2019

Development of a novel Periconceptual Nutrition Score (PENS) to examine the relationship between maternal dietary quality and fetal growth

Rachel AK Kennedy

Michael J. Turner

Funder: Technological University Dublin

Early Human Development 132 (2019) 6–12

Contents lists available at ScienceDirect

Early Human Development

journal homepage: www.elsevier.com/locate/earlhumdev

Development of a novel Periconceptual Nutrition Score (PENS) to examine the relationship between maternal dietary quality and fetal growth

Rachel A.K. Kennedy[a,b,*], Michael J. Turner[a]

[a] UCD Centre for Human Reproduction, Coombe Women and Infants University Hospital, Cork Street, Dublin 8, Ireland
[b] School of Biological Sciences, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland

ARTICLE INFO

Keywords:
Maternal nutrition
Fetal growth
Dietary quality

ABSTRACT

Background: Maternal nutrition may influence intrauterine fetal development. To date, the relationship between contemporary European dietary guidelines and fetal growth has not been examined.
Aims: To develop a novel Periconceptual Nutrition Score (PENS) to assess maternal dietary quality in early pregnancy and examine its relationship with fetal growth.
Study design: Women were recruited conveniently at their first clinic visit and completed a supervised four day retrospective diet history. The PENS was developed using European Food Safety Authority recommended dietary intakes for pregnancy. The relationship between PENS and fetal growth was examined.
Subjects: Women with a singleton pregnancy.
Outcome measures: Birthweight, small for gestational age (SGA), neonatal head circumference.
Results and conclusions: Of the 202 women, the mean age was 32.2 ± 5.0 years and 44.6% were nulliparas. The mean PENS was 9.4 ± 3.1. On multivariable regression, there was a positive relationship between the PENS and birthweight (beta = 45.3, 95%CI 14.8–75.9, P = 0.002) and neonatal head circumference (beta = 0.12, 95%CI 0.01–0.23, P = 0.03). Compared with the lowest PENS quartile, the mean birthweight was increased in the highest quartile (Mean difference 328 g, P = 0.02). The incidence of SGA was 16.4% (n = 10/61) in the lowest PENS quartile compared to 6.5% (n = 9/139) in the top three quartiles (P = 0.03). Thus, higher maternal dietary quality was associated with increased intrauterine fetal growth. The PENS is potentially useful in identifying those women before or during pregnancy who may benefit from dietary interventions that may optimise fetal growth. It may also be useful in tracking maternal dietary quality during pregnancy.

1. Introduction

Suboptimal fetal growth is associated with adverse neonatal outcomes. For example, infants born small for gestational age (i.e. < 10th centile for birthweight) are at increased risk of morbidity and mortality in the neonatal period. These neonates have an increased risk of complications such as infection, perinatal respiratory depression, jaundice, hypoglycaemia and poor feeding [1]. As a result, the risk of neonatal death increases. There may also be lifelong consequences of fetal growth restriction such as cardiovascular disorders [2–4].

There are many risk factors that are associated with suboptimal fetal growth [5]. Some of these are modifiable, others are not. Maternal dietary intake is a modifiable risk factor for adverse pregnancy outcomes. Both inadequate and excessive dietary intakes have been associated with suboptimal fetal growth [6,7]. In the past, nutrition research has focused on the relationship between both individual micronutrients and macronutrients and health outcomes [8]. However, a causative relationship between single nutrient inadequacies and restricted fetal growth has not been proven and the effectiveness of dietary interventions challenging to confirm, particularly in well-resourced countries [9].

The complex relationship between dietary behaviours and the intake of micronutrients and macronutrients has led to the development of dietary quality indices outside of pregnancy, which are based on the recommended daily dietary intakes by national and international public health bodies [10]. These indices are not easily applicable to pregnancy because nutrient requirements increase as pregnancy advances. Also, the transfer of nutrients between mother and baby varies by individual nutrient and varies according to the individual needs of the woman and her offspring.

Abbreviations: BW, birthweight; NHC, neonatal head circumference

* Corresponding author at: School of Biological Sciences, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland.
E-mail address: rachel_kennedy@live.ie (R.A.K. Kennedy).

https://doi.org/10.1016/j.earlhumdev.2019.03.004
Received 11 December 2018; Received in revised form 20 February 2019; Accepted 9 March 2019

Thus, a number of pregnancy-specific dietary quality indices have been developed, mainly in North America [11–13]. Evaluation of the quality of maternal dietary intakes to date, however, has been based predominantly on modified food frequency questionnaires (FFQ) in the second half of pregnancy benchmarked against a variety of American recommendations.

The aim of this study was to develop a composite Periconceptual Nutrition Score (PENS) to assess maternal dietary quality in early pregnancy using European recommendations, and subsequently, evaluate the relationship between the PENS and intrauterine fetal growth.

2. Material and methods

Women were recruited from the Coombe Women and Infants University Hospital. The Hospital is one of the largest maternity hospitals in Europe. It accepts patients from all socioeconomic groups across the urban rural divide. Women were enrolled conveniently as they presented for antenatal care following sonographic confirmation of a singleton ongoing pregnancy. Women were excluded if they were > 18 weeks gestation or if they were unable to give informed written consent. Clinical and sociodemographic details were routinely collected and computerised by a trained midwife at the first visit and again immediately after delivery.

At the first antenatal visit, women's height was measured to the nearest cm and weight was measured to the nearest 0 .1kg by a trained researcher. Body Mass Index (BMI) was then calculated. To assess habitual food and nutrient intakes the same researcher (a registered dietitian) conducted a supervised four day, retrospective diet history with all women to limit inter-observer variability. The research dietitian asked women to provide descriptions of all foods and beverages consumed, including brand names where possible, and their method of preparation and cooking were recorded. For composite dishes, the amount of each ingredient used in the recipe was quantified. All portion sizes were also fully quantified using standard household measures (e.g. cups and spoons). Two weekdays and two weekend days were included in the four day history.

Women also completed a self-administered paper based questionnaire which collected additional data on psychometric and lifestyle factors. These included self-reported levels of habitual alcohol consumption, nausea and vomiting levels (PUQE score) and a self-reported quality of life score rated from 1 to 10 [14]. A physical activity level (PAL) was estimated for each woman. These levels ranged 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)) [15]. Additionally, the questionnaire collected data on women's socioeconomic status using questions from the EU Survey on Income and Living Conditions (EU-SILC) [16]. Relative deprivation status was based on whether the woman had reported experiencing the enforced absence (due to financial limitation) of two or more basic necessities from a list of eleven over the previous year.

Birthweight (BW) was measured by a midwife and documented within 30 min of birth. Neonatal head circumference (NHC) was measured by a neonatologist within the first three days after delivery at the time of a routine examination. Customised BW centiles were calculated subsequently using the New Global Bulk Centile Calculator v8.0.1, 2018 (Perinatal Institute for Maternal and Child Health). Women's weight, height, ethnicity, parity and infant gender, gestational age at birth and BW were entered into the calculator.

Maternal dietary intake data from the diet histories were entered into Nutritics Version 3.7 (University Edition) to convert the reported food intakes into nutrient intakes. Average daily nutrient intakes for the four day period were then calculated. The food composition tables used in Nutritics are based on McCance and Widdowson's Food Composition Tables (7th edition, and supplemental volumes) [17]. To assess dietary misreporting women's basal metabolic rate (BMR) was established using standard equations tailored to gender, weight and age [18]. Energy intake (EI) was calculated using data from the four day retrospective diet histories and Nutritics (version 3.7 University Edition). Lowest plausible thresholds for PAL were calculated using women's self-reported PAL [18]. Women categorised as under-reporters were those whose ratio of EI to their calculated BMR (EI/BMR) fell below the calculated plausible threshold for their physical activity category [19,20]. Over-reporters were classified as those whose EI ratio to calculated BMR was > 2.5 [20]. A sensitivity analysis was conducted by repeating analyses as appropriate with only those classified as plausible reporters.

A Periconceptual Nutrition Score (PENS) was developed and included nutrients that were considered important in pregnancy for maternal and neonatal outcomes [6,9,11,21]. Women were classified as either those meeting or not meeting recommended daily intake guidelines for dietary macronutrients and micronutrients based on the European Food Safety Authority guidelines [22]. These guidelines provide up-to-date, pregnancy-specific nutrient recommendations.

Where possible, the recommended value for Population Reference Intake (PRI) was used i.e. the level of nutrient intake that is adequate for the majority of people in a population group. Where a PRI was not provided, an Adequate Intake (AI) value was used i.e. the value estimated when a PRI cannot be determined. An AI is the average observed daily level of intake by a population group(s) of seemingly healthy people that is considered to be adequate. Reference intake ranges (RI) were used for carbohydrate and fat. RI ranges for macronutrients are the ranges of intakes that are adequate to maintain health and are linked with a lower risk of certain chronic diseases [22]. A recommendation by EFSA (2017) has not yet been released in relation to sodium, therefore, recommendations from the World Health Organization (WHO) were used [22,23].

The dietary quality score consisted of a total of 23 nutrients (Table 2). If the woman met the recommendation for an individual macronutrient or micronutrient included in the nutrient score, they received one point per recommendation, whereas if they were not meeting the recommendations, they received zero points. These individual nutrient scores were subsequently added together to provide a total score out of a maximum of 23 points and thus formulated the Periconceptual Nutrition Score (PENS) as a continuous variable. For additional analyses, the PENS was also divided into quartiles, with the lowest quartile representing women with the lowest dietary quality.

Data analysis was carried out using SPSS version 24.0 (IBM Corporation, Armonk, New York). The normality of continuous variables was evaluated by determination of the kurtosis and skewness of the distribution, visual analysis of their histograms and interpretation of their Kolmogorov-Smirnov statistics. Descriptive statistics were used to describe the study participant's characteristics. Cross-tabulation and Chi-square tests for independence was used to establish differences in categorical variables between groups. Differences in normally distributed continuous variables were assessed using an independent samples *t*-test, and Man Whitney U was used for non-normally distributed continuous variables.

Univariate analysis was performed to examine the relationship between maternal characteristics and PENS using simple linear regression. Simple linear regression was also used to assess the relationship between the nutrient score and neonatal outcomes. Multivariable linear regression was used to control for potential confounding variables where appropriate [9,11,24–26]. Tukey's post hoc test was used to compare pairwise differences in mean BW and NHC between PENS quartiles. Simple linear regression was used to determine the relationship between the PENS (continuous) and babies born small for gestational age (SGA, i.e. < 10th centile for BW). Binary logistic regression was used to examine the relationship between the lowest quartile of the PENS and babies born SGA. In all statistics, a P value of < 0.05 was considered statistically significant. This study received ethical approval from the Hospital's Research Ethics Committee and from the Dublin

Table 1
Maternal and neonatal characteristics of the study population (n = 202).

	n, mean	%, SD
Maternal characteristics		
Age (years; mean, SD)	32.2	5.0
Nulliparas (n, %)	90	44.6
BMI (kg/m^2; mean, SD)	26.2	5.8
Obesity (n, %)[a]	44	21.8
Smokers (n, %)	16	7.9
Drink alcohol habitually (n, %)[b]	171	84.7
Pre-pregnancy folic acid (n, %)	112	55.4
Planned pregnancy (n, %)	149	73.8
Third level education (n, %)[c]	145	75.5
Relative deprivation[d]	17.0	9.0
Neonatal characteristics		
Females (n, %)	95	47.0
Birthweight (g; mean, SD)	3523.9	588.5
SGA (n, %)[e]	19	9.4
LBW (n, %)	7	3.5
Neonatal head circumference (cm; mean, SD)[f]	35.1	1.7

SD, standard deviation.
BMI, body mass index.
cm, centimetres.
g, grams.
SGA, small for gestational age (< 10th centile).
LBW, low birthweight (< 2500 g).
[a] Obesity, defined as those with a BMI ≥ 30.0kg/m^2, in accordance with the World Health Organization (WHO).
[b] Prior to pregnancy.
[c] n = 192.
[d] n = 188.
[e] n = 200.
[f] n = 153.

Institute of Technology Research Ethics Committee.

3. Results

A total of 202 women were included in the study. Table 1 outlines the study characteristics. A total of 19 women with neonatal outcome data did not complete the PAL self-assessment. Of the women with complete data for calculation of dietary misreporting (n = 183), 73.2% were plausible reporters (n = 134), 26.8% were under-reporters (n = 49), there were no over-reporters in the sample, and 9.4% were unclassifiable due to lack of PAL data (n = 19/202).

Table 2 outlines the nutrients included in the PENS and the percentage of women meeting the macronutrient and micronutrient recommendations. The mean PENS was 9.4 ± 3.1 with women's scores ranging from 3 to 19 points on the scale out of a maximum score of 23 points. There was no mean differences for PENS between smokers (9.4 ± 2.0) and non-smokers (9.3 ± 3.2) P = 0.96, multiparous women (9.3 ± 3.1) and nulliparas (9.4 ± 3.1) P = 0.81 or between obese (10.0 ± 3.0) and non-obese (9.2 ± 3.2) P = 0.11. However, women with a third level education had a higher mean PENS (9.7 ± 3.2) compared to those without a third level education (8.3 ± 2.7) P = 0.005. Plausible dietary reporters also had a higher mean PENS (10.0 ± 3.2) compared to dietary under-reporters (7.5 ± 2.3) P < 0.001.

On simple linear regression, there was a positive relationship between PENS and BW (beta = 42.9 95%CI 17.4–68.3 P = 0.001) and the PENS and NHC (beta = 0.14 95%CI 0.05–0.3 P = 0.002). These relationships persisted on analysis with only plausible reporters (BW (n = 134): beta = 34.4 95%CI 4.9–64.0, P = 0.02; NHC (n = 100): beta = 0.12 95%CI 0.01–0.24, P = 0.04). These relationships also persisted on multivariable analysis (Table 3 model 1 and Table 4 model 1). There was a negative relationship between the lowest quartile of the PENS and BW (Table 3 model 2).

Table 2
Percentage of women meeting EFSA nutrition recommendation (n = 202).

Nutrient	EFSA recommendation	PRI, AI, RI	% of women meeting EFSA recommendation
Macronutrients			
Protein (g/kg per day)	+ 1 g/d[a]	PRI	85.6
Carbohydrate (% of energy)	45–60	RI	42.1
Fat (% of energy)	20–35	RI	42.1
Micronutrients			
Vitamin A (μg)	700	PRI	64.4
Vitamin C (mg)	105	PRI	36.1
Vitamin B1 (Thiamine) (mg/MJ)	0.1	PRI	100.0
Vitamin B2 (Riboflavin) (mg)	1.9	PRI	15.8
Vitamin B3 (Niacin) (mg NE/MJ)	1.6	PRI	98.0
Vitamin B5 (Pantothenic acid) (mg)	5	AI	60.4
Vitamin B6 (mg)	1.8	PRI	60.9
Vitamin B7 (Biotin) (μg)	40	AI	8.4
Vitamin B12 (Cobalamin) (μg)	4.5	AI	40.6
Folate (μg DFEs)	600	AI	2.5
Vitamin D (μg)	15	AI	0.0
Iodine (μg)	200	AI	2.0
Iron (mg)	16	PRI	13.4
Copper (mg)	1.5	AI	8.4
Calcium (mg)	950/1000[b]	PRI	18.8
Potassium (mg)	3500	AI	19.8
Zinc (mg)	+ 1.6[c]	PRI	49.9
Magnesium (mg)	300	AI	22.3
Sodium (mg)	2000	–	45.5
Phosphorous (mg)	550	AI	99.0

DFEs, dietary folate equivalents.
NE, niacin equivalent.
PRI, population reference intake, the level of nutrient intake that is adequate for the majority of people in a population group.
AI, Adequate Intake, the average observed daily level of intake by a population group (or groups) of apparently healthy people that is assumed to be adequate.
RI, reference intake range, ranges of intakes that are adequate for maintaining health and associated with a low risk of selected chronic diseases.
Nutrition recommendations based on EFSA guidelines (2017), apart from sodium, which is based on WHO [23].
[a] In addition to the PRI for protein of non-pregnant, non-lactating women, if second trimester, + 9 g/d.
[b] 18–24 years – 1000 mg, ≥ 25 years – 950 mg.
[c] In addition to the PRIs for non-pregnant, non-lactating women.

On analysis of pairwise mean differences for BW by PENS quartiles, the mean BW of babies born to women in the lowest quartile was 3360.4g ± 569.5g compared with a mean BW of 3688.73g ± 625.6g with babies born to women in the highest quartile (mean difference 328 g, P = 0.02). There was no difference in mean NHC between the lowest quartile and the highest PENS quartiles (P = 0.08).

The distribution of babies born SGA per PENS quartile is outlined in Table 5. Of the babies born to women in the lowest PENS quartile, 16.4% were SGA (n = 10/61) when compared to the other quartiles, only 6.5% of babies were SGA (n = 9/139) P = 0.03.

On simple linear regression, as women's PENS increased, their babies BW centile increased (beta 2.1 95%CI 0.85–3.37, P = 0.001). On binary logistic regression, babies born to women in the lowest quartile for PENS were more likely to be SGA (OR 2.8 95%CI 1.1–7.4 P = 0.03). These relationships persisted when analysed with only plausible reporters included (PENS and BW centiles (continuous) n = 132, beta 1.7 95%CI 0.09–3.2 P = 0.04; PENS lowest quartile and SGA OR4.2, 95%CI 1.2–14.8, P = 0.03).

Table 3
Multiple linear regression between Periconceptual Nutrient Score (PENS) and birthweight (n = 202).

Birthweight	Unstandardized coefficients		Standardized coefficients	95%CI		P
	B	SE	Beta	Lower bound	Upper bound	
Model 1 (R^2 0.16)						
PENS (continuous)	45.3	15.5	0.25	14.8	75.9	0.002
Age	9.4	10.1	0.08	−10.5	29.5	0.35
Parity (Nulliparas)	−53.9	94.4	−0.05	−240.6	132.9	0.57
Planned pregnancy	−85.0	114.3	−0.07	−311.0	141.1	0.46
BMI	18.2	8.1	0.18	2.0	34.5	0.03
Pre-pregnancy folic acid	−89.9	102.5	−0.08	−292.5	112.9	0.38
Third level education	−31.5	108.9	−0.02	−247.0	184.0	0.77
Relative deprivation	−212.7	170.1	−0.10	−549.1	123.6	0.21
Smoking	−18.6	179.8	−0.01	−374.5	337.0	0.92
Infant gender	22.4	82.3	0.02	−139.8	184.7	0.79
Gestational age at birth	−0.3	0.4	−0.06	−1.1	0.5	0.45
PUQE score	17.3	20.8	−0.08	−58.5	23.8	0.40
Quality of life score	−36.7	30.0	−1.2	−95.9	22.6	0.22
Model 2 (R^2 0.16)						
PENS lowest quartile	−326.5	105.0	−0.26	−543.2	−118.9	0.004
Age	10.9	10.1	0.09	−9.0	30.8	0.28
Parity (Nulliparas)	−39.1	93.6	−0.03	−224.3	146.1	0.68
Planned pregnancy	−145.8	115.5	−0.12	−374.1	82.6	0.21
BMI	18.2	8.2	0.18	2.0	34.3	0.03
Pre-pregnancy folic acid	−118.7	102.9	−0.10	−322.2	84.8	0.25
Third level education	−18.8	107.8	−0.01	−231.9	194.4	0.86
Relative deprivation	−181.9	170.6	−0.09	−519.4	155.5	0.29
Smoking	−51.8	179.9	−0.02	−407.6	304.0	0.77
Infant gender	88.8	94.8	0.08	−98.6	276.2	0.35
Gestational age at birth	−0.35	0.42	−0.07	0.4	−1.2	0.41
PUQE score	−9.7	20.9	−0.05	−51.0	31.5	0.64
Quality of life score	−31.2	29.6	−0.11	−89.7	27.3	0.29

PENS, periconceptual nutrition score.
BMI, body mass index.
SE, standard error.
CI, confidence interval.
PUQE score, Pregnancy-Unique Quantification of Emesis/Nausea score.

4. Discussion

This prospective study developed a new dietary quality score, the PENS, which was based on the 2017 EFSA guidelines. The study findings showed that a higher quality of maternal diet in early pregnancy was associated with increased intrauterine fetal growth. This study also highlighted that women with the lowest dietary quality score are more likely to deliver a SGA infant. The findings show that a composite score of dietary quality is an effective way of assessing the influence of maternal dietary intakes on fetal growth rather than single measurements of individual nutrients.

To date, dietary quality indices have been primarily based on American dietary guidelines and recommendations. There is significant heterogeneity between studies in terms of dietary data collection methods, the dietary indices used to assess dietary quality and the time points and frequency of data collection. Few have used pregnancy specific recommendations. Furthermore, there is scant evidence on the relationship between dietary indices and neonatal outcomes. To our knowledge, this is the first study to use the 2017 European dietary guidelines, which are specific to pregnancy, to generate a novel composite dietary quality score. We also accounted for dietary misreporting.

This study highlighted that there are inadequacies within women's dietary intakes in early pregnancy. The PENS may be a valuable means of identifying women with the lowest dietary quality who are also more likely to deliver a SGA baby and may require prioritisation for intervention where resources are limited. SGA infants, defined as those born < 10th centile for BW, are at increased risk of mortality and morbidity [26]. For example, SGA infants are at higher risk of infection, perinatal respiratory depression, jaundice and neonatal death [1]. In addition, these offspring are at increased risk of adverse metabolic profiles in adulthood [27]. It is thought that with the combination of catch up growth and risk of childhood obesity, there may be a transgenerational effect in infants who are growth restricted in utero [28–30].

There are financial implications when a baby is born SGA, for example, if they require neonatal intensive care unit admission and increased length of hospital stay. In a study conducted in France (n = 777, 720), the cost for an SGA infant was €2783 more expensive than an appropriate gestational age infant [31]. The financial cost of SGA was estimated at 23% of the total cost for deliveries. This was explained by greater complication rates, more hospital readmissions and longer duration of stay. Therefore, the PENS could be a tool used in early pregnancy, particularly within Europe, to identify women who may benefit from dietary intervention, and indeed closer fetal surveillance from their obstetrician throughout their pregnancy.

Poor maternal nutrition both preconceptionally and during the pregnancy has been established to impact neonatal outcomes. However, evidence regarding singular nutrients and their impact on fetal growth has been conflicting [32]. A systematic review and meta-analysis, which included 29 randomised controlled trials (RCTs) and 10,026 participants, examined the evidence on the effects of dietary interventions on neonatal and infant outcomes [33]. The review findings highlighted dietary intervention to be an effective method to increase infant size at birth. It emphasised that food or fortified food products increased BW (by ~125 g) and decreased the rates of low BW. However, the review also stated that large, high quality RCTs that research combination dietary intervention and micronutrient provision from food are necessary to improve knowledge of optimal maternal nutrition for neonatal outcomes.

Table 4
Multiple linear regression between Periconceptual Nutrient Score (PENS) and neonatal head circumference (n = 153).

Neonatal head circumference	Unstandardized coefficients		Standardized coefficients	95%CI		P
	B	SE	Beta	Lower bound	Upper bound	
Model 1 (R^2 0.26)						
PENS (continuous)	0.12	0.06	0.20	0.01	0.23	0.03
Age	0.07	0.04	0.16	−0.01	0.14	0.08
Parity (Nulliparas)	−0.70	0.33	−0.19	−1.36	−0.04	0.04
Planned pregnancy	0.40	0.40	0.10	−0.39	1.17	0.32
BMI	0.03	0.03	0.08	−0.03	0.08	0.36
Pre-pregnancy folic acid	−0.14	0.35	−0.04	0.68	−0.84	0.56
Third level education	−0.38	0.38	−0.09	−1.12	0.37	0.32
Relative deprivation	−0.19	0.62	−0.03	−1.42	1.04	0.76
Smoking	0.71	0.66	0.09	−0.61	2.02	0.29
Infant gender	0.11	0.34	0.03	−0.56	0.77	0.74
Gestational age at birth	0.37	0.13	0.26	0.12	0.63	0.004
PUQE score	−0.06	0.08	−0.09	−0.22	0.09	0.42
Quality of life score	0.12	0.11	0.13	−0.09	0.34	0.24
Model 2 (R2 0.26)						
PENS lowest quartile	−0.66	0.37	−0.17	−1.39	0.07	0.08
Age	0.07	0.04	0.18	0.00	0.15	0.05
Parity (Nulliparas)	−0.61	0.33	−0.16	−1.27	−0.05	0.07
Planned pregnancy	0.34	0.40	0.08	−0.45	1.10	0.45
BMI	0.03	0.03	0.09	−0.03	0.08	0.34
Pre-pregnancy folic acid	−0.16	−0.36	−0.04	−0.87	0.54	0.65
Third level education	−0.31	0.38	−0.07	−1.06	0.43	0.41
Relative deprivation	−0.12	0.64	−0.02	−1.38	1.14	0.85
Smoking	0.60	0.67	0.08	−0.73	1.9	0.37
Infant gender	0.15	0.34	0.04	−0.52	0.82	0.66
Gestational age at birth	0.38	0.13	0.27	0.13	0.64	0.003
PUQE score	−0.05	0.08	−0.07	−0.21	0.11	0.52
Quality of life score	0.14	0.11	−0.15	−0.07	0.36	0.19

PENS, periconceptual nutrition score.
BMI, body mass index.
SE, standard error.
CI, confidence interval.
PUQE score, Pregnancy-Unique Quantification of Emesis/Nausea score.

Table 5
The distribution of babies SGA in each quartile of Periconceptual Nutrient Score (PENS) (n = 200).

PENS quartiles		SGA	
		n	%
Lowest (≤7.0)	(n = 61)	10	16.4
Low-medium (8.0–9.0)	(n = 53)	3	5.7
Medium-high (10.0–11.0)	(n = 40)	4	10.0
Highest (12.0+)	(n = 46)	2	4.3

SGA, small for gestational age.

There is a dearth of studies examining the impact of dietary quality on neonatal outcomes using nutrient recommendations that are specific to pregnancy. A study conducted in Spain examined the relationship between dietary quality (assessed by using a modification of the Alternate Healthy Eating Index (AHEI)) and fetal growth [11]. The study used an FFQ that was adapted for adults living in Spain to assess dietary intakes. This study found that there was a positive relationship between dietary quality scores and adjusted BW and adjusted birth length. Neonates born to women in the fourth quintile for dietary quality were on average 126.3g heavier and 0.47 cm longer than those in the lowest quintile. Furthermore, women with the highest dietary scores had a lower risk of delivering a fetal growth-restricted infant for weight than women in the lowest quintile, but these differences were not observed in the case of fetal growth restriction in length or head circumference.

Conversely, a US study (n = 893), found no relationship between dietary quality between 28 and 36 weeks of gestation (evaluated by the Alternative Healthy Eating Index for Pregnancy and alternate Mediterranean diet) and BW, size for gestational age (small or large), and infant growth in the first 4–6 months of life [21]. These studies differed from our study in terms of population, dietary assessment methodology, and indices used to assess dietary quality.

Our study also found that women without a third level education were more likely to have a lower dietary quality than those with a third level education. These findings are similar to previous reports [34,35]. This may highlight the need to focus dietary interventions on women with lower levels of education, where resources are limited.

Strengths of this study include that the PENS was customised to dietary requirements during pregnancy and was based on the latest European recommendations. All dietary data were collected by a single research dietitian (RK). Furthermore, this study used a retrospective food diary, whereas most studies to date have used FFQs to develop dietary quality scores. FFQ's can be associated with less accuracy than alternative dietary assessment methods [36,37]. Maternal weight and height were measured and used to calculate BMI. Self-reporting of anthropometric data is unreliable in early pregnancy [38]. All women had sonographic confirmation of gestational age and thus the BW centiles were accurate [39].

A limitation is that the study was undertaken in a developed country with good food security. In Europe, food fortification practices may vary from country to country and thus, this may impact the reproducibility of the study results. For example, in the Republic of Ireland, food fortification with folic acid is voluntary, whereas certain countries in Europe follow mandatory folic acid food fortification practices [40]. The study was also confined to one country in Europe. It may be a stronger or weaker predictor in other countries where women's dietary and supplement intakes differ during pregnancy [5,41]. Supplement data were not included in the final analysis. Current national obstetric guidelines advise women on folic acid, iron and vitamin D supplementation in pregnancy [42]. Thus, further research is needed to determine if the addition of nutrition supplements reduces the differences in fetal growth attributable to inadequate nutrients. Additionally, as this study was exploratory research, the P-values and claims for statistical significance should be viewed in that context and accompanied by inspection of the effect sizes and their confidence intervals.

This study aimed to control for factors which may influence fetal growth, however, this was limited to the data collected and the sample size available only allowing for the inclusion of a select number of confounding variables. As consecutive recruitment in a busy clinical service is not feasible, women were conveniently recruited. This method can result in a study cohort who differs from the wider population. However, the study characteristics were similar to the general hospital population's characteristics [43].

5. Conclusion

This study found that higher maternal dietary quality was associated with higher measurements of birthweight and neonatal head circumference which reflect intrauterine fetal growth. The PENS, a newly developed dietary quality score, is potentially useful in identifying those women who would benefit from dietary interventions before or during pregnancy that would optimise intrauterine fetal growth. It may also be useful in tracking maternal dietary quality as pregnancy advances.

Conflict of interest statement

None of the authors have any conflicts of interest to declare.

Funding

This work was partly funded through a Dublin Institute of Technology Fiosraigh scholarship provided to author RAKK. DIT had no role in the study design, collection, analysis or interpretation of data, writing of the article or in the decision to submit the article for publication.

Acknowledgements

We would like to acknowledge with gratitude, Dublin Institute of Technology for partly funding this work through a Fiosraigh scholarship to author RAKK. We would also like to acknowledge and express thanks to all participants who took part in this study.

References

[1] A.C. Lee, N. Kozuki, S. Cousens, G.A. Stevens, H.B. Lencowe, M.F. Silveira et al., Estimates of burden and consequences of infants born small for gestational age in low and middle income countries with INTERGROWTH-21st standard: analysis of CHERG datasets. BMJ, 17 (2017) 358:j3677. doi:https://doi.org/10.1136/bmj.j3677.
[2] K. da Silva Lopes, E. Ota, P. Shakya, A. Dagvadorj, O.O. Balogun, J.P. Peña-Rosas et al., Effects of nutrition interventions during pregnancy on low birth weight: an overview of systematic reviews. BMJ Global Health, 2 (3) (2017) e000389. doi:https://doi.org/10.1136/bmjgh-2017-000389.
[3] S. Langley-Evans, Nutrition in early life and the programming of adult disease: a review, J. Hum. Nutr. Diet. 28 (1) (2015) 1–14, https://doi.org/10.1111/jhn.12212.
[4] D.J. Barker, Early growth and cardiovascular disease, Arch. Dis. Child. 80 (4) (1999) 305–307.
[5] A.R. Dunford, J.M. Sangster, Maternal and paternal periconceptional nutrition as an indicator of offspring metabolic syndrome risk in later life through epigenetic imprinting: a systematic review, Diabetes Metab. Syndr. 11 (2017) S655–S662.
[6] S. Cawley, L. Mullaney, A. McKeating, M. Farren, D. McCartney, M.J. Turner, An analysis of folic acid supplementation in women presenting for antenatal care, J. Public Health (Oxf.) 38 (1) (2015) 122–129, https://doi.org/10.1093/pubmed/fdv019.
[7] J.L. Morrison, T.R.H. Regnault, Nutrition in pregnancy: optimising maternal diet and foetal adaptations to altered nutrient supply, Nutrients 8 (6) (2016) 342, https://doi.org/10.3390/nu8060342.
[8] C.A. McGowan, F.M. McAuliffe, Maternal dietary patterns and associated nutrient intakes during each trimester of pregnancy, Public Health Nutr. 16 (2013) 97–107, https://doi.org/10.1017/S1368980012000997.
[9] J.A. Grieger, V.L. Clifton, A review of the impact of dietary intakes in human pregnancy on infant birthweight, Nutrients 7 (1) (2015) 153–178, https://doi.org/10.3390/nu7010153.
[10] P.M. Waijers, E.J. Feskens, M.C. Ocké, A critical review of predefined diet quality scores, Br. J. Nutr. 97 (2) (2007) 219–231.
[11] C.L. Rodríguez-Bernal, M. Rebagliato, C. Iñiguez, J. Vioque, E.M. Navarrete-Muñoz, M. Murcia et al., Diet quality in early pregnancy and its effects on foetal growth outcomes: the Infancia y Medio Ambiente [childhood and environment] mother and child cohort study in Spain. Am. J. Clin. Nutr., 91 (6) (2010) 1659–1666. doi:https://doi.org/10.3945/ajcn.2009.28866.
[12] E. Gesteiro, B. Rodríguez Bernal, S. Bastida, F.J. Sánchez-Muniz, Maternal diets with low healthy eating index or Mediterranean diet adherence scores are associated with high cord-blood insulin levels and insulin resistance markers at birth, Eur. J. Clin. Nutr. 66 (9) (2012) 1008–1015, https://doi.org/10.1038/ejcn.2012.92.
[13] A.L. Shapiro, J.L. Kaar, T.L. Crume, A.P. Starling, A.M. Siega-Riz, B.M. Ringham et al., Maternal diet quality in pregnancy and neonatal adiposity: the healthy start study. Int. J. Obes., 40 (7) (2016) 1056–1062. doi:https://doi.org/10.1038/ijo.2016.79.
[14] G. Koren, C. Piwko, E. Ahn, R. Boskovic, C. Maltepe, A. Einarson et al. Validation studies of the Pregnancy Unique-Quantification of Emesis (PUQE) scores. J. Obstet. Gynaecol., 25(2005) 241–244.
[15] Food and Agricultural Organisation/World Health Organisation/United Nations University, Human Energy Requirements. Report of a Joint FAO/WHO/UNU Expert Consultation, Food and Agricultural Organisation, Rome, 2001.
[16] Central Statistics Office, EU Survey on Income and Living Conditions (EU-SILC) 2011 and Revised 2010 Results, Central Statistics Office, Dublin, 2013.
[17] R.A. McCance, E.M. Widdowson, Food Standards Agency McCance and Widdowson's the Composition of Foods, 6th edition, Royal Society of Chemistry, Great Britain, 2002.
[18] C.J. Henry, Basal metabolic rate studies in humans: measurement and development of new equations, Public Health Nutr. 8 (7A) (2005) 1133–1152.
[19] A.E. Black, Critical evaluation of energy intake using the Goldberg cut-off for energy intake: basal metabolic rate. A practical guide to its calculation, use and limitations, Int. J. Obes. Relat. Metab. Disord. 24 (9) (2000) 1119–1130.
[20] G.R. Goldberg, A.E. Black, S.A. Jebb T.J. Cole, P.R. Murgatroyd, W.A. Coward et al., Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. Eur. J. Clin. Nutr., 45 (12) (1991) 569–581.
[21] A.K. Poon, E. Yeung, N. Boghossian, P.S. Albert, C. Zhang, Maternal dietary patterns during third trimester in association with birthweight characteristics and early infant growth, Scientifica 2013 (2013) 786409.
[22] European Food Safety Authority, Dietary Reference Values for Nutrients. Summary Report. EFSA Supporting Publication, (2017).
[23] WHO, Guideline: Sodium Intake for Adults and Children, World Health Organization (WHO), Geneva, 2012.
[24] M. Tanvig, Offspring body size and metabolic profile-effects of lifestyle intervention in obese pregnant women, Dan. Med. J. 61 (7) (2014) B4893.
[25] C.M.E. Reynolds, B. Egan, A. McKeating, N. Daly, S.R. Sheehan, M.J. Turner, Five year trends in maternal smoking behaviour reported at the first prenatal appointment, Ir. J. Med. Sci. 186 (4) (2017) 971–979, https://doi.org/10.1007/s11845-017-1575-2.
[26] J.V. Madden, C.J. Flatley, S. Kumar, Term small-for-gestational-age infants from low-risk women are at significantly greater risk of adverse neonatal outcomes, Am. J. Obstet. Gynecol. 218 (5) (2018) 525.e1–525.e9, https://doi.org/10.1016/j.ajog.2018.02.008.
[27] H.K. Nam, K.H. Lee, Small for gestational age and obesity: epidemiology and general risks, Ann. Pediatr. Endocrinol. Metab. 23 (1) (2018) 9–13, https://doi.org/10.6065/apem.2018.23.1.9.
[28] C.J. Smith, K.K. Ryckman, Epigenetic and developmental influences on the risk of obesity, diabetes, and metabolic syndrome, Diabetes Metab. Syndr. Obes. 8 (2015) 295–302, https://doi.org/10.2147/DMSO.S61296.
[29] K.K. Ryckman, K.S. Borowski, N.I. Parikh, A.F. Saftlas, Pregnancy complications and the risk of metabolic syndrome for the offspring, Curr. Cardiovasc. Risk Rep. 7 (3) (2013) 217–223, https://doi.org/10.1007/s12170-013-0308-y.
[30] G. Wu, F.W. Bazer, T.A. Cudd, C.J. Meininger, T.E. Spencer, Maternal nutrition and foetal development, J. Nutr. 134 (9) (2004) 2169–2172.
[31] A. Marzouk, A. Filipovic-Pierucci, O. Baud, V. Tsatsaris, A. Ego, M.A. Charles et al., Prenatal and post-natal cost of small for gestational age infants: a national study. BMC Health Serv. Res., 17 (2017) 221. doi:https://doi.org/10.1186/s12913-017-2155-x.
[32] R.A.K. Kennedy, L. Mullaney, A.C. O'Higgins A. Doolan, D.M. McCartney, M.J. Turner, The relationship between early pregnancy dietary intakes and subsequent birthweight and neonatal adiposity. J. Public Health (Oxf.), 9 (2017) 1–9. doi:https://doi.org/10.1093/pubmed/fdx13.
[33] E. Gresham, J.E. Byles, A. Bisquera, A.J. Hure, Effects of dietary interventions on neonatal and infant outcomes: a systematic review and meta-analysis, Am. J. Clin. Nutr. 100 (2014) 1298–1321.
[34] E.R. Fowles, M. Bryant, S. Kim, L.O. Walker, R.J. Ruiz, G.M. Timmerman et al., Predictors of dietary quality in low-income pregnant women: a path analysis. Nurs. Res., 60 (2011) 286–294. doi:https://doi.org/10.1097/NNR.0b013e3182266461.
[35] S.L. Rifas-Shiman, J.W. Rich-Edwards, K.P. Kleinman, E. Oken, M.W. Gillman,

Dietary quality during pregnancy varies by maternal characteristics in project viva: a US cohort, J. Am. Diet. Assoc. 109 (6) (2009) 1004–1011, https://doi.org/10.1016/j.jada.2009.03.001.

[36] L. Mullaney, A.C. O'Higgins, S. Cawley, R. Kennedy, D. McCartney, M.J. Turner, Use of a web-based dietary assessment tool in early pregnancy, Ir. J. Med. Sci. 185 (2) (2016) 341–355.

[37] R.L. Prentice, Y. Mossavar-Rahmani, Y. Huang, L. Van Horn, S.A.A. Beresford et al., Evaluation and comparison of food records, recalls, and frequencies for energy and protein assessment by using recovery biomarkers. Am. J. Epidemiol., 174 (5) (2011) 591–603.

[38] C. Fattah, N. Farah, S. Barry, N. O'Connor, B. Stuart, M.J. Turner, The measurement of maternal adiposity, J. Obstet. Gynaecol. 29 (8) (2009) 686–689, https://doi.org/10.3109/01443610903184025.

[39] C.D. Lynch, J. Zhang, The research implications of the selection of a gestational age estimation method, Paediatr. Perinat. Epidemiol. 21 (2) (2007) 86–96.

[40] M.L. Blumfield, A.J. Hure, L. Macdonald-Wicks, R. Smith, C.E. Collins, Micronutrient intakes during pregnancy in developed countries: a systematic review and meta-analysis, Nutr. Rev. 71 (2) (2013) 118–132, https://doi.org/10.1111/nure.12003.

[41] S. Cawley, D. McCartney, J.V. Woodside, M.R. Sweeney, R. McDonnell, A.M. Molloy, M.J. Turner, Optimization of folic acid supplementation in the prevention of neural tube defects, J. Public Health (Oxf.) 40 (4) (2018) 827–834, https://doi.org/10.1093/pubmed/fdx137.

[42] Health Service Executive, Clinical Practice Guideline Nutrition in Pregnancy, Health Service Executive, Dublin, 2013.

[43] Coombe Women and Infants University, Hospital annual clinical report, HSE Print and Design, 2015.