar-sweetened fizzy drinks per week
Oily fish	7.5 (6.7 %)	No. of servings of fresh or tinned oily fish per week
Supplements	6.0 (5.4 %)	No. of times per week taking a vitamin D supplement
		No. of times per week taking a multivitamin supplement
		No. of times per week taking an Omega-3 supplement
Total	112 (100 %)	

obtained from the DAT. Diet and nutrition scores were divided into quartiles [(low <51.4) to high (>66.6 scores)]. The Kruskal–Wallis test was used to compare median diet and nutrition scores between the WFFQ energy, dietary fibre and energy-adjusted and unadjusted nutrient intake quartiles.

Results

Sample characteristics

Of the 588 women surveyed, 524 (89 %) were included in the final analysis. Fifty-two (8.8 %) of the originally recruited women did not complete the PAL self-assessment and 12 women (2.0 %) did not complete the WFFQ due to time constraints. Age (30.1 ± 5.3 vs. 30.3 ± 5.3 years, respectively), weight (69.3 ± 14.6 vs. 69.7 ± 17.2 kg, respectively) and BMI (25.4 ± 5.6 vs. 25.3 ± 5.3 kg/m^2, respectively) did not differ between women who completed both questionnaires and those who did not. Nulliparous women were more likely to have completed both questionnaires than multiparous women however (45.2 vs. 27.3 %, $P = 0.002$).

For the remaining study population ($n = 524$), the mean age was 30.1 ± 5.3 years (94.7 % between 20–39 years), the mean gestational age at assessment was 12.6 ± 2.6 weeks, the mean BMI was 25.4 ± 5.6 kg/m^2, and the mean PAL was 1.75 ± 0.2 METs. Forty-five percent were primigravidas and 16.6 % were obese. This sample is representative of the obstetric population in Ireland. Of women booking into the Coombe for antenatal care in 2014, 39.1 % were primiparous, 15.3 % were obese, and 91.8 % were between 20 and 39 years of age [59, 60].

Under-reported EI was observed in 122 women (23.3 %). There were no over-reporters in the sample. The baseline characteristics of the study sample (plausible reporters; $n = 402$) and the excluded under-reporters are shown in Table 2 and have been described previously [7]. Mean BMI was greater in the under-reporters (28.1 kg/m^2) than the plausible reporters (24.6 kg/m^2, $P < 0.001$), and a greater proportion of these under-reporters (35.2 %) than the plausible reporters (10.9 %) were classified as obese ($P < 0.001$). The under-reporters were also younger than the plausible reporters ($P < 0.001$) and were more likely to be martially deprived ($P = 0.001$).

The majority of plausible reporters met phosphate, niacin, copper and vitamin B_6 intake guidelines. Higher diet and nutrition scores were observed among those who were compliant with recommended intake guidelines for carbohydrate ($P = 0.02$), total fat ($P < 0.001$), saturated fat ($P = 0.01$), calcium ($P = 0.001$) and iron ($P = 0.01$)

Table 2 Characteristics of study subjects at initial antenatal visit

	Plausible reporters ($n = 402$)	Under-reporters ($n = 122$)	P
Weight (kg)[a]	67.1 ± 12.5	76.9 ± 18.3	<0.001
Height (m)[a]	1.65 ± 7.3	1.66 ± 6.2	NS
Age (years)[a]	30.8 ± 5.2	28.0 ± 4.8	<0.001
Gestational age (weeks)[a]	12.7 ± 2.6	12.3 ± 2.3	NS
BMI (kg/m^2)[a]	24.6 ± 4.7	28.1 ± 6.9	<0.001
Underweight (%)	3.5	0.8	–
Ideal weight (%)	55.8	36.9	0.002
Overweight (%)	29.8	27	NS
Obese (%)	10.9	35.2	<0.001
Fat mass (kg)[b]	19 (10)	24 (15.6)	<0.001
Fat mass (%)[a]	29.7 ± 6.6	33.2 ± 7.6	<0.001
Fat-free mass (kg)[b]	46 (6.3)	49 (9.3)	<0.001
Fat-free mass (%)[a]	70.2 ± 6.7	66.8 ± 7.6	<0.001
Parity[b]	1 (1)	0 (1)	–
Cultural background			
Irish (%)	75.6	82.0	NS
Other European (%)	17.2	13.9	NS
Asian (%)	1.5	1.6	–
African (%)	1.0	0	–
Other (%)	4.7	2.5	–
Have you ceased full time education?			
Yes (%)	71.1	72.1	NS
No (%)	28.9	27.9	
Smoking status			
Current smoker (%)	12.7	11.5	NS
Former smoker (%)	45.0	39.3	
Never smoked (%)	42.3	49.2	
Alcohol consumption			
Yes (%)	57.2	54.1	NS
No (%)	42.8	45.9	
Relative income poverty[c]			
At risk (%)	34.6	24.6	NS
Not at risk (%)	65.4	71.3	
Relative deprivation[d]			
At risk (%)	7.7	18.9	0.001
Not at risk (%)	88.3	81.1	
Consistent poverty[e]			
At risk (%)	7.7	7.4	NS
Not at risk (%)	88.6	88.5	

[a] Mean ± SD

[b] Median (IQR)

[c] Missing data for $n = 5$

[d] Missing data for $n = 16$

[e] Missing data for $n = 21$

according to their WFFQ-derived nutrient intake data (Table 3).

A positive correlation was observed between respondents' diet and nutrition scores and their intakes of nutrients pertinent to fetal growth and development. For example, diet and nutrition scores rose as folate ($P < 0.001$), vitamin B_{12} ($P = 0.007$), vitamin C ($P < 0.001$), vitamin D ($P < 0.001$) and calcium ($P = 0.01$) intakes rose (Table 4). In addition, after micronutrient intakes were adjusted for total energy consumption, positive correlations were observed between respondents' diet and nutrition scores and their iron

($P < 0.001$), folate ($P < 0.001$), vitamin B_{12} ($P < 0.001$), calcium ($P < 0.001$), magnesium ($P = 0.04$), zinc ($P < 0.001$) and iodine ($P < 0.001$) intakes per mega-joule of energy consumed (Table 5).

For energy and macronutrient intakes, negative correlation coefficients were observed between participants' diet and nutrition scores and their total energy intake ($P = 0.02$) (Table 4), and their percentage energy from fat ($P < 0.001$), saturated fat ($P < 0.001$) and NMES ($P < 0.001$) (Table 5).

Median diet and nutrition scores differed across quartiles of dietary fibre, folate, carotene, vitamin D, and vitamin C intakes derived from the WFFQ ($P < 0.001$) (Table 4). Diet and nutrition scores increased moving from the lowest to the highest dietary fibre concentration and protein intake quartiles (both $P < 0.001$); while these diet and nutrition scores declined moving from the lowest to the highest quartiles for percentage of energy from NMES ($P < 0.001$), total fat ($P < 0.001$) and saturated fat ($P = 0.001$) (Table 5).

Table 3 Comparison of DAT scores between respondents meeting and not meeting nutrient intake recommendations ($n = 402$)

Nutrients	Recommended daily intake	% meeting guideline[g]	% of compliers[h]	Median diet and nutrition score (IQR) for compliers	% not meeting guideline[g]	% of non-compliers[h]	Median diet and nutrition score (IQR) for non-compliers	P
Carbohydrate	>50 % of energy[c]	35.3	89.3	60.4 (15)	64.7	10.7	57.4 (15)	0.02[i]
Dietary fibre	>25 g/day[c]	68.2	100	58.6 (15)	31.8	0.00	–	–
Non-milk extrinsic sugars	<11 % of energy[c]	88.5	100	58.6 (15)	11.5	0.00	–	–
Alcohol	0 units/week[d]	37.6	37.6	61.0 (14)	62.4	62.4	58.6 (15)	NS[i]
Total fat	<35 % of energy[b]	40.3	93.8	60.4 (14)	59.7	6.20	49.2 (16)	<0.001[i]
Saturated fat	<10 % of energy[b]	9.50	44.5	62.7 (14)	90.5	55.5	57.6 (16)	<0.001[i]

		% meeting guideline[g]	Median diet and nutrition score (IQR)	% not meeting guideline[g]	Median diet and nutrition score (IQR)	
Protein	54 g/day[e]	98.3	59.6 (15)	1.70	70.5 (28)	NS[j]
Sodium	<2400 mg/day[f]	26.4	59.1 (16)	73.6	59.9 (16)	NS[j]
Calcium[a]	>615 mg/day[e]	85.9	60.0 (15)	14.1	55.0 (14)	0.001[j]
Iron[a]	>10.8 mg/day[e]	72.5	60.1 (15)	27.5	56.4 (16)	0.01[j]
Zinc[a]	>5.5 mg/day[e]	100	58.6 (15)	0.00	–	–
Vitamin B_{12}[a]	>1.0 µg/day[e]	99.8	59.6 (15)	0.20	70.5 (–)	NS[j]
Vitamin D[a]	>10 µg/day[e]	1.1	40.9 (34)	98.9	59.1 (15)	NS[j]
Vitamin C[a]	>46 mg/day[e]	99.3	59.6 (15)	0.70	57.4 (–)	NS[j]

IQR interquartile range, *NS* non-significant

[a] Goals are for Estimated Average Requirements

[b] Food Safety Authority of Ireland 2011 [46]

[c] DOH 1991[74]

[d] DOH 2016[75]

[e] Food Safety Authority of Ireland 1999[76]

[f] Food Safety Authority of Ireland 2005[77]

[g] Approach one-individual level

[h] Approach two-population level. Mann–Whitney *U* test used to test differences between median DAT scores of:

[i] Compliers vs. non-compliers (approach two) and

[j] % meeting guideline vs. % not meeting guideline (approach one)

Table 4 Correlation between DAT scores and FFQ nutrient intakes and comparison of DAT scores between FFQ nutrient intake quartiles ($n = 402$)

	Quartiles	Median diet and nutrition score (IQR)	Correlation coefficient (P value)	Kruskal–Wallis
Energy[a]	<1671	60.5 (17)	−0.12 (0.02)	NS
	1671–2104	61.3 (14)		
	2105–2681	58.6 (16)		
	>2681	59.1 (20)		
Dietary Fibre[b]	<20.09	53.0 (19)	0.31 (<0.001)	<0.001
	20.10–27.09	57.5 (13)		
	27.10–35.09	60.9 (16)		
	>35.10	64.4 (13)		
Alcohol[c]	<0.000	61.0 (14)	−0.13 (0.01)	NS
	0.001–0.139	59.6 (19)		
	0.140–0.389	61.3 (16)		
	>0.390	56.6 (14)		
Sodium[d]	<2055	60.4 (18)	−0.05 (NS)	NS
	2055–2625	58.6 (13)		
	2626–3517	61.5 (16)		
	>3517	59.1 (18)		
Potassium[d]	<3249	53.2 (16)	0.13 (0.01)	0.02
	3249–4291	60.7 (15)		
	4291–8126	61.9 (15)		
	>8126	59.7 (13)		
Calcium[d]	<801.5	55.9 (19)	0.12 (0.01)	0.02
	801.6–1133	58.2 (16)		
	1134–1484	61.5 (15)		
	>1485	60.5 (15)		
Magnesium[d]	<270.0	52.8 (15)	0.15 (0.003)	0.01
	270.1–366.8	59.5 (16)		
	366.9–694.7	64.3 (14)		
	>694.8	59.6 (12)		
Iron[d]	<10.04	59.6 (16)	0.09 (NS)	NS
	10.05–14.04	57.2 (17)		
	14.05–21.11	61.4 (14)		
	>21.12	60.3 (17)		
Zinc[d]	<8.500	57.2 (18)	0.05 (NS)	NS
	8.501–11.50	59.6 (15)		
	11.51–14.50	60.4 (15)		
	>14.51	60.5 (15)		
Iodine[e]	<112.7	54.2 (18)	0.11 (0.008)	0.001
	112.8–167.7	59.6 (14)		
	167.8–236.2	61.9 (14)		
	>236.3	60.5 (17)		
Folate[e]	<260.0	55.0 (17)	0.22 (<0.001)	<0.001
	260.1–332.2	56.4 (13)		
	332.3–440.2	62.2 (17)		
	>440.3	61.9 (13)		
Vitamin B_{12}[e]	<4.500	56.9 (16)	0.13 (0.007)	0.05
	4.501–6.500	58.6 (14)		
	6.509–9.139	60.3 (14)		
	>9.140	62.8 (17)		

Table 4 continued

	Quartiles	Median diet and nutrition score (IQR)	Correlation coefficient (P value)	Kruskal–Wallis
Retinol[e]	<260.7	58.2 (16)	0.01 (NS)	NS
	260.8–371.5	58.7 (15)		
	371.6–600.5	61.4 (16)		
	>600.6	59.9 (15)		
Carotene[e]	<3588	51.3 (18)	0.40 (<0.001)	<0.001
	3589–5937	56.7 (17)		
	5938–8681	59.6 (14)		
	>8682	65.4 (12)		
Vitamin D[e]	<1.819	53.6 (14)	0.22 (<0.001)	<0.001
	1.820–2.009	57.2 (14)		
	2.010–3.819	61.4 (13)		
	>3.820	64.1 (16)		
Vitamin C[d]	<130.5	52.0 (16)	0.35 (<0.001)	<0.001
	130.5–199.0	57.6 (17)		
	199.1–287.5	60.4 (13)		
	>287.6	64.1 (12)		

Spearman correlation coefficient, Kruskal–Wallis test assesses differences in the median diet and nutrition scores between each of the nutrient intake quartiles

IQR interquartile range, *NS* non-significant

[a] kcal/day

[b] g/day

[c] units/week

[d] mg/day

[e] µg/day

Discussion

Main findings

This observational study in early pregnancy found that dietary quality scores from a novel, web-based DAT for evaluating dietary quality in early pregnancy correlated with nutrient intakes derived from the previously validated WFFQ in this obstetric population. Higher diet and nutrition scores were associated with increased intake of nutrients known to be important in optimising pregnancy outcome, while these higher scores also correlated with reduced intakes of nutrients associated with adverse health outcomes.

Low iron status in pregnancy has been linked to low birth weight and impaired cognitive development [1, 2]. In this study, the correlation coefficient between the diet and nutrition score generated by the DAT and the energy-adjusted iron intake derived from the WFFQ was 0.21 ($P < 0.001$) showing that higher diet and nutrition scores were associated with better dietary intakes of iron.

Low folate status is a critical risk factor for NTD births [3]. The correlation coefficient between the diet and nutrition score and energy-adjusted folate intake derived from the WFFQ was 0.47 ($P < 0.001$), showing that higher diet and nutrition scores were strongly associated with better dietary intakes of folate.

Maternal vitamin D intakes may influence fetal growth [4], while vitamin C intake has also been positively associated with birthweight [5]. The correlation coefficients between the diet and nutrition score from the DAT and participants' energy-adjusted vitamin D and vitamin C intakes were 0.23 ($P < 0.001$) and 0.39 ($P < 0.001$) respectively.

Metabolic ill-health in pregnancy has been linked to excessive saturated fat and refined sugar intake [34, 61], while frequent consumption of four or more units of alcohol during pregnancy may adversely affect childhood academic outcomes [62]. The correlation coefficient between respondents' diet and nutrition scores and their WFFQ–derived intake of saturated fat was −0.22 ($P < 0.001$). For NMES intake, the correlation coefficient with the diet and nutrition score was −0.25 ($P < 0.001$), and for alcohol intake it was −0.13 ($P = 0.01$); showing that higher diet and nutrition scores are also associated with lower intakes of these potentially deleterious nutrients.

Table 5 Correlation between DAT scores and Energy-adjusted FFQ nutrient intakes and comparison of DAT scores between energy-adjusted FFQ nutrient intake quartiles ($n = 402$)

	Quartiles	Median diet and nutrition score (IQR)	Correlation coefficient (*P*)	Kruskal–Wallis
Fibre[a]	<2.45	50.6 (17)	0.53 (<0.001)	<0.001
	2.46–2.94	58.7 (12)		
	2.95–3.72	63.0 (13)		
	>3.73	66.8 (13)		
Protein[a]	<15.95	52.8 (19)	0.22 (<0.001)	<0.001
	15.96–18.11	58.7 (17)		
	18.12–20.26	62.4 (13)		
	>20.27	61.6 (11)		
Carbohydrate[a]	<43.18	57.4 (18)	0.07 (NS)	0.03
	43.19–47.50	59.6 (14)		
	47.51–52.11	62.1 (15)		
	>52.12	60.0 (18)		
Total fat[a]	<32.41	63.7 (16)	−0.26 (<0.001)	<0.001
	32.42–36.53	60.5 (12)		
	36.54–39.73	59.5 (18)		
	>39.74	55.1 (18)		
Saturated fat[a]	<11.60	62.2 (14)	−0.22 (<0.001)	0.001
	11.61–13.25	61.4 (14)		
	13.26–15.12	60.6 (15)		
	>15.13	54.4 (18)		
Monounsaturated fat[a]	<9.96	63.6 (15)	−0.31 (<0.001)	<0.001
	9.97–11.41	63.0 (13)		
	11.42–12.78	58.2 (15)		
	>12.79	54.0 (17)		
Polyunsaturated fat[a]	<5.83	61.4 (15)	−0.16 (0.001)	0.003
	5.84–7.00	62.2 (16)		
	7.01–8.30	58.0 (16)		
	>8.31	57.4 (18)		
Non-milk extrinsic sugars[a]	<4.21	61.1 (12)	−0.25 (<0.001)	<0.001
	4.22–6.70	63.2 (15)		
	6.71–8.39	59.1 (13)		
	>8.40	53.5 (20)		
Alcohol[b]	<0.00	59.8 (14)	−0.11 (0.03)	NS
	0.01–0.11	59.1 (24)		
	0.12–0.36	60.5 (15)		
	>0.37	56.6 (14)		
Sodium[c]	<270.9	56.4 (16)	0.05 (NS)	NS
	271.0–298.3	57.6 (16)		
	298.4–346.0	61.6 (14)		
	>346.1	61.4 (14)		
Potassium[c]	<397.2	51.4 (20)	0.09 (NS)	<0.001
	397.3–488.9	61.3 (13)		
	489.0–739.5	65.9 (13)		
	>739.6	59.6 (12)		
Calcium[c]	<99.09	52.8 (17)	0.27 (<0.001)	<0.001
	99.10–123.8	59.6 (15)		
	123.9–150.0	63.2 (15)		
	>150.1	62.8 (13)		
Magnesium[c]	<34.01	49.9 (15)	0.11 (0.04)	<0.001
	34.02–40.92	63.2 (11)		
	40.93–66.27	65.5 (12)		
	>66.28	59.9 (12)		

Table 5 continued

	Quartiles	Median diet and nutrition score (IQR)	Correlation coefficient (*P*)	Kruskal–Wallis
Phosphorus[c]	<166.7	52.1 (17)	0.25 (<0.001)	<0.001
	166.8–188.9	59.6 (17		
	189.0–217.1	63.0 (11)		
	>217.2	61.9 (14)		
Iron[c]	<1.30	52.8 (19)	0.21 (<0.001)	<0.001
	1.31–1.59	60.8 (15)		
	1.60–2.05	61.4 (12)		
	>2.06	61.9 (12)		
Zinc[c]	<1.11	53.2 (18)	0.21 (<0.001)	<0.001
	1.12-1.25	59.5 (17)		
	1.26-1.41	61.5 (14)		
	>1.42	61.9 (14)		
Iodine[d]	<13.52	53.2 (19)	0.21 (<0.001)	<0.001
	13.53–18.08	59.7 (12)		
	18.09–23.94	61.0 (15)		
	>23.95	63.2 (14)		
Folate[d]	<32.06	49.8 (18)	0.47 (<0.001)	<0.001
	32.07–37.94	58.6 (14)		
	37.95–45.62	63.0 (15)		
	>45.63	65.4 (10)		
Vitamin B_6^e	<22.38	58.7 (13)	−0.006 (NS)	NS
	22.39–27.28	59.6 (15)		
	27.29–32.59	61.4 (16)		
	>32.60	58.6 (17)		
Vitamin B_{12}^d	<0.57	56.4 (17)	0.24 (<0.001)	0.001
	0.58–0.73	57.6 (16)		
	0.74–0.93	61.3 (16)		
	>0.94	63.9 (12)		
Retinol[d]	<32.10	57.3 (19)	0.05 (NS)	NS
	32.11–40.76	59.6 (14)		
	40.77–56.08	60.5 (14)		
	>56.09	60.1 (13)		
Carotene[d]	<418.5	51.7 (18)	0.37 (0.001)	<0.001
	418.6–654.9	57.8 (16)		
	655.0–993.6	62.4 (11)		
	>993.7	65.8 (13)		
Vitamin D[d]	<0.19	54.8 (14)	0.23 (0.001)	<0.001
	0.20–0.25	56.5 (19)		
	0.26–0.38	61.4 (12)		
	>0.39	65.5 (13)		
Vitamin C[c]	<14.80	51.9 (21)	0.39 (<0.001)	<0.001
	14.81–22.32	56.6 (15)		
	22.33–31.27	61.9 (11)		
	>31.28	66.0 (12)		

Spearman correlation coefficient, Kruskal–Wallis assesses differences in median diet and nutrition scores between each of the FFQ nutrient intake quartiles

IQR interquartile range, *NS* non-significant

[a] g/MJ/day

[b] units/MJ/day

[c] mg/MJ/day

[d] μg/MJ/day

[e] μg/g protein per day

Interpretation

In evaluating a web-based DAT in pregnancy, the first issue to be addressed is the dietary assessment method by which the reference (comparator) nutrient intake data will be collected. Validation studies of the WFFQ have been carried out in pregnancy and these show meaningful estimates of nutrient intake which can be used to rank individuals within their distribution [10, 63]. In a recent Irish study, the WFFQ used in the current study was validated against three-day food diaries in 130 pregnant women [10]. In that study, energy-adjusted Pearson's correlation coefficients ranged from 0.24 (riboflavin) to 0.59 (magnesium) ($P < 0.05$). In addition, 74.2 % of participants were classified into the same/adjacent quartile of nutrient intake using both dietary assessment methods, showing reasonable to good agreement between the WFFQ and the 3-day food diaries in ranking participants' nutrient intakes. Therefore, the existing evidence supports the validity of the WFFQ as a means of dietary data capture in obstetric populations, and supports our use of this FFQ protocol in the collection of reference nutrient intake data for the current study.

Often in the past, nutrition research favoured a somewhat reductionist approach which emphasised the role of single nutrients in diet-health relationships [64]. This approach resulted in important advances; for example, in learning the basic pathology of vitamin deficiency syndromes, and in identifying effective strategies for their prevention, e.g. the role of folic acid in the prevention of neural tube defects [3]. However, there are also many limitations to this approach in nutritional epidemiology. Firstly, foods and nutrients are not eaten in isolation and synergism and antagonism between certain foods and nutrients is likely to occur, not to mention the inter-individual and intra-individual variations which exist in nutrient effect at the metabolic interface [64]. Additionally, the physiological effect of a single nutrient may be too small to be detected, while statistically significant associations between nutrient intakes and health outcomes may simply occur by chance when numerous nutrients and foods are analysed independently [65, 66].

Investigating "whole diet" patterns in relation to health outcomes has emerged as a more holistic and practical method of dietary assessment than the single-nutrient approach [49]. Dietary patterns encompass a broad representation of food and nutrient intakes and, therefore, may be more predictive of diet-related health risk than single nutrients.

What this study adds

Currently, there is a dearth of research describing the use of online tools in the assessment of dietary quality in pregnant women. It has been recommended that more research is needed to validate innovative web-based DATs [8]. The use of the internet has increased significantly in recent years, with latest figures from the Central Statistics Office estimating that 81 % of Irish households now have access to the internet at home [67]. To our knowledge, this study is the first investigating the use of an online tool for quantitative dietary assessment in an obstetric population. Over 400 participants were included in this observational study, increasing the strength of our findings.

The use of dietary quality scores in obstetric populations has previously been examined in a Canadian study, where the validity of the Healthy Eating Index (HEI) in reflecting nutrient intakes important for pregnancy was examined [68]. That study found that the HEI scores for pregnant and non-pregnant women were the same. However, when essential nutrients for pregnancy were examined, folate and iron intakes were below the recommended intakes for pregnancy. The nutrient analyses in this Canadian study did not include supplement intake however. As 79 % of participants were taking supplements, it is likely that most of these pregnant women met their nutrient requirements through supplement use. The need for a new HEI designed to target food choices and micronutrients associated with enhanced maternal and fetal outcomes was therefore proposed to better reflect the dietary quality priorities of pregnant women [68]. An online DAT is advantageous because it collects information on dietary patterns and overall dietary quality, and assigns respondents a diet and nutrition score which is simple to interpret and understand. The DAT used in this study highlights food groups of key importance in pregnancy such as breakfast cereals, oily fish, refined sugar and fructose, and alcohol [22, 30, 34, 62]. The DAT employed also incorporates further key indicators of the evidence-based dietary advice for pregnancy disseminated by national and international expert agencies [46–48].

A Diet Quality Index for Pregnancy (DQI-P) was investigated in 2063 pregnant women from North Carolina [69]. Dietary intake was assessed using a FFQ between 26 to 28 weeks of gestation. The DQI-P score was then calculated from eight food and nutrient intake components derived from this FFQ which were deemed important dietary quality measures for pregnancy: percentage of recommended servings of grains, vegetables and fruits; percentage of recommended intake for folate, iron and calcium; percentage of energy from fat; and meal/snack patterning score.

An Alternate Healthy Eating Index (AHEI) for pregnancy (AHEI-P) was also investigated, this time in 1777 American women [70]. This score was formulated from nine food and nutrient intake components: vegetables; fruit; ratio of white to red meat; fibre; trans-fat; ratio of polyunsaturated to saturated fatty acids; and folate, calcium, and iron intake from foods. A disadvantage of the DQI-P and AHEI-P is that they rely on estimated nutrient intakes and require the derivation of these nutrient intake data from dietary intake data using nutrient analysis software. The DAT is advantageous as its focus is on food intakes and its web-based delivery obviates the need for explicit nutrient intake data and the use of nutrient analysis software to derive these data. In addition, the web-based DAT is quick, easy, and inexpensive to administer. While significant cost is incurred in the development of such computerised systems; once they are established, the incremental cost of adding extra participants to a research study is low. Thus web-based dietary questionnaires have the potential to enhance dietary assessment through more cost- and time-effective, less laborious methods of data collection which have been found to be feasible and acceptable to respondents [8].

In this regard, the feasibility of using a Personal Digital Assistant (PDA) to collect dietary information was investigated in low Socioeconomic Status (SES) pregnant women [71]. This study found no significant difference in the quality of dietary data collected using a 24-hour diet recall and dietary data collected by PDA. The 10 women who participated in this study found the PDA an easier way to record food intake then the 24-hour diet recall and believed that their reports of dietary intake were more accurate using the PDA, supporting the acceptability of such electronic interfaces in dietary data collection. However the small sample size of this study is a major limitation. Further studies would be useful to assess the user acceptability of the DAT among pregnant women.

Other advantages of a web-based DAT are that the dietary data collected can be linked to individuals' physical activity and other lifestyle behaviours. It can also collect ancillary information regarding users' medical history and socio-demographic details which are potentially useful in a research setting. Its technological advantages include the facilitation of efficient data capture and analysis, as well as the use of images in accurately assessing users' food portion sizes.

Limitations of this study

A limitation of the study is that only one dietary assessment method, the WFFQ, was used to compare against the DAT. Studies have shown that accuracy of FFQs can be lower than other methods, with some FFQs incurring a degree of measurement error because they make several assumptions about food portion size, and also because they can underestimate dietary intake due to an inadequate list of food items [72]. Nonetheless, while FFQs can therefore be a less precise tool in measuring an individual's nutrient intakes, they can be reliably used in large representative study populations to rank individuals according to their relative food or nutrient intakes. In addition, the WFFQ used in this study has also been recently validated against three-day food diaries in an Irish obstetric population [10].

In addition, consistent completion of one dietary assessment method prior to another (i.e. the WFFQ completed before the DAT) may have resulted in systematic bias, with participants attempting to replicate their reported diet in the second dietary assessment measure. The prior use of the WFFQ may also have heightened awareness and conditioned responses to specific aspects of the participant's diet when they subsequently used the DAT. Further studies incorporating a weighted randomisation protocol would be valuable to assess if the order in which the dietary assessment methods are administered influences intake estimates.

The DAT used in this study is not suitable for precise, quantitative analysis of dietary macro- and micro- nutrient intakes, which highlights the importance of correlating its diet and nutrition scores against nutrient intake data generated from previously-validated dietary assessment methods such as the WFFQ in the current study. Use of the DAT also depends on the availability of a computer and internet access which may not be available to all women across the social gradient outside the research setting, particularly in low-resource countries [73]. However, the correlation of dietary scores generated by this DAT with nutrient intakes which are important to pregnancy outcome suggests that this tool could be usefully deployed for nutritional screening in obstetric populations, and followed by more precise nutritional assessment and intervention where indicated.

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Compliance with ethical standards

Conflict of interest LM, ACOH, SC, RK and MJT declare no conflict of interest. DMcC developed the online dietary assessment tool (DAT) and is the proprietary owner of this technology and the intellectual property embedded in it (outlined in conflict of interest form).

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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