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# The relationship between early pregnancy dietary intakes and subsequent birthweight and neonatal adiposity

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## ABSTRACT

**Background** Maternal nutrition intakes may influence neonatal birthweight and adiposity; however, inconsistencies within the literature exist. The relationships between maternal dietary intakes in early pregnancy and both birthweight and neonatal adiposity requires elucidation. This study examined the relationship between early pregnancy dietary intakes and subsequent birthweight and neonatal adiposity.

**Methods** Women were recruited at their convenience after sonographic confirmation of a singleton pregnancy. Women completed a Willet food frequency questionnaire evaluating habitual food and nutrient intakes at their first antenatal visit. Neonatal body composition was measured using air-displacement plethysmography.

**Results** Of the 385 mother-neonate dyads, mean maternal age was  $30.8 \pm 5.3$  years, mean Body Mass Index (BMI) was  $24.5 \pm 4.8$  kg/m<sup>2</sup> and 41.8% ( $n = 161$ ) were nulliparous. There were no relationships between maternal food intakes and birthweight ( $P > 0.05$ ) ( $n = 385$ ). On multivariable analysis there was a positive relationship between polyunsaturated fat and neonatal fat mass index (FMI) (beta = 0.015, 95% CI = 0.002–0.028,  $P = 0.04$ ) ( $n = 80$ ).

**Conclusion** Dietary intakes of polyunsaturated fat in early pregnancy are positively associated with neonatal FMI at birth on multivariable analysis. Further longitudinal studies need to explore this association and the long-term implications for the neonate.

**Keywords** food and nutrition, neonates, public health

## Introduction

Foetal growth is complex, with the foetus requiring the appropriate intrauterine environment to support its optimal growth and development.<sup>1,2</sup> There are many parameters at play *in utero* which may influence foetal development, such as the woman's metabolic status, her lifestyle behaviours and her nutritional intake both periconceptionally and over the course of her pregnancy.<sup>3–5</sup>

Neonatal anthropometric outcomes are linked to the metabolic status and health outcomes of the offspring in later life.<sup>6,7</sup> For instance, low birthweight has been linked to increased likelihood of cardiovascular disease, Type 2 Diabetes Mellitus (T2DM) and metabolic syndrome.<sup>8,9</sup> Similarly, macrosomic neonates are at increased risk of adult obesity and T2DM.<sup>10,11</sup> Less well studied is neonatal adiposity composition and its associations with long-term health.

Emerging evidence suggests, however, that neonates with higher neonatal adiposity may be at increased risk of health complications such as insulin resistance, which may influence metabolic health in adulthood.<sup>12,13</sup>

Nutrient availability in pregnancy is an important determinant of foetal growth and, therefore, impacts birthweight and neonatal body composition.<sup>14,15</sup> Inadequate intakes of key nutrients at critical periods of gestation can have lasting deleterious effects on the developing foetus.<sup>5</sup> For example, low-maternal iron status has been linked with low

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birthweight<sup>16</sup> and, low vitamin D status has been linked with low birthweight and poor skeletal development.<sup>17–20</sup> Additionally, maternal dietary composition may influence neonatal adiposity. Research has found that maternal dietary intakes during pregnancy are associated with neonatal adiposity. However, further research is needed to determine optimal macro- and micro-nutrients distributions in pregnancy to promote favourable neonatal adiposity, which may reduce the likelihood of adverse metabolic profiles later in life.<sup>21</sup>

It is evident that the most advantageous nutritional intakes in pregnancy, as well as the most favourable birthweight and neonatal body composition at birth, still remain to be fully elucidated.<sup>22,23</sup> There is a paucity of research examining neonatal adiposity using direct measurement such as air-displacement plethysmography. Of the existing literature, the results are inconsistent and many rely on surrogate measurements for adiposity measurements, such as skinfold thickness or ponderal index.<sup>24</sup> Skinfold thickness measurements introduce the risk of inter-observer variation and may compromise the accuracy of the data collected. Ponderal index, may only reflect total adiposity and does not offer insights into fat distribution. Furthermore, evidence has shown, this measurement may be a poor predictor of total neonatal body adiposity.<sup>25</sup>

It has been challenging to draw conclusions from existing literature examining the relationship between maternal nutrition and foetal growth parameters, given the heterogeneity in terms of methodology, study populations and the nutrients under investigation.<sup>24,26</sup> Furthermore, there is a need for research to examine the impact of maternal macro- and micro-nutrient intakes on both neonatal birthweight and adiposity, using a direct measurement, in the same study cohort.

## Aim

This study examined the relationship between early pregnancy food and nutrient intakes and subsequent birthweight and neonatal adiposity.

## Methods

### Maternal data collection

This study was a secondary analysis of a longitudinal study investigating maternal weight trajectories in pregnancy and the post-partum period.<sup>27</sup> Women were recruited at their first antenatal visit before 18 weeks gestation following ultrasound confirmation of an ongoing singleton pregnancy. All women were recruited at their convenience between

February and August 2013. The Coombe Women and Infants University Hospital (CWIUH) is one of the largest maternity hospitals in the European Union (EU) and cares for women from all socioeconomic groups and from across the urban–rural divide. Women's clinical and sociodemographic details were computerized routinely at the first antenatal visit and updated immediately after delivery.<sup>28</sup>

Exclusion criteria included multiple pregnancies, age <18 years, gestation >18 weeks at booking, and delivery at another centre. Written informed consent was obtained from all study participants.

Height was measured to the nearest centimetre using a Seca wall-mounted digital metre stick with the woman standing in her bare feet looking straight forward with her head held in the Frankfort position. Weight was measured digitally to the nearest 0.1 kg (Tanita MC 180, Tokyo, Japan) and Body Mass Index (BMI) calculated.

### Food frequency questionnaire

Women's habitual food and nutrient intakes were collected using a self-administered, semi-quantitative Willet food frequency questionnaire (WFFQ), which women completed unsupervised at their first antenatal visit. This WFFQ was adapted from the European Prospective Investigation into Cancer and Nutrition (EPIC) study and validated for use in a population of Irish adults.<sup>29–31</sup> The WFFQ has also more recently been validated in an Irish obstetric population.<sup>32</sup>

The adapted WFFQ contains 170 food and beverage items. Frequency of consumption of a standard portion of each food or beverage item consumed is divided into nine categories which range from 'never or less than once per month' to 'six or more times per day'.<sup>33</sup> This tool collects food intake data reflective of the previous year from the time of completion, and food and nutrient intake estimations derived from these data are thus reflective of early pregnancy and the periconceptional period. The WFFQ data were entered into WISP version 4.0 (Tinuviel Software, Llanfechell, Anglesey, UK) to convert women's reported dietary intakes into nutrient intakes.<sup>33</sup> The food composition tables used in WISP are derived from McCance and Widdowson's Food Composition tables fifth and sixth editions, and all supplemental volumes.<sup>33,34</sup>

### Lifestyle information

Self-estimated habitual physical activity levels (PALs) were collected using a self-administered, unsupervised questionnaire. Individual PALs were estimated for each woman using six categories: 1.45 metabolic equivalents (METs), seated work with no option of moving around and no strenuous leisure time activity; 1.60 METs, seated work with discretion

and requirement to move around but no strenuous leisure time; 1.75 METs, active commute/daily walk with seated work and some requirement to move around, 1.90 METs, standing work (extended periods of standing or walking daily) and moderately active leisure time; 2.05 METs, standing work (extended periods of standing or walking daily) and active leisure time, and finally, 2.20 METs, strenuous work or highly active leisure time (e.g. competitive athletes in daily training).<sup>35</sup>

### Assessment of energy under-reporting and over-reporting

Women's basal metabolic rate (BMR) was calculated using standard equations based on gender, weight and age.<sup>36</sup> Energy Intake (EI) was calculated using WFFQ food intake data and WISP v 4.0 software (Tinuviel Software Ltd.). Lowest plausible thresholds for PAL were calculated using women's self-reported PAL.<sup>37</sup> Women whose ratio of EI to their calculated BMR (EI/BMR) fell below of the calculated plausible threshold for their physical activity category were classified as dietary under-reporters.<sup>33,37,38</sup> Women whose EI ratio to calculated BMR was >2.5 were categorized as dietary over-reporters.<sup>39</sup> All dietary mis-reporters were removed from the dataset before inferential statistical analyses were undertaken.

### Neonatal data collection

Infant weight and length were measured. Circumference measurements (occipital-frontal, abdominal, mid-upper arm and thigh) were taken in addition to body composition measurements (fat mass, percentage body fat, fat free mass and percentage fat free mass). All measurements were taken within three days of birth. Body composition parameters were assessed by air-displacement plethysmography (ADP) using a PEA POD<sup>®</sup> analyser (PEA POD, COSMED, Concord, CA, USA).<sup>40</sup>

The PEA POD<sup>®</sup> analyser determines percent body fat and fat free mass in infants by application of the theory of whole body densitometry.<sup>41</sup> Infant volume, calculated using gas laws and direct measurement of body mass, are used to calculate density. The infants' body density is then used to calculate percentage fat and fat free mass. Percentage body fat is calculated by use of age and gender specific fat free mass density values.<sup>41,42</sup> The PEA POD<sup>®</sup> analyser is used for measurements of body composition in infants weighing between 1.0 and 8.0 kg.<sup>42</sup>

For the PEA POD<sup>®</sup> measurement, the neonate had all clothing removed. Any un-removable items such as the hospital security tag, name tags and umbilical clamp were used

to tare the scales and volume chamber.<sup>40</sup> The neonate's hair was smoothed down with water to limit its isothermal activity. Further maternal and neonatal data were derived from hospital records including maternal diabetes status, maternal parity, infant gestational age at birth and infant gender. The study was approved by the Coombe Women and Infants University Hospital Research Ethics Committee (Study number 7–2012).

### Statistical analysis

Data were analysed using IBM SPSS statistics version 22.0 (IBM Corporation, Armonk, New York). Continuous variables were assessed for normality by determination of the kurtosis and skewness of the distribution, visual inspection of their histograms and assessment of their Kolmogorov–Smirnov statistics. Descriptive statistics were used to describe the general characteristics of the study participants.

Infant neonatal fat mass (FM) was adjusted for neonatal length and, therefore, expressed as fat mass index (FMI; FM (kg)/(length (m))<sup>2</sup>). This is considered to be the best proxy for neonatal body composition and adiposity.<sup>14,43,44</sup> Simple linear regression was used to determine the associations between maternal food and nutrient intakes and neonatal birthweight and FMI. A separate linear model was run for each nutrient of interest. The variables significantly associated with neonatal FMI on univariate analysis were included in a multivariable linear regression model(s). Model 1, controlled for maternal BMI, Model 2 controlled for maternal BMI, neonatal gender and gestational age at birth, and Model 3 included polyunsaturated fat and controlled for maternal BMI, infant gender and gestational age at birth. A *P*-value of <0.05 was considered statistically significant.

### Results

A total of 524 women with completed WFFQ data were recruited to the study. Of these, 402 women were classified as plausible dietary reporters, and 122 women were classified as dietary under-reporters. There were no dietary over-reporters in the sample. Of the plausible reporters, there were 385 women who also had neonatal measurements taken, with PEA POD<sup>®</sup> analysis performed on 80 neonates within 3 days of birth.

Table 1 outlines the characteristics of the study population included in analysis (*n* = 385). Of the women included in the analysis, 12.7% (*n* = 49/385) reported their smoking status as 'current smoker' at their first antenatal visit and over half of women (57.4%, *n* = 221/385), reported habitually

**Table 1** Study population characteristics (*n* = 385)

	Total population ( <i>n</i> = 385)		Those without neonatal adiposity measurements ( <i>n</i> = 305)		Those with neonatal adiposity measurements ( <i>n</i> = 80)		P
	<i>n</i> , mean, median	%, SD, IQR	<i>n</i> , mean, median	%, SD, IQR	<i>n</i> , mean, median	%, SD, IQR	
Maternal characteristics							
Maternal age [years; mean, SD]	30.8	5.3	30.9	5.3	30.1	4.8	0.21
Nulliparous [ <i>n</i> , %]	161.0	41.8	122.0	40.0	39.0	48.8	0.16
Maternal BMI [kg/m <sup>2</sup> ; mean, SD]	24.5	4.8	24.7	4.9	24.4	4.4	0.64
Maternal BMI category [ <i>n</i> , %]							
Underweight	4.0	3.6	12.0	3.9	2.0	2.5	–
Ideal weight	214.0	55.6	168.0	55.1	46.0	57.5	0.70
Overweight	115.0	29.9	92.0	30.2	23.0	28.7	0.80
Obese	42.0	10.9	33.0	10.9	9.0	11.2	0.91
Smokers [ <i>n</i> , %]	49.0	12.7	43.0	14.1	6.0	7.5	0.19
Drink alcohol habitually [ <i>n</i> , %]	221.0	57.4	175.0	57.4	46.0	57.5	0.98
GDM	10.0	2.6	7.0	2.3	3.0	3.8	–
Pre-existing diabetes	6.0	1.6	5.0	1.6	1.0	1.3	–
Neonatal characteristics							
Males	201.0	52.2	157.0	51.5	44.0	55.0	0.57
Females	184.0	47.8	148.0	48.5	36.0	45.0	0.57
Gestational age at birth [median, IQR]	40.0	1.9	40.0	2.0	40.2	1.7	0.26

SD, standard deviation; IQR, inter quartile range; kg, kilogram; m, metre; –, insufficient sample to perform analysis; BMI, body mass index; GDM, gestational diabetes mellitus.

**Table 2** Neonatal anthropometric characteristics (*n* = 385)

Neonatal characteristics	Total cohort			Males			Females		
	<i>n</i>	mean	SD	<i>n</i>	mean	SD	<i>n</i>	mean	SD
Birthweight (kg)	385	3.50	0.58	201	3.48	0.60	184	3.42	0.57
Fat mass (kg)	80	0.32	0.16	44	0.31	0.17	36	0.34	0.15
Percentage fat mass (%)	80	9.44	3.90	44	8.76	4.06	36	10.28	3.67
FMI [(kg)/(length (m)) <sup>2</sup> ]	80	1.27	0.60	44	1.20	0.63	36	1.35	0.50
Infant length at birth (cm)	81	50.09	2.00	45	50.38	1.97	36	49.73	2.00
Occipital-frontal circumference (cm)	81	34.85	1.29	45	35.17	1.23	36	34.45	1.27
Mid-upper arm circumference (cm)	80	10.70	1.06	44	10.72	0.94	36	10.76	1.20
Mid-thigh circumference (cm)	80	15.97	1.32	44	15.26	1.40	36	14.83	1.19
Abdominal circumference (cm)	80	33.99	2.20	44	33.20	2.09	36	32.34	2.32

SD, standard deviation; cm, centimetres; kg, kilograms; m, metre; FM, fat mass.

consuming alcohol. Table 2 describes the characteristics of the neonatal study population.

Table 3 outlines the associations between maternal macro- and micro-nutrients intakes in early pregnancy and birthweight, and neonatal FMI using simple linear regression. On univariate analysis, total fat (beta = 0.004, 95% CI = 0.001–0.007, *P* = 0.02), monounsaturated fat (beta = 0.010,

95% CI = 0.001–0.02, *P* = 0.04), polyunsaturated fat (beta = 0.021, 95% CI = 0.007–0.04, *P* = 0.004) and vitamin E (beta = 0.020, 95% CI = 0.00–0.045, *P* = 0.048) were each positively associated with neonatal FMI. Removal of potential confounding variables gestational diabetes mellitus (GDM) and pre-existing diabetes did not result in any change in the findings outlined in Table 3.

**Table 3** Simple linear regression between maternal macro-nutrient and micro-nutrients intakes and neonatal outcomes

	<i>Birthweight (n = 385)</i>						<i>FMI (n = 80)</i>					
	<i>Unstandardized</i>		<i>Standardized</i>		<i>t</i>	<i>P</i>	<i>Unstandardized</i>		<i>Standardized</i>		<i>t</i>	<i>P</i>
	<i>B</i>	<i>SE</i>	<i>Beta</i>				<i>B</i>	<i>SE</i>	<i>Beta</i>			
<b>Macro-nutrient</b>												
Carbohydrate (g)	-0.24	0.23	-0.052	-1.02	-0.7-0.2	0.31	0.000	0.000	0.099	0.88	0.000-0.001	0.16
Starch (g)	-0.45	0.34	-0.068	-1.3	-1.1-0.3	0.18	0.000	0.000	0.093	0.82	-0.001-0.001	0.38
Sugars (g)	-0.10	0.43	-0.012	-0.23	-1.0-0.8	0.82	0.001	0.001	0.059	0.52	-0.002-0.003	0.60
Fibre (g)	-0.42	1.42	-0.030	-0.40	-3.2-2.4	0.78	0.002	0.002	0.103	0.92	-0.002-0.006	0.36
NMES (g)	-0.39	0.81	-0.025	-0.48	-2.0-1.2	0.63	0.002	0.002	0.077	0.68	-0.003-0.006	0.50
Protein (g)	0.10	0.59	0.008	0.17	-1.1-1.3	0.87	0.002	0.002	0.159	1.52	-0.001-0.005	0.16
Fat (total) (g)	-0.20	0.50	-0.020	-0.40	-1.2-0.8	0.69	0.004	0.002	0.252	2.30	0.001-0.007	0.02
Monounsaturated fat (g)	0.04	0.91	-0.052	-0.10	-4.3-2.0	0.97	0.010	0.005	0.236	2.14	0.001-0.02	0.04
Polyunsaturated fat (g)	-3.22	3.14	-0.040	-0.72	-9.3-2.9	0.48	0.021	0.007	0.318	2.96	0.007-0.04	0.004
Saturated fat (g)	0.37	0.91	0.002	0.04	-1.8-1.8	0.97	0.008	0.005	0.179	1.61	-0.002-0.019	0.11
<b>Micro-nutrient</b>												
Calcium	0.04	0.04	0.040	0.85	-0.05-0.1	0.40	0.000	0.00	0.01	0.12	0.00-0.00	0.91
Magnesium	0.06	0.05	0.060	1.17	-0.04-0.16	0.24	0.000	0.00	0.08	0.67	0.00-0.00	0.50
Iron	2.10	2.88	0.040	0.72	-3.6-7.7	0.48	0.010	0.01	0.14	1.21	-0.005-0.021	0.23
Zinc	-0.98	0.51	-0.010	-0.19	-11.0-9.0	0.85	0.010	0.01	0.16	1.46	-0.005-0.031	0.15
Iodine	0.06	0.18	0.020	0.32	-0.3-0.4	0.72	0.001	0.001	0.65	0.58	-0.002-0.003	0.57
Retinol	0.02	0.03	0.030	0.61	-0.04-0.07	0.54	0.000	0.00	0.11	0.96	0.00-0.00	0.34
Carotene	-0.00	0.01	-0.030	-0.63	-0.01-0.01	0.53	0.000	0.00	0.04	0.33	0.00-0.00	0.74
Vitamin D	1.00	11.20	0.010	0.09	-21.0-22.0	0.93	-0.002	0.02	-0.01	-0.1	-0.041-0.037	0.93
Vitamin E	-2.60	4.90	-0.027	-0.52	-12.2-7.0	0.60	0.020	0.01	0.22	2.01	0.00-0.045	0.048
Thiamin	-36.08	28.00	-0.070	-1.29	-91.0-18.9	0.20	0.040	0.06	0.08	0.67	-0.081-0.163	0.50
Riboflavin	18.70	29.70	0.030	0.63	-39.7-77.1	0.53	0.060	0.08	0.07	0.69	-0.109-0.224	0.50
Niacin	0.51	2.70	-0.060	-1.25	-8.5-1.9	0.85	0.010	0.01	0.15	1.33	-0.004-0.017	0.21
Vitamin B6	-21.90	24.60	-0.050	-0.89	-70.3-26.5	0.37	0.100	0.05	0.21	1.88	-0.006-0.210	0.06
Vitamin B12	1.93	8.50	0.010	0.23	-14.8-18.8	0.82	0.010	0.01	0.10	0.90	-0.015-0.040	0.37
Folate	0.25	0.18	0.010	0.14	-0.33-0.38	0.89	0.000	0.00	0.18	1.62	0.000-0.001	0.11

NMES, non-milk extrinsic sugars; g, grams; CI, confidence interval.

**Table 4** Multivariable linear regression of maternal nutrient intakes and neonatal FMI ( $n = 80$ )

	FMI					
	Unstandardized coefficients		Standardized coefficients		95% CI	P
	B	SE	Beta	t		
<b>Model 1</b>						
Adj $R^2 = 0.265$						
Monounsaturated fat (g)	-0.009	0.008	-0.199	-1.033	-0.025–0.008	0.31
Polyunsaturated fat (g)	0.036	0.017	0.545	2.131	0.002–0.076	0.04
Vitamin E (mg)	-0.019	0.019	-0.186	-1.007	-0.025–0.008	0.32
Maternal BMI (kg/m <sup>2</sup> )	0.059	0.013	0.443	4.465	0.033–0.086	<0.001
<b>Model 2</b>						
Adj $R^2 = 0.258$						
Monounsaturated fat (g)	-0.008	0.008	-0.196	-1.013	-0.025–0.008	0.31
Polyunsaturated fat (g)	0.035	0.017	0.521	2.019	0.000–0.069	0.047
Vitamin E (mg)	-0.015	0.019	-0.150	-0.797	-0.053–0.023	0.43
Maternal BMI (kg/m <sup>2</sup> )	0.059	0.014	0.444	4.280	0.032–0.087	<0.001
Infant gender	0.136	0.120	0.115	1.132	-0.103–0.374	0.26
Gestational age at birth	0.008	0.040	0.021	0.202	-0.103–0.374	0.84
<b>Model 3</b>						
Adj $R^2 = 0.262$						
Polyunsaturated fat (g)	0.015	0.007	0.225	2.247	0.002–0.028	0.03
Maternal BMI (kg/m <sup>2</sup> )	0.059	0.014	0.439	4.255	0.031–0.086	<0.001
Infant gender	0.151	0.118	0.128	1.287	-0.083–0.386	0.20
Gestational age at birth	0.007	0.039	0.019	0.185	-0.083–0.386	0.85

Dependent variable: FMI; g, grams; mg, milligram.

Table 4 outlines three models of multivariable linear regression analysis of WFFQ nutrient intakes and neonatal FMI. On multivariable regression, only the relationship between polyunsaturated fat and neonatal FMI persisted in all three models (Model 1 beta = 0.036, 95% CI = 0.002–0.076,  $P = 0.04$ ; Model 2 beta = 0.035, 95% CI = 0.000–0.069,  $P = 0.047$ ; Model 3 beta = 0.015, 95% CI = 0.002–0.028,  $P = 0.03$ ).

## Discussion

### Main finding of this study

This prospective observational study found that maternal dietary intakes of polyunsaturated fat in early pregnancy are positively associated with neonatal FMI on multivariable analysis. There was no relationship between maternal macro- or micro-nutrient intakes in early pregnancy and birthweight ( $P > 0.05$ ). Given the emerging data suggesting associations between maternal dietary intakes and neonatal adiposity, further longitudinal studies are needed to explore this association and its long-term implications for the neonate.

Strengths of this study include that gestational age was confirmed by ultrasound scan, rather than estimated based on the last menstrual period.<sup>45</sup> Second, ADP was used to measure neonatal body composition. This is a validated, direct measurement of neonatal birthweight and volume, which is used to calculate neonatal fat mass, fat free mass and percentage body fat.<sup>40,41,46</sup> Further strengths are that maternal height and weight were measured rather than self-reported. This ensured accurate calculation and classification of maternal BMI. Individual PALs were also collected for participants, facilitating more accurate identification and removal of respondents who had misreported their dietary intakes.<sup>33</sup>

### What is already known about this topic

Appropriate maternal nutritional intakes in pregnancy are important determinants of the long-term health status of the neonate. Inadequate intakes of key micro-nutrients at critical periods of gestation can have lasting deleterious effects on the developing foetus.<sup>4</sup> For example, deficiencies in maternal

iron status have been linked with lower birthweight<sup>16</sup> and poorer cognitive development<sup>47,48</sup> while low folate status is a critical risk factor for neural tube defect (NTD) births.<sup>5</sup> Research has shown deficiencies of nutrients at sensitive periods of gestation may compromise the long-term health of the foetus by subverting normal tissue growth and organogenesis in the cardiovascular, respiratory, gastrointestinal, musculo-skeletal, neurological, immune and endocrine systems.<sup>49–51</sup> Conversely, excess nutrient intakes can also influence foetal growth. Excessive intakes of fat, saturated fat<sup>52</sup> and refined sugar<sup>53</sup> during gestation have been linked to adverse maternal metabolic consequences, which can adversely affect foetal growth.

Data describing the influence of maternal dietary intakes on birthweight and neonatal body composition are continuing to emerge. A secondary analysis of the Healthy Start study<sup>54</sup> examined the relationship between maternal dietary quality during pregnancy and neonatal adiposity amongst 1079 mother–infant dyads. This study found that poor dietary scores ( $\leq 57$ ) as determined by using the Healthy Eating Index 2010 dietary quality scoring system, were associated with higher neonatal fat mass and percentage body fat ( $P < 0.05$ ). However, this study differed to our study design in terms of its dietary assessment methodology. The study population also excluded those with prior diabetes mellitus and included pregnant women up to 24 weeks gestation.

A further study investigated the associations between maternal macronutrient intake, carbohydrate quality (GI Index) and neonatal body composition, in women at risk of GDM.<sup>14</sup> This study identified trimester specific effects of specific dietary intakes on neonatal body composition, and suggested that over consumption of carbohydrates and high glycaemic (GI) index foods at sensitive stages of gestation may compromise fat free mass accretion in the foetus which persists at birth. Additionally, this study highlighted that high fat and saturated fat intakes in mid-pregnancy were positively associated with neonatal fat free mass index, while in late pregnancy, high intakes of these macronutrients were positively associated with neonatal FMI.<sup>14</sup>

Further results from a secondary analysis of the ROLO study (Randomized cOntrol trial of LOw glycaemic index diet versus no dietary intervention to prevent recurrence of foetal macrosomia) found that maternal saturated fat intakes were positively associated with neonatal adiposity.<sup>55</sup> This study however, only recruited women who were secundigravida with a previous macrosomic baby ( $>4.0$  kg).

To date, the findings in relation to the relationship between omega fatty acids, fish oils and birth outcomes is mixed. In a large observational study, low-maternal plasma

levels of certain omega-3 and omega-6 fatty acids, and high concentrations of other omega-6 fatty acids in early pregnancy, were associated with decreased foetal growth, decrease in birthweight, and increased risk of small for gestational age (SGA) infants. Additionally, neonates born to the women in the study cohort with the most adverse fatty acid profile, were on average 125 g lighter and twice as likely to be SGA.<sup>56</sup>

A systematic review concluded that omega-3 LC PUFA supplementation during pregnancy resulted in a modest increase in birthweight.<sup>57</sup> Disproportionate consumption of fish in high quantities may result in a negative relationship with birthweight. While research suggests a positive association with omega-3 supplementation and birthweight, the appropriate dose requires verification.<sup>58–60</sup>

A US study found that higher n23 PUFA concentrations in the maternal diet and in umbilical cord plasma phospholipids, were associated with lower adiposity in children at age 3 years as measured by the sum of skinfold thicknesses, likelihood of obesity, and the concentration of leptin (a biomarker directly correlated with adiposity). Higher maternal fish intake in pregnancy, a primary source of n23 PUFA, was also associated with lower child adiposity.<sup>61</sup>

### What this study adds

While there is extensive literature on the impact of isolated nutrients and birthweight, and emerging data with regard to adiposity composition measurements, to our knowledge, this is the first study to investigate the association between a wide range of macro-and micro-nutrients in early pregnancy with birthweight and neonatal adiposity using a direct measurement, in the same study cohort.

Pregnancy offers a unique opportunity to enhance maternal lifestyle behaviours which could yield more favourable neonatal health outcomes at birth and across the life course.<sup>1,23</sup> Our study findings suggest that dietary interventions in early pregnancy which target maternal dietary fat intake could influence neonatal adiposity at birth. Further longitudinal studies need to explore this association and evaluate the lifelong implications.

While the associations between neonatal body composition and long-term health outcomes remain to be fully elucidated, there is suggestive evidence that higher neonatal abdominal circumference (as a proxy of visceral adiposity) is associated with less favourable metabolic status in early childhood.<sup>23</sup> This suggests that maternal food and nutrient intakes which influence differences in neonatal body composition may impact long-term health outcomes in offspring.

## Limitations

A limitation of this study is the small sample population for neonatal adiposity data. Of the women recruited to the study, PEA POD<sup>®</sup> measurements with corresponding maternal FFQ data on plausible reporters were available on 80 neonates; a sample size similar to that of other studies measuring neonatal body composition by air-displacement plethysmography.<sup>14,40</sup> This sample size however, may be insufficient to power inferential statistical analysis.

A further potential limitation of the study is the convenience recruitment method. This methodology can result in the recruitment of participants who differ from the wider population. However, the characteristics of our study population were similar to those of the broader hospital population<sup>28</sup> and to the national normative range for neonatal anthropometric measurements<sup>42</sup> suggesting that they are generally representative of their peers. Also, consecutive recruitment of pregnant women in a busy clinical service is not feasible.

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