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An Investigation into the Dietary and Health Behaviours of Pregnant Women in Ireland

By

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BSc Human Nutrition & Dietetics

A Thesis for the Degree of

Doctor of Philosophy (PhD)

Dublin Institute of Technology

Supervisors:

Dr. Daniel McCartney

Professor Michael Turner

School of Biological Sciences

March 2016

Abstract

Maternal obesity increases the risk of metabolic complications in pregnancy such as gestational diabetes mellitus (GDM). Effective weight management following childbirth may reduce long-term metabolic risks among women of child bearing age. The aim of this study was to investigate the diet and health behaviours of pregnant and postpartum women in Ireland.

Accurate dietary assessment in pregnancy is often difficult to achieve. We have shown that dietary under-reporting is more likely among pregnant women who are younger, materially deprived, obese and who have increased adiposity. These findings suggest that dietary under-reporting represents a source of potential bias in obstetric obesity research. Obese pregnant women of low socioeconomic status may require more specialised dietary assessment methods.

Technology increasingly dictates the way in which we collect and communicate information, highlighting the potential utility of innovative web-based dietary assessment and intervention tools. We compared dietary quality scores from a newly developed online Dietary Assessment Tool against nutrient intakes derived using the recently validated Willett Food Frequency Questionnaire. The relatively good agreement between these two dietary assessment methods suggests that our food-based dietary quality scores are reflective of important nutrient intakes in pregnancy.

Nutritional manipulation based on dietary intervention does not appear to prevent GDM. Neither food group nor macronutrient intakes in the periconceptional period were associated with fasting plasma glucose (FPG) levels in our cohort of pregnant women. Obesity in early pregnancy was the main predictor of elevated FPG levels, highlighting the potential value of pre-conceptional weight management interventions in preventing GDM.

There is a paucity of data describing maternal weight changes in the postpartum period. We found that maternal weight and body composition trajectories after pregnancy were not linear, and that they differed between women who were obese and those who were not obese in the first trimester. The role of breastfeeding in postpartum weight change is not clear. We found that postpartum changes in maternal weight and percentage body fat were not associated with infant feeding method after adjusting for important confounders such as diet and exercise.

Overall, my findings commend the pre-conceptional period as an important window of opportunity in the prevention of GDM and postpartum obesity.

Declaration

I certify that this thesis which I now submit for examination for the award of PhD, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any Institute.

The work reported on in this thesis conforms to the principles and requirements of the Institute's guidelines for ethics in research.

The Institute has permission to keep, lend or copy this thesis in whole or in part, on condition that any such use of the material of the thesis be duly acknowledged.

Signature _____ Date _____

Laura Mullaney Candidate

Acknowledgements

There are a huge amount of people that without them this thesis would not have been possible.

Firstly I would like to express my sincere gratitude to my supervisors Dr. Daniel McCartney *(School of Biological Sciences, Dublin Institute of Technology)* and Professor Michael Turner (*UCD Centre for Human Reproduction, Coombe Women and Infants University Hospital*). I cannot overstate my gratitude to them. They provided me with expert advice and ideas, generous guidance and constant encouragement and support. Their energy, enthusiasm and passion for research inspired and motivated me. They have been fantastic role models and have made my research experience thoroughly enjoyable.

I would like to thank my fellow research team – Amy O'Higgins, Shona Cawley, Rachel Kennedy, Ciara Reynolds, Anne Dolan, Niamh Byrne, Maria Farren, Aoife Fitzgerald, Georsan Caruth, Fiona Dulevy, and Laura Bowes. I was very lucky to be part of such a fantastic team of people. Their support and care helped me stay focused and overcome any set-backs. I couldn't have completed this research without their guidance, advice, friendship, and many coffee breaks. I greatly value their friendship and their belief in me throughout the project.

This project was supported by DANONE Nutricia Early Life Nutrition. I would like to take this opportunity to thank most sincerely DANONE Nutricia Early Life Nutrition for their financial support of this research. I am also very thankful for the support of the UCD Centre for Human Reproduction and Dublin Institute of Technology. Additionally I would like to thank the Environmental Sustainability and Health Institute, in particular Dr. Noreen Layden, whose generous support enabled me to present at national and international conferences.

I am very thankful to the staff of the Coombe Hospital, in particular the administrative staff and nurses whose help assisted with the recruitment and follow-up for this study.

I would like to thank the study participants who took part in this research, without whom this work would not have been possible. I very much enjoyed working with the study participants and I am very grateful for their continued dedication throughout the study and their generosity with their time.

Finally to my family & friends, I am extremely grateful for their love and support. To my Mom and Dad for their everlasting love. They have always been a fantastic support throughout my education and life. Also a big thank you to my brothers Andrew and Simon for their friendship and encouragement. To my friends, thank you so much for your support and empathy throughout this project. I love you all very much and I am extremely grateful to have you in my life. I could not have done this without you.

Abbreviations

AAP	American Academy of Paediatrics
ACOG	American College of Obstetricians and Gynecologists
ADA	American Diabetes Association
AHEI	Alternate Healthy Eating Index
AHEI-P	Alternate Healthy Eating Index for Pregnancy
AMP	Active Mothers Postpartum
AOAC	Association of Organic and Analytic Chemists
BIA	Bio-Impedance Analysis
BIP	Body Composition in Pregnancy
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CBF	Complimentary Breastfeeding
CI	Confidence Interval
CSO	Central Statistics Office
CVD	Cardiovascular Disease
CWIUH	Coombe Women Infants University Hospital
DAT	Dietary Assessment Tool
DIT	Dublin Institute of Technology
DLW	Doubly Labelled Water
DEXA	Dual Energy X-ray Absorptiometry
DQI-P	Diet Quality Index for Pregnancy
EBF	Exclusively Breastfeeding
ECW	Extracellular Water
EI	Energy Intake
EPIC	European Prospective Investigation into Cancer and Nutrition
EU	European Union
EU-SILC	European Union-Survey on Income and Living Conditions
FAO	Food and Agricultural Organisation
FDA	Food and Drug Administration
FFM	Fat Free Mass
FFQ	Food Frequency Questionnaire
FM	Fat Mass
FPG	Fasting Plasma Glucose
FSAI	Food Safety Authority of Ireland
g	Grams
GI	Glycaemic Index
GDM	Gestational Diabetes Mellitus
GUI	Growing Up in Ireland
GWG	Gestational Weight Gain
HAPO	Hyperglycemia and Adverse Pregnancy Outcomes
HEI	Healthy Eating Index
HSE	Health Service Executive
Hz	Hertz
IADPSG	International Association of Diabetes and Pregnancy Study Group
IBM	International Business Machines

ICW	Intracellular Water
IGT	Impaired Glucose Tolerance
IoM	Institute of Medicine
IQR	Inter-Quartile Range
IT	Information Technology
kg	Kilogram
LiP	Lifestyle in Pregnancy
m	Metre
MET	Metabolic Equivalent
MF	Multi Frequency
mg	Milligram
µg	Microgram
MJ	Mega Joule
n	Sample Size
NDDG	National Diabetes Data Group
NICE	National Institute for Health and Care Excellence
NMES	Non Milk Extrinsic Sugars
NS	Non Significant
NTD	Neural Tube Defect
OGTT	Oral Glucose Tolerance Test
PAL	Physical Activity Level
PCA	Principal Component Analysis
PDA	Personal Digital Assistant
PG	Plasma Glucose
PPWR	Postpartum Weight Retention
R	Resistance
RCPI	Royal College of Physicians Ireland
RCT	Randomised Control Trial
SES	Socioeconomic Status
SF	Single Frequency
SSB	Sugar Sweetened Beverages
SD	Standard Deviation
SMART	Specific, Measurable, Achievable, Relevant, Time specific
SPSS	Statistical Package for Social Sciences
TBW	Total body Water
TEE	Total Energy Expenditure
UNU	United Nations University
WFFQ	Willet Food Frequency Questionnaire
WHO	World Health Organisation
WHR	Waist to Hip Ratio
WHtR	Waist to Height Ratio
WISP	Weighed Intake Software Package
Xc	Capacitance
Z	Impedance

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Journal Publications

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Chapter 1

Introduction

More than half of Irish women aged >20 years are considered to be overweight or obese; which is in excess of the European average of 47.6% (Ng *et al.,* 2014). Obesity affects one in five women booking for antenatal care in the Coombe Women and Infants University Hospital (CWIUH) and is an important modifiable risk factor for adverse pregnancy outcomes (Fattah *et al.,* 2009). Maternal obesity matters because it is associated with an increase in both fetal and maternal complications; it is technically challenging from an obstetric viewpoint; it is economically costly; and it carries with it potential lifelong health consequences for the woman and her offspring (Ben-Haroush *et al.,* 2003; Chu *et al*., 2007; Oddy *et al.,* 2009; Marinou *et al.,* 2010; O'Dwyer *et al.,* 2011; Safefood, 2012). While obesity is associated with comorbidities such as cardiovascular disease, diabetes mellitus and hypertension (Marinou *et al.,* 2010), maternal obesity is also associated with an increase in obstetric interventions such as caesarean section, as well as an increased risk of congenital malformations such as Neural Tube Defects (NTDs) (Oddy *et al.,* 2009; O'Dwyer *et al.,* 2011).

Maternal obesity additionally increases the risk of metabolic complications in pregnancy. These include Gestational Diabetes Mellitus (GDM); a condition also associated with elevated risk of type 2 diabetes mellitus in later life (Ben-Haroush *et al.,* 2003; Chu *et al.,* 2007). It is now well established that the risk of developing GDM is increased in women with higher pre-pregnancy Body Mass Index (BMI) and that the risk significantly and progressively increases across BMI categories of overweight, obesity, and morbid obesity (Torloni *et al.,* 2008; Morisset *et al.,* 2010; Heude *et al*., 2012).

While weight retention related to pregnancy is highly variable, effective weight management following childbirth may reduce the long-term risks of heart disease, cancer, obesity and diabetes among women of child bearing age; as well as reducing the risk of entering future pregnancies overweight or obese (Gore *et al.,* 2003). The National Institute for Health and Care Excellence (NICE) Obesity Guidelines 2006 identified the postpartum period as a vulnerable life stage for weight gain (NICE, 2006), perhaps because women often receive little or no advice on weight management after childbirth. Although the Institute of Medicine (IoM) recommends that counseling on diet and exercise be offered to women to eliminate postpartum weight retention (IoM, 2009), the postpartum period has been associated with an increase in food intake and a decrease in Physical Activity Level (PAL) (Sadurskis *et al.,* 1988; Clark & Ogden, 1999; Symons Downs & Hausenblas, 2004). Studies have also shown that dietary quality for women in the postpartum period is suboptimal (Mackey *et al.,* 1998; George *et al.*, 2005; Fowles & Walker, 2006; Durham *et al.,* 2011; Wiltheiss *et al.,* 2013).

The postpartum period is also, for many women, an inter-partum or pre-conceptional interval before the birth of their next baby. A prospective study by Bobrow *et al.,* (2013), found that BMI increased significantly in women following the birth of each child, independent of socioeconomic group, physical activity, region of residence, and smoking. An Irish longitudinal study also found that two thirds of first time mothers had gained weight when they re-attended for antenatal care on their next pregnancy, and as a result, one in 5 women moved into a higher BMI category, and one in 20 women became obese (Crosby *et al.,* 2014). A nationally representative observational study additionally found that among socioeconomically disadvantaged women, increasing parity was associated with obesity at nine months postpartum (Turner & Layte, 2013).

It has been suggested that more evidence in the area of weight management during the postpartum period is needed (Messina *et al.,* 2009). The IoM have also stated that there are gaps in the surveillance of Postpartum Weight Retention (PPWR) (IoM, 2009). With regard to weight management before, during and after pregnancy, NICE (2010) recognise that a population based approach is needed in reaching all women of childbearing age, as many pregnancies are unplanned. NICE (2010) have also stated that there is a lack of evidence identifying the most effective time for women to start managing their weight after childbirth, and describing the optimal rate of weight loss in the postpartum period.

While maternal obesity, GDM and PPWR are multifactorial in their aetiology, healthy diet and exercise have been suggested as modifiable behaviours which can ameliorate the risk of both GDM and postpartum obesity (Ohlin & Rossner, 1994; Zhang *et al.,* 2006; Ley *et al.,* 2011; Tobias *et al.,* 2011; Walsh *et al.,* 2012; Bowers *et al.,* 2012; Bao *et al.,* 2013; Wiltheiss *et al.,* 2013; Russo *et al.,* 2015). However, dietary assessment is a problematic area, with accurate assessment often difficult to achieve. In addition, the assessment of food and nutrient intake in pregnant women is further complicated as conception causes complex and sequential physiological changes. These changes alter maternal nutrient absorption and metabolism, energy and nutrient needs, appetite, and meal pattern (Picciano, 2003). The difficulties associated with accurate quantitative dietary assessment in pregnancy, as well as these natural changes in physiological nutrient requirements, may give rise to aberrant conclusions regarding the effects of maternal diet on the course and outcome of pregnancy. Given the importance of maternal diet in fetal health (Zeisel, 2009) and in later infant and adult heath (Silveira *et al.,* 2007; Koletzko *et al.,* 2012) however, accurate dietary assessment and interpretation is crucial to the derivation of efficacious, evidence based nutritional interventions in this population.

This thesis is divided into nine chapters. After the first introductory chapter, **Chapter 2** describes the study design and methodology, and its aims and objectives. Subsequent chapters each begin with their own detailed literature review by way of introduction, followed by more detailed description of the research methods, results and discussion relevant to that specific chapter. **Chapter 3** deals with the area of Energy Intake (EI) mis-reporting in pregnancy. **Chapter 4** compares a newly developed online Dietary Assessment Tool (DAT) against the previously validated Willet Food Frequency Questionnaire (WFFQ). **Chapter 5** investigates the association between maternal absolute and energy adjusted food group and micro- and macro-nutrient intakes and Fasting Plasma Glucose (FPG) levels in pregnancy. **Chapters 6 - 8** investigate trajectories in postpartum maternal weight and body composition, taking into account important factors such as maternal diet, exercise, Socioeconomic Status (SES), and infant feeding practices. The final **Chapter 9** discusses the conclusions and implications of this research.

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Chapter 2

Methods

2.0 Introduction

This chapter outlines the overall aims and objectives of this study together with the methods that are used in Chapters 4-8. Specific details that are pertinent to a particular methodology will be described in more depth in the relevant chapters.

2.1 Aim

To investigate the diet and health behaviours of pregnant and postpartum women in Ireland.

2.2 Objectives

1. To analyse the characteristics of women who mis-reported EI in early pregnancy according to the WFFQ.
2. To compare a newly developed online DAT against the previously validated WFFQ.
3. To investigate the association (if any), between maternal absolute and energy adjusted food group and macro- nutrient intakes and FPG levels in pregnancy.
4. To examine trajectories in maternal weight and body composition between the first antenatal visit and four and nine months postpartum, and to analyse these trajectories according to BMI category.
5. To examine whether breastfeeding, and in particular Exclusive Breast Feeding (EBF), is associated with maternal weight and body composition changes after delivery,

independently of other variables such as diet, physical activity, smoking, demography and SES.

6. To investigate the dietary, nutritional, health behavioural and socioeconomic factors associated with postpartum weight and body composition changes from early pregnancy to nine months postpartum.

2.3 Study Hypothesis

1. Women who mis-report EI in early pregnancy according to the WFFQ will have different characteristics compared to plausible EI reporters.
2. The DAT score in early pregnancy will correlate with nutrient data from the WFFQ in early pregnancy.
3. Maternal absolute and energy adjusted food group and macro- nutrient intakes will be associated with FPG levels in pregnancy.
4. Maternal weight and body composition trajectories between early pregnancy, four and nine months postpartum will vary according to BMI status.
5. Breastfeeding will be associated with decreased weight gain and associated with body composition changes in the postpartum period independent of other variables such as diet, physical activity, smoking, demography and SES.
6. Dietary, nutritional, health behavioural and socioeconomic factors will be associated with postpartum weight and body composition changes from early pregnancy to nine months postpartum.

2.4 Ethical Considerations

Ethical approval for this study was obtained from the CWIUH Research Ethics Committee (**Appendix 1**) and the Dublin Institute of Technology (DIT) (**Appendix 2**), upon submission of a written project protocol **(Appendix 3**).Written informed consent was obtained from all women prior to data collection; including consent for follow-up. Written consent forms and project information sheets were provided to all those participating in the study (**Appendix 4 & 5**).

2.5 Research Design

The Body Composition in Pregnancy (BIP) study was a longitudinal investigation of maternal weight and body composition trajectories in pregnancy conducted at CWIUH between 2012 and 2014. Women were recruited in the first trimester of pregnancy after an ultrasound examination confirmed an ongoing pregnancy. Height was measured to the nearest centimetre using a Seca wall-mounted digital height measure (Seca, Birmingham, United Kingdom) with the woman standing in her bare feet. Weight and body composition were measured using 8-electrode Bioelectrical Impedance Analysis (BIA) (Tanita MC 180, Tokyo, Japan) and BMI (weight in kg / (height in m)^2) was calculated. Maternal dietary intakes and dietary quality indicators were collected at this visit. Participants' dietary intake data were entered into a nutrient analysis software package (Weighed Intake Software Package (WISP) version 4.0, Tinuviel Software, Llanfechell, Anglesey, UK) to assess their macro- and micro- nutrient intakes; while the dietary quality indicators were used to generate an overall dietary quality score. Socioeconomic, health behavioural and PAL data were also gathered at this visit.

Women returned to the hospital for their anatomy scan at ~20 weeks gestation. Maternal weight and body composition status were re-measured. Women were invited back for an

additional ultrasound examination and weight and body composition measurements at ~28 and ~39 weeks gestation. These additional scans were used to incentivise women's participation in the study as they are not offered routinely by the hospital.

At delivery, the women's details were collected. These included gestational age at delivery and mode of delivery. Their baby's birthweight and body composition measurements were taken using air displacement plethysmography (PAEPOD) within three days of delivery. Women were invited back to the hospital for review at four and nine months postpartum. Women's weight and body composition were again measured at both of these postpartum visits. Baby measurements were also re-taken at this visit using air displacement plethysmography where appropriate (if the baby was too big for the PAEPOD or distressed, standard weight, length and circumference measurements were taken instead). Maternal dietary intakes and dietary quality data were gathered at both of these postpartum visits and used to generate nutrient intakes and dietary scores as previously described. Socioeconomic, health behavioural and PAL data were also collected at both of these postpartum visits, as well as maternal infant feeding practices. Table 2.1 shows a flow diagram of the Ph.D. candidate's involvement in the recruitment phase of the study.

Table 2.1: Flow diagram of Study Involvement

Study Involvement	Study Flow Chart	Ph.D. Candidates Involvement
	Preparatory Phase	
• Hospital ethical approval applied for by obstetrician	Ethical approval, Development of Questionnaires	• Applied for DIT ethical approval • Discussed study protocol and questionnaires to be used to achieve the aims of this study
	Recruitment in Early Pregnancy	

• Recruitment of initial 551 women by obstetrician - weight and body composition measurements, no additional PAL, socio-demographic, WFFQ or dietary quality data		• Recruitment of 524 women • Weight and body composition measurements taken • Additional PAL, socio-demographic, WFFQ and dietary quality data collected • WFFQ data input into excel and WISP nutrient analysis software
	20-24 weeks gestation	
• Ultrasound scan carried out by obstetrician or midwife as part of standard hospital care • Maternal weight and body composition measurements taken		• Aided in measuring maternal weight and body composition
	28 and 39 weeks gestation	
• Additional ultrasound scans carried out by obstetrician • Maternal weight and body composition measurements taken		• Aided in measuring maternal weight and body composition
	Delivery	
• Baby body composition measurements taken by paediatrician		• 40 women excluded as delivered elsewhere or miscarried • Aided with baby body composition measurements and/or weights
	Four months Postpartum	
Data Collection		**Preparatory Phase**
• Baby body composition measurements taken by paediatrician		• Development of invitation follow-up letters • Posted follow-up invitation letters and questionnaires to 1035 women • Telephone and/or text message reminders of follow-up appointments sent to women
		Data Collection and Input
		• Received 494 returning

		women • Re-measured maternal weight and body composition • Collected questionnaires • Collected dietary quality data • Aided with baby body composition measurements and/or weights • WFFQ data entered into Excel and WISP
	Nine months Postpartum	
		Preparatory Phase
		• Development of invitation follow-up letters • Posted follow-up invitation letters and questionnaires to 494 women who attended their four month postpartum follow-up • Telephone and/or text message reminders of follow-up appointments sent to women
		Data Collection
		• Received 328 returning women • Re-measured maternal weight and body composition • Collected questionnaires • Collected dietary quality data • Baby weight and body measurements taken • WFFQ data entered into Excel and WISP

2.5.1 Maternal weight, height and BMI

Maternal height was measured to the nearest centimetre at each of the study visits using a Seca wall-mounted digital height measure with the woman standing in her bare feet. Maternal

weight was measured to the nearest 0.1 kg using the Tanita MC-180 and BMI was calculated by dividing the participant's weight in kilograms by the square of their height in meters.

Accurate assessment of early pregnancy weight as a baseline measurement is a challenge in obstetric research. Some studies use pre-pregnancy weight which may be either measured or self-reported. However the accuracy of this estimate (where self-reported), and the time interval between measured weights and conception are highly variable. Women may actively try to gain or lose weight before coming pregnant. In fact, often a change in weight can be a trigger for conception because anovulatory infertility can be treated by weight loss in obese women and in women with polycystic ovarian syndrome, and by weight gain in underweight women. Furthermore, about half of pregnancies are unintended, therefore, measured pre-pregnancy weights are often unavailable (Finer *et al.*, 2006). Many studies also rely on self-reported pre-pregnancy weight (Siega-Riz *et al.*, 1994; Abrams *et al.*, 1995; Abrams & Selvin, 1995; Carmichael *et al.*, 1997; Widen *et al.*, 2015) which is unreliable and leads to BMI misclassification (Turner, 2011). Self-reporting of weight in obese women may be particularly subject to error (Fattah *et al.*, 2009).

There is a lack of data investigating changes in weight and body composition from pre-pregnancy to the first trimester. Measured pre-pregnancy weights are very rarely available and many studies investigating weight and body composition during pregnancy often begin baseline measurements after 18 weeks gestation (Ghezzi *et al.*, 2001). Additionally gestational age may be uncertain, as it has not been confirmed by ultrasound.

In an American study (n=63) measured weight and body composition (Total Body Water (TBW), Fat Free Mass (FFM), Fat Mass (FM) and % of FM) changed between the start of

pregnancy and nine weeks gestation (P=0.001-0.002). Weight changed from 0.033 to 0.068 kg in this group of women in the first nine weeks of gestation (Butte *et al.,* 2003). Another American study (n=557) used thigh, triceps and subscapula skinfold thickness measurements to investigate subcutaneous body fat changes from preconception to throughout pregnancy in well-educated middle class Caucasians (Sidebottom *et al.,* 2001). Weight increased from 6 to 18 weeks gestation by 6 kg and subcutaneous fat began to accumulate around 6 weeks after conception.

For baseline weight measurement during pregnancy, the gestational age at the time of measurement is important. Although previous reports suggest that women gain 0.2-2.0 kg in the first trimester (Siega-Riz *et al.,* 1994; Abrams *et al.,* 1995; Abrams & Selvin, 1995), our research group has shown that there is no increase in average maternal weight and no changes in maternal body composition in the first trimester (Fattah *et al.,* 2010). Indeed, data indicate that maternal weight only starts to increase, on average, at around 18 weeks of gestation (Fattah *et al.,* 2010). Thus, measurements of weight taken before 18 weeks of gestation can be used as an accurate baseline estimate of habitual bodyweight.

2.5.2 BMI as a surrogate marker for body composition

BMI does not measure body fat directly, but research has shown that BMI is moderately correlated with more direct measures of body fat obtained from skinfold thickness measurements, bioelectrical impedance, densitometry, Dual Energy X-ray Absorptiometry (DEXA) and other methods (Garrow & Webster, 1985; Freedman *et al.,* 2013; Wohlfahrt-Veje *et al.,* 2014). Furthermore, BMI appears to be correlated with various metabolic and disease outcomes as are these more direct measures of body fatness (Steinberger *et al.,* 2005; Willett *et*

al., 2006; Flegal & Gaubard, 2009; Freedman *et al.*, 2009; Lawlor *et al.*, 2010; Sun *et al.*, 2010). Table 2.2 shows the World Health Organization (WHO) BMI classification of body fatness.

BMI however is a surrogate marker for adiposity and does not measure body fatness directly. It also gives no information on the distribution of adipose tissue (Prentice & Jebb, 2001). In addition recent literature has shown that abdominal obesity measures such as Waist to Height Ratio (WHtR) and Waist to Hip Ratio (WHR) were shown to be more accurate measures of body fat and more significantly associated with mortality than BMI (Ashwell *et al.*, 2012). This study included data from more than 300,000 subjects, and showed that compared with BMI, the use of waist circumference improved discrimination of adverse outcomes by 3%. However, the use of WHtR improved discrimination by 4-5% over BMI. Most importantly, the study showed WHtR to be a significantly better predictor of diabetes, hypertension, Cardiovascular Disease (CVD) and all adverse outcomes than waist circumference alone in both men and women.

Table 2.2: World Health Organization BMI classification of body fatness (WHO, 1998)

Body Mass Index (kg\m^2)	
<18.5	Underweight
18.5-24.9	Ideal Weight
25.0-29.9	Overweight
30.0-34.9	Mild Obesity (Obese Class 1)
35.0-39.9	Moderate Obesity (Obese Class 2)
>40.0	Morbid Obesity (Obese Class 3)

The value of using site specific measures of abdominal obesity such as waist circumference and waist to height ratio has been further emphasised by additional research by

Carmienke and colleagues in 2013. This study used data from 689,465 subjects across 18 studies to show that measures of abdominal obesity such as waist circumference and WHtR were superior to general measures such as BMI or body weight in determining disease risk and mortality (Carmienke *et al.*, 2013).

2.5.3 Maternal bioelectrical impedance analysis (Tanita MC 180MA, Tokyo, Japan)

Maternal body composition in this study was analysed using advanced BIA at each of the study visits (Tanita MC 180). The measurements were taken with women wearing light clothing and standing in their bare feet. BIA measures the resistance of body tissue to a small electrical current. The resistance of conductive material is proportional to its length and inversely proportional to its cross-sectional area. In practice, height is used rather than length. The body offers two types of resistance to electrical current: capacitance resistance (reactance) and resistive resistance (simply called resistance). The capacitance (Xc) arises from cell membranes, and the resistive resistance (R) from extra- and intra- cellular fluid. Impedance (Z) is the term used to describe the combination of the two (Kyle *et al.*, 2004a). Current passes quickly through lean mass and water, and more slowly through FM.

Single Frequency (SF) BIA was the first type of BIA to become available. It can be used to measure FFM and TBW in normally hydrated patients. SF BIA is limited in its ability to distinguish the distribution of body water into its intra- and extra- cellular compartments however. It uses a current at 50 Hz passed through electrodes on the hand and foot (Wells & Fewtrell, 2008).

Since the advent of SF BIA, there have been significant technical advances in BIA. Multi Frequency (MF) and segmental BIA provides more accurate measurements than SF BIA and

allows separate estimates of Intracellular Water (ICW) and Extracellular Water (ECW) (Larciprete *et al.,* 2003; Hu, 2008). MF BIA uses currents between 0 and 500 HZ to evaluate FFM, TBW, ECW, and ICW. Segmental BIA can be used to measure limb and trunk composition as well as total body composition (Kyle *et al.,* 2004a).

The algorithms used by the MF Tanita BIA employed in this study were calculated using DEXA and the dilution method. A regression formula derived from the multiple regression analyses while specifying the height, weight, age, and impedance values between the arms and legs as variables was developed for the derivation of FM, % of FM, FFM, muscle mass, and TBW in accordance with data acquired from the DEXA method and dilution method targeted from Europeans and Americans. These formulae were developed for both standard and athletic body types. The standard body type only was used in this research. The correlations for the segmental measurements were found to be both reliable and reproducible (Tanita multifrequency Body Composition Analyser MC-180MA Instruction Manual, Tokyo).

International guidelines have concluded that BIA is safe, non-invasive, and relatively inexpensive and does not expose subjects to ionizing radiation which would be prohibited in obstetric research (Kyle *et al.,* 2004a; Kyle *et al.,* 2004b). The advantages of BIA in the measurement of body composition also include its ease of use and the minimal subject participation required, making it suitable for large scale research among pregnant populations (McCarthy *et al.,* 2004; Lee & Gallagher, 2008).

2.5.4 Bioelectrical impedance analysis in pregnancy and postpartum

The use of BIA to measure body composition in adults has been well validated compared with other techniques (Buchholz *et al.,* 2004; Kyle *et al.,* 2004a; Kyle *et al.,* 2004b; Dehghan &

Merchant, 2008). In our research group, normal body composition measurements using segmental MF BIA have been described in 1000 women booking for antenatal care in the first trimester of pregnancy (Fattah *et al.*, 2010). This study found that mean maternal FM, FFM and bone mass remained unchanged in the first trimester of pregnancy. These findings indicate that changes in maternal body composition usually occur after the first trimester of pregnancy, making it possible to use these measurements as a baseline for comparison in the postpartum period.

One Italian longitudinal study has measured body composition using a tetrapolar impedance analyser (BIA Quantum, Rome) in 169 Italian women with an uncomplicated singleton pregnancy who booked for antenatal care before 12 weeks gestation. The most important increase in TBW and ECW occurred in the second and third trimesters. A change in weight of 1.4 ± 1.9 kg was observed at <15 weeks gestation (Ghezzi *et al.*, 2001). This was consistent with a previous study using BIA which found that the most significant variation in TBW occurred after the first trimester (Lukaski *et al*., 1994). This study also found that SF BIA changes during pregnancy (reactance and resistance) reverted to early pregnancy levels within 60 days after delivery in healthy uncomplicated pregnancies (Ghezzi *et al.*, 2001).

In another longitudinal Italian study, MF BIA measurements (Tefal, Rowenta, France) were completed eight times between 10 and 38 weeks gestation in 170 healthy pregnant women (Larciprete *et al.*, 2003). This study of BIA during pregnancy has provided greater detail than other studies in relation to the ranges of change in different body compartments as it used MF BIA and not SF BIA as previously described (Ghezzi *et al.*, 2001). Similar to previous studies, this study found that TBW and ECW significantly increase during the second and third trimester of gestation.

There is a lack of studies investigating postpartum changes in body composition using BIA in developed western countries, however a limited number of studies have been carried out in Asia which are explained in further detail in later Chapters.

2.5.5 Willett Food Frequency Questionnaire (WFFQ)

To collect 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. For the four and nine month postpartum follow-ups, women were sent the WFFQ in the post and asked to fill them out and bring them to their postpartum follow-up appointment.

Food frequency Questionnaires (FFQ) consist of a list of foods and options relating to the frequency of consumption of each food listed. FFQs are designed to collect dietary information from large numbers of individuals and are normally self-administered, though interviewer administered and telephone interviewer administered protocols are also used (Willet, 1998). FFQs normally ask about intake within a given time frame (e.g. in the past 2-3 months, 1 year or longer) and therefore aim to capture habitual intake. The length of the food list can vary depending on the nutrients or foods of interest, and the target population under examination.

The strengths of the FFQ approach include its low respondent burden, its accommodation of seasonal variations in intake, and its suitability for large scale studies. Several different types of FFQs have been used to assess dietary intake in pregnant women (Suitor *et al.,* 1989; Brown *et al.,* 1996; Robinson *et al.,* 1996; Mathews *et al.,* 1999; Erkkola *et al.,* 2001; Fawzi *et al.,* 2004; Baer *et al.,* 2005; Emmett, 2009).

2.5.5.1 Validation of the WFFQ in pregnancy

As FFQs are designed for use in a specific population, they need to be validated in any new target population before use (Cade *et al.,* 2002). The large intra-individual variability in dietary intake in pregnancy (due to nausea, idiosyncratic food aversions etc.) makes it more difficult for a single FFQ to accurately estimate usual intake. Thus, it is crucial that any FFQ for use among pregnant women is validated in this specific population even if its validity in adult non-pregnant populations has already been demonstrated.

Validation studies of various FFQs have been carried out in pregnancy and show meaningful estimations of nutrient intake which can be used to rank individuals within their distribution (Suitor *et al.,* 1989; Greeley *et al.,* 1992; Forsythe & Gage, 1994; Brown *et al.,* 1996; Robinson *et al.,* 1996; Erkkola *et al.,* 2001; Baer *et al.,* 2005; Cheng *et al.,* 2008; Pinto *et al.,* 2010; Shatenstein *et al.,* 2011; Barbieri *et al.,* 2013). The 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 (Kaaks *et al.,* 1997; Morgan *et al.,* 2008) by comparison with seven day weighed records and the use of one biomarker, 24 hour urinary nitrogen (Harrington, 1997). In a recent Irish study (McGowan *et al.,* 2014) the WFFQ adapted from the EPIC study (Kaaks *et al.,* 1997) was given once during pregnancy between 12 and 34 weeks of gestation and validated against three 3-day food diaries, one completed in each trimester of pregnancy. On average, 74.2% of participants were classified into the same/adjacent quartile of nutrient intake showing reasonable to good agreement of these methods in ranking participants along the nutrient intake continuum.

Using the WFFQ, frequency of consumption of a 'standard portion' of each food or beverage item consumed was divided into 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 reference text (Food Standards Agency, 2006). In this way, food and nutrient intake data reflective of the peri-conceptual period up to nine months postpartum were captured as the WFFQ protocol focuses on intake over the previous year.

The WFFQ dietary data were entered into excel and then 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 (McCance & Widdowson, 2002).

2.5.6 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) (Kearney *et al.*, 1997; Kearney *et al.*, 1999; Allen & Newsholme, 2003). Questions collecting socioeconomic data were derived from the European Union Survey on Income and Living Conditions (EU-SILC) (European Commission Working Group, 2003; Central Statistics Office (CSO), 2013).

Part two of the computer based tool collected self-assessed habitual 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)) (FAO/WHO/UNU, 2001).

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 2.3. 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 twelve 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 micro-nutrient intake and neonatal outcomes (Snook-Parrott *et al.*, 2009; Kuehn *et al.*, 2012; Grieger & Clifton, 2015). Dietary domains with weaker, less developed or less consistent evidence to support their associations with neonatal health outcomes such as fatty foods (White *et al.*, 2009; Murrin *et al.*, 2013; Williams *et al*., 2014), starchy foods (Hernandez *et al.*, 2014; Horan *et al*., 2014), refined sugar (Englund-Ogge *et al.*, 2012; Grundt *et al.*, 2012; Regnault *et al*., 2013; D'Alessandro *et al.*, 2014; Moses *et al.*, 2014; Sloboda *et al.*, 2014) and oily fish (De Giuseppe *et al.*, 2014; Leventakou *et al*., 2014; Saccone & Berghella, 2015a; Saccone & Berghella, 2015b), 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 (Alwan *et al.*, 2010; Catov *et al.*, 2011; Asemi *et al.*, 2013; Carlson *et al.*, 2013; Asemi *et al.*, 2014; Harvey *et al.*, 2014).

Each dietary domain yielded a score which contributed to an overall composite score (%) which reflected the overall quality of the diet. The ten dietary domains with their respective weightings are shown in Table 2.3. This dietary scoring system is compatible with existing guidelines for healthy diet in pregnancy disseminated by national and international health agencies (FSAI, 2011; HSE, 2013; National Health and Medical Research Council, 2013). It is also consistent with previous efforts to operationalise food based dietary guidelines for

pregnancy using existing dietary quality indices (Pick *et al.*, 2005; Melere *et al.*, 2013; Shin *et al.*, 2014).

Table 2.3: Composition and relative weightings of dietary intake domains in the 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 per week with processed red meats at the main meal 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

Totals	**112 (100%)**

2.5.7 Statistical Analysis

All data collected were coded and entered into the Statistics Package for the Social Sciences (SPSS) for Windows, Version 20 (IBM Corporation, Armonk, New York) and all statistical analyses were carried out using SPSS. Further details of the relevant statistical analyses performed will be provided in each individual chapter.

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Chapter 3

Dietary Mis-reporting

3.0 Introduction

This chapter was based on the publication **(Appendix 6)**:

Mullaney L, O'Higgins AC, Cawley S, Doolan A, McCartney D, Turner MJ (2015) An estimation of periconceptional under-reporting of dietary energy intake. *J Public Health (Oxf)* **37**, 728-736.

The Ph.D. candidate's contribution was data collection, data preparation, statistical analysis, and preparation and finalisation of the manuscript.

3.0.1 Determination of mis-reporting

Dietary mis-reporting is an accepted shortcoming in nutritional surveys (Livingstone & Black, 2003; McCartney, 2008). The use of external reference measures, such as whole body calorimetry, and biomarkers, such as urinary nitrogen excretion and Doubly Labelled Water (DLW), have confirmed that mis-reporting is common in self-reported dietary assessments, with a strong tendency towards under-reporting (Schoeller, 1990; Black *et al.,* 1993). It has consequently been recommended that all dietary intake studies include an external independent measure of validity (Black *et al.,* 1993). The DLW method, for example, can measure energy expenditure with good accuracy (International Dietary Energy Consultant Group, 1990). However, it is costly and unsuitable for large samples (Black *et al.,* 1991).

As a pragmatic response to these challenges, Goldberg and colleagues developed a method based on the ratio of reported EI to Basal Metabolic Rate (BMR) (EI/BMR) (Goldberg *et al.*, 1991). This method was based on calorimetry and DLW studies, where a direct relationship between BMR and body weight was found. As Total Energy Expenditure (TEE) comprises of BMR and energy expended in physical activity in weight stable populations, the following equation was derived:

$$EI = BMR \times PAL = TEE$$

This has been further manipulated to express PAL as a function or multiple of BMR as follows:

$$EI/BMR = PAL$$

These formulae were revised by Black (2000a) based on the further collection of data from metabolic studies over the intervening period. The application of these formulae elicits a series of thresholds or "cut offs" for PAL (EI/BMR), below which it is assumed that metabolic stability (assumed weight homeostasis) is implausible based on the findings of previous metabolic studies. The equation for the derivation of mis-reporting thresholds is shown below:

$$EI\backslash BMR < PAL \times \exp\left[SD_{Min} \times ((S/100)/\downarrow n)\right]$$

Where, PAL = the estimated group physical activity level of the population.

SD_{Min} = -2 for the lower 95% confidence interval.

n = the sample size of the population.

The expression S in the formula above is derived as follows:

$$S = \downarrow[(CV^2_{wEI}/d) + CV^2_{WB} + CV^2_{tP}]$$

Here, CV_{wEI} = the mean within individual coefficient of variation energy intake.

CV_{WB} = the mean coefficient of variation for BMR estimated from Schofield (1985).

CV_{tP} = the mean coefficient of variation for PAL.

d = the number of days of dietary assessment.

The use of the appropriate PAL to estimate the group PAL of the population under examination is critical to the derivation of suitable cut-off thresholds. Goldberg *et al.,* (1991) estimated the average PAL to be 1.35 using whole body calorimetry data from a number of studies, with an average lower 95% confidence threshold of 1.16. This low threshold was attributed to subject error (moving during BMR estimation), and particularly to the very sedentary nature of the calorimetry protocol which can inappropriately suppress typical PAL. The DLW studies reported in the same paper (Goldberg *et al.*, 1991), estimated free living energy expenditure over 10-15 days, a more robust measure of habitual energy expenditure. In the studies examined, PAL from this method averaged 1.67 for the full population (1.62 in women), with an average minus lower 95% confidence threshold of 1.28, which is largely in agreement with the 1.27 estimated by the FAO/WHO/UNU (1985). This group therefore concluded that it was reasonable to assume a minimum PAL of 1.35 for all "normal" circumstances. From this assumption, Goldberg's ratio of EI/BMR $\leq$ 1.2 may indicate under-reporting and a ratio of < 0.9 is a sign of definite under-reporting at a group level (Goldberg *et al.,* 1991).

The use of the appropriate PAL to estimate the group PAL for the derivation of suitable cut off thresholds is fraught with difficulty, as estimates of habitual PALs among free living populations vary widely. It has been suggested that to optimise both the sensitivity (the ability to accurately identify "mis-reporters") and the specificity (the ability to accurately identify "non mis-reporters"), that some measure of physical activity must be collected, which permits stratification of subjects into various activity levels. Individual PAL values may then be applied in the derivation of separate cut offs for each of these activity groups (Black, 2000b).

3.0.2 Factors influencing under-reporting

Under-reporting could result from either under recording or under eating by the individual during the assessment period, or a combination of both (Goris *et al.,* 2001). Under-reporting of EI could be explained by a lack of precision in the assessment instrument, or by the inability, difficulty or lack of motivation on the part of the study respondents to accurately report their dietary intakes (Johansson *et al*., 2001).

Under-reporting is a subject specific bias with a systemic and a random component (Kaaks *et al.,* 2002). Reporting of EI may be influenced by factors including those related to socio-demographic (age, sex) (Horner *et al.,* 2002; Bedard *et al*., 2004); physiological (weight, BMI, body fat) (Heitmann & Lissner 1995; Voss *et al.,* 1998; Samaras *et al.,* 1999; Johansson *et al.,* 2001; Bedard *et al.,* 2004; Scagliusi *et al.,* 2009); socioeconomic (education and income level) (Bedard *et al.,* 2004; Scagliusi *et al.,* 2009); and psychological (social desirability, body image, history of restrained eating, depression) (Lafay *et al.,* 1997; Kretsch *et al,* 1999; Horner *et al.,* 2002; Scagiusi *et al.,* 2009) status. Lifestyle behaviours such as smoking have also been linked to under-reporting (Johansson *et al.,* 1998). Some studies have also shown preferential mis-reporting patterns with respect to different foods in under-reporters (Briefel *et al.,* 1997; Voss *et al.,* 1998).

3.0.3 Under-reporting in pregnancy

The characteristics of dietary under-reporters have been well documented in the general population. There are fewer studies investigating the characteristics of under-reporters in the periconceptional period. Among 260 Irish multigravidas women assessed between 10 and 18

weeks gestation, 44.0% were found to possibly be under-reporting EI (Golberg's ratios of EI/BMR ≤ 1.2) and 10.9% (Goldberg ratio of EI/BMR < 0.9) were classified as definite under-reporters (Goldberg *et al.,* 1991; McGowan & McAuliffe, 2012). A BMI > 25 kg/m^2 was the main predictor of under-reporting in this study, while low educational attainment was also an important correlate. Under-reporters reported a lower percentage of energy from fat and a higher percentage of energy from protein than plausible reporters. A limitation in this study however, was that individual PALs were not collected. Thus Goldberg's ratios were used to determine under-reporting at a population level, instead of calculating subgroup thresholds for EI/BMR based on individual self-reported PALs.

Among 490 Indonesian women, 29.7% in the first trimester, 13.7% in the second trimester and 15.0% in the third trimester were classified as under-reporters using Goldberg's equations when all women were presumptively classified as sedentary (PAL=1.55) (Winkvist *et al.,* 2001). When these women were subsequently classified into two categories of PAL according to their occupation level, energy under-reporting remained the same in the first trimester (29.7%), but increased to 16.2% in the second trimester, and 17.6% in the third trimester. This sample is not representative of the developed world however, while the use of women's occupation as a proxy for PAL may also be subject to limitations. However, similar to findings from Western studies, the Indonesian women who under-reported had a higher BMI and lower educational attainment than plausible reporters.

In a further study, second trimester diet was assessed by FFQ in 998 American women (Nowicki *et al.,* 2011). Individual PALs were collected, however Goldberg thresholds were calculated as low as 0.76, 0.73, and 0.72 for low, normal, and high BMI women, respectively. As a result, under-reporting occurred in 29.5% of ideal weight women, 42.3% of overweight women

and 49.8% of obese women. In univariate analyses, under-reporting differed by education, pregravid BMI, Gestational Weight Gain (GWG), physical activity, and restrained eating behaviour. In multivariate analysis, under-reporting was higher in both overweight women [OR 1.96; P=0.03] and obese [OR 3.29; P<0.001] women compared with normal weight women, after adjusting for maternal baseline characteristics (e.g. GWG, marital status, physical activity).

Two smaller UK based studies also found evidence of maternal under-reporting in pregnant women. Among 72 primiparous, non-smoking women, 24% were classified as under-reporters using the Goldberg criteria of EI/BMR<1.2 (Goldberg *et al.,* 1991; Derbyshire *et al.,* 2006). Women with a high pre-pregnancy BMI were more likely to under-report EI. In 12 well-educated, affluent, healthy pregnant women, under-reporting of EI was assessed using DLW and food diaries throughout pregnancy. Under-reporting of EI occurred in 33% (n=4) of women (Goldberg *et al.,* 1993). However, these studies are limited by their small sample sizes and are not representative of the broader population.

3.1 Aim

Awareness of under-reporting is of key importance if we are to improve dietary assessment methods, enhance the integrity of food and nutrient intake data, and optimise the effectiveness of interventions based on these data. Our aim was to analyse the characteristics of women who mis-reported dietary EI in the periconceptional period according to the validated WFFQ (McGowan *et al.,* 2014).

3.2 Methods

Women were recruited at their convenience in the first trimester as outlined in Chapter 2. The main inclusion criteria were women booking for antenatal care after an ultrasound

examination confirmed a singleton ongoing pregnancy in the first trimester. The main exclusion criteria were multiple pregnancies or women less than 18 years of age so to reduce the number of potential confounding variables.

Height was measured to the nearest centimetre using a Seca wall-mounted digital metre stick with women standing in their bare feet. Weight and body composition were measured digitally to the nearest 0.1 kg (Tanita MC 180, Tokyo, Japan) and BMI calculated. Socioeconomic, health behavioural, and physical activity data were also collected at the same time using the online assessment tool. The clinical and health behavioural data gathered included any medical conditions or medications which applied to the individual, as well as their use of dietary supplements. Supplement data was not included in the final nutrient estimation, as these vitamin and mineral preparations do not affect EI and might artefactually influence the nutrient density of the diet.

To collect habitual food and nutrient intakes, women were asked to complete a self-administered, semi-quantitative WFFQ at their first antenatal visit. The WFFQ is explained in further detail in Chapter 2. Women were given the WFFQ at the start of their antenatal visit and asked to complete the questionnaire unsupervised. Women completed the online assessment tool as outlined in Chapter 2.

3.2.1 Assessment of energy under- and over- reporting

BMR was calculated using standard equations based on gender, weight, and age (Henry, 2005). EIs were calculated using WFFQ data and WISP version 4.0 software (Tinuviel Software, Llanfechell, Anglesey, UK). Lowest plausible thresholds for PAL were calculated according to respondents' individual self-reported PAL (Black, 2000a). The calculations for the PAL

thresholds are shown in **Appendix 7.** 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 (Goldberg *et al.*, 1991). In all categories, those with an EI/BMR greater than 2.5 were classified as dietary over-reporters (Black *et al.*, 1996).

3.2.2 Statistical analysis

Data analysis was carried out using SPSS statistics version 20.0 (IBM Corporation, Armonk, New York). Respondent data for weight, height, age, gestational age, BMI, % FM, and % FFM were all normally distributed. Independent samples t-tests were used to compare the mean values for these variables between the plausible reporter and mis-reporter groups. As FM and FFM levels were non-normally distributed, differences in their median levels between the plausible reporter and mis-reporter groups were assessed using Mann Whitney U tests. Cross-tabulation with Chi-square analyses were used to test differences between the proportions of plausible reporters and mis-reporters in different socioeconomic and health behavioural groups e.g. ethnicity, smoking status; reporting the Yates continuity correction for all dichotomous 2 x 2 tests.

Dietary nutrient intake data was non-normally distributed, thus Mann Whitney U tests were used to test differences in median absolute dietary nutrient intakes between plausible reporters and mis-reporters. Dietary nutrient intakes per Mega Joule (MJ) of EI were calculated, and again were non-normally distributed. Mann Whitney U tests were used to test differences in median energy adjusted macro- and micro- nutrient intakes between these two groups.

3.3 Results

Of the 588 women studied, 524 women were included in the final analyses, for the following reasons: Fifty two women (8.8%) 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. Primiparous women were more likely to have completed both questionnaires than multiparous women however (45.2% vs. 27.3%, *P*=0.002). For the total included population (*n*=524), the mean age was 30.1 ± 5.3 years (94.7% between 20-39 years), the mean gestational age was 12.6 ± 2.6 weeks, the mean BMI was 25.4 ± 5.6 kg/m^2, with 16.6% obese; and the mean PAL was 1.75 ± 0.2 METs. Forty-five percent of the sample was primigravidas. This sample is representative of the obstetric population in Ireland. Of women booking into the Coombe in 2014, 39.1% of women primiparous, 15.3% were obese, and 91.8% were between 20 and 39 years of age (ESRI, 2013; CWIUH, 2014).

The mean ratio of EI/BMR was 2.1 ± 0.9 in the underweight BMI category, 1.7 ± 0.7 in the ideal weight BMI category, 1.6 ± 0.7 in the overweight BMI category and 1.3 ± 0.9 in the obese BMI category (*P*<0.001). Under-reported EIs were observed in 122 women (23.3%). There were no over-reporters in the sample. Differences in anthropometric and SES between the under-reporters and plausible reporters are outlined in Table 3.1. Under-reporters were less likely to have a normal BMI (*P*=0.002), more likely to be younger (*P*<0.001), and more likely to be obese (*P*<0.001) than plausible reporters. Under-reporters also had higher % FM and lower % FFM than plausible reporters (both *P*<0.001). Under-reporters were more likely to be at risk of relative deprivation (*P*=0.001), however, consistent poverty levels did not differ between the plausible and under-reporter groups.

Table 3.1: Characteristics of Study Subjects

	Plausible Reporters (*n*=402)	**Under-reporters (*n*=122)**	***P***
Weight (kg)[1]	67.1 ± 12.5	76.9 ± 18.3	<0.001
Height (m)[1]	1.65 ± 7.3	1.66 ± 6.2	*NS*
Age (years)[1]	30.8 ± 5.2	28.0 ± 4.8	<0.001
Gestational Age at first visit (weeks)[1]	12.7 ± 10.4	12.3 ± 2.3	*NS*
BMI (kg/m^2)[1]	24.6 ± 2.6	28.1 ± 6.9	<0.001
Underweight[2]	14 (3.5)	1 (0.8)	-
Ideal weight	225 (55.8)	45 (36.9)	0.002
Overweight	120 (29.8)	33 (27.0)	*NS*
Obese	44 (10.9)	43 (35.2)	<0.001
Fat Mass (kg)[3]	19 (10)	24 (15.6)	<0.001
Fat Mass (%)[1]	29.7 ± 6.6	33.2 ± 7.6	<0.001
Fat Free Mass (kg)[3]	46 (6.3)	49 (9.3)	<0.001
Fat Free Mass (%)[1]	70.2 ± 6.7	66.8 ± 7.6	<0.001
Parity[3]	1 (1)	0 (1)	-
Cultural Background[2]			
Irish	304 (75.6)	100 (82.0)	*NS*
Other European	69 (17.2)	17 (13.9)	*NS*
Asian	6 (1.5)	2 (1.6)	-
African	4 (1.0)	0 (0)	-
Other	19 (4.7)	3 (2.5)	-
Have you ceased full time education?[2]			
Yes	286 (71.1)	88 (72.1)	*NS*
No	116 (28.9)	34 (27.9)	
Smoking Status[2]			
Current Smoker	51 (12.7)	14 (11.5)	*NS*
Former Smoker	181 (45.0)	48 (39.3)	
Never Smoked	170 (42.3)	60 (49.2)	
Alcohol Consumption[2]			
Yes	230 (57.2)	66 (54.1)	*NS*

No	172 (42.8)	56 (45.9)	
Relative Income Poverty[2, a]			
At Risk	139 (34.6)	30 (24.6)	*NS*
Not at Risk	263 (65.4)	87 (71.3)	
Relative Deprivation[2, b]			
At Risk	31 (7.7)	23 (18.9)	0.001
Not at Risk	355 (88.3)	99 (81.1)	
Consistent Poverty[2, c]			
At Risk	31 (7.7)	9 (7.4)	*NS*
Not at Risk	356 (88.6)	108 (88.5)	

[1] Mean ± SD [2] Number (% of group) [3]median (IQR) [a] missing data *n*=5 [b]missing data *n*=16 [c] missing data *n*=15

Table 3.2: Comparison of absolute macro- and micro- nutrient intakes between plausible reporters and under-reporters

	Plausible Reporters[1] (*n*=402)	**Under-reporters[1] (*n*=122)**	***P***
Protein (g)	94.0 (51)	56.0 (19)	<0.001
Carbohydrate (g)	259 (129)	155 (61)	<0.001
Fat (g)	84.5 (41)	47.0 (21)	<0.001
Saturates (g)	29.0 (15)	16.5 (8)	<0.001
Monounsaturated fat (g)	27.0 (14)	15.0 (8)	<0.001
Polyunsaturated fat (g)	19.0 (10)	10.0 (5)	<0.001
Fibre (g) (AOAC)	30.0 (15)	18.0 (9)	0.001
Non-Milk Extrinsic Sugar (g)	35.0 (32)	20.0 (18)	<0.001
Alcohol (g)	1.00 (5)	0.00 (1)	<0.001
Sodium (mg)	2837 (1465)	1655 (982)	<0.001
Potassium (mg)	4292 (6736)	2427 (1108)	<0.001
Calcium (mg)	794 (534)	425 (230)	<0.001
Magnesium (mg)	387 (588)	207 (101)	<0.001
Phosphorus (mg)	1553 (952)	889 (346)	<0.001
Iron (mg)	17.0 (12)	9.00 (5)	<0.001
Copper (mg)	2.00 (1)	1.00 (0)	<0.001
Zinc (mg)	11.0 (5)	6.00 (2)	<0.001
Chloride (mg)	4131 (2028)	2412 (1434)	<0.001
Iodine (mg)	91.0 (48)	53.0 (28)	*NS*
Retinol (µg)	297 (244)	160 (108)	0.002
Carotene (µg)	6437 (4976)	4016 (4040)	*NS*
Vitamin D (µg)	3.00 (2)	1.00 (1)	<0.001

Vitamin E (mg)	11.0 (6)	7.00 (3)	<0.001
Vitamin C (mg)	220 (149)	132 (109)	<0.001
Thiamine (mg)	2.00 (1)	1.00 (1)	<0.001
Riboflavin (mg)	2.00 (1)	1.0 0(0)	<0.001
Niacin (mg)	26.0 (11)	16.0 (7)	<0.001
Vitamin B_6 (mg)	3.00 (1)	2.00 (1)	<0.001
Vitamin B_{12} (mg)	4.00 (3)	2.00 (1)	0.001
Folate (µg)	337 (170)	213 (95)	0.006

[1]median (IQR); AOAC: Association of Organic and Analytic Chemists method used by WISP version 4 to measure fibre content of food

Under-reporters reported lower absolute intakes of most macro- and micro- nutrients as shown in Table 3.2, with a small number of notable exceptions such as carotene and folate. Under-reporters reported a higher percentage of energy from carbohydrate (P=0.02) and higher intakes of riboflavin (P<0.001), thiamine (P=0.03), niacin (P=0.001), vitamin B_6 (P=0.002), folate (P=0.006) and dietary fibre (P<0.004) per MJ of energy consumed according to intake data derived from their WFFQs. Under-reporters reported lower intakes of calcium (P=0.01), magnesium (P=0.03) and retinol (P=0.002) per MJ of energy consumed as per their WFFQs (Table 3.3 & 3.4).

Table 3.3: Comparison of dietary fibre and percentage energy intakes from macro-nutrients between plausible reporters and under-reporters

	Plausible Reporters[1] (*n*=402)	**Under-Reporters[1] (*n*=122)**	***P***
Protein (%/MJ/day)	17.3 (5)	17.3 (4)	*NS*
Carbohydrate (%/MJ/day)	48.1 (10)	49.9 (11)	0.02
Fat (%/MJ/day)	36.2 (7)	35.2 (10)	*NS*
Saturated Fat (%/MJ/day)	12.0 (3)	11.7 (4)	*NS*
Monounsaturated fat (%/MJ/day)	11.6 (3)	11.1 (4)	*NS*
Polyunsaturated fat (%/MJ/day)	7.70 (3)	7.40 (3)	*NS*
Dietary fibre (g/MJ/day) (AOAC)	3.20 (1)	3.70 (1)	0.004
Non-Milk Extrinsic Sugar (%/MJ/day)	6.70 (5)	6.60 (5)	*NS*

[1]median (IQR); AOAC: Association of Organic and Analytic Chemists method used by WISP version 4 to measure fibre content of food

Table 3.4: Comparison of energy adjusted micro-nutrient intakes between plausible reporters and under-reporters

	Plausible Reporters[1] (*n*=402)	**Under-Reporters[1] (*n*=122)**	***P***
Sodium (mg/MJ/day)	308 (84)	313 (114)	*NS*
Potassium (mg/MJ/day)	653 (508)	451 (165)	*NS*
Calcium (mg/MJ/day)	86.2 (34)	78.1 (31)	0.01
Magnesium (mg/MJ/day)	41.6 (44)	37.9 (16)	0.03
Phosphorus (mg/MJ/day)	166 (49)	164 (31)	*NS*
Iron (mg/MJ/day)	1.70 (0.9)	1.70 (0.7)	*NS*
Copper (mg/MJ/day)	0.20 (0.1)	0.20 (0.1)	*NS*
Zinc (mg/MJ/day)	1.20 (0.3)	1.20 (0.3)	*NS*
Chloride (mg/MJ/day)	453 (124)	454 (162)	*NS*
Iodine (mg/MJ/day)	9.70 (4)	9.90 (4)	*NS*
Retinol (µg/MJ/d)	33.1 (22)	29.6 (18)	0.002
Carotene (µg/MJ/d)	709 (591)	752 (789)	*NS*
Vitamin D (µg/MJ/d)	0.30 (0.2)	0.30 (0.2)	*NS*
Vitamin E (mg/MJ/day)	1.30 (0.4)	1.20 (0.4)	*NS*
Vitamin C (mg/MJ/day)	22.8 (17)	25.2 (23)	*NS*
Thiamine (mg/MJ/day)	0.22 (0.1)	0.23 (0.1)	0.03
Riboflavin (mg/MJ/day)	0.17(0.1)	0.19 (0.1)	<0.001
Niacin (mg/MJ/day)	2.90 (0.9)	3.10 (1)	0.001
Vitamin B_6 (mg/MJ/day)	0.30 (0.1)	0.33 (0.1)	0.002
Vitamin B_{12} (mg/MJ/day)	0.50 (0.2)	0.50 (0.3)	*NS*
Folate (µg/MJ/d)	37.1 (14)	42.0 (15)	0.006

[1]median (IQR)

3.4 Discussion

3.4.1 Main finding of this study

This cross-sectional study, using the WFFQ to assess periconceptional diet, found that under-reporting was more likely to occur in obese women. Under-reporting was also positively associated with increasing FM and increasing % FM. The under-reporters were younger than the

plausible reporters (P<0.001), and had a higher prevalence of relative deprivation (P=0.001). Therefore, excluding under-reporters introduces a potential bias in assessing the links between food and nutrient intake and obesity among pregnant women as there is a disproportionate removal of younger, obese, low SES women from the analysed sample, potentially compromising its representativeness.

When macro-nutrients were expressed as percentages of total energy, under-reporters reported a higher percentage of energy from carbohydrate than plausible reporters (P=0.02), as well as showing higher energy adjusted intakes of nutrients such as folate and B vitamins usually associated with low energy, nutrient dense-foods such as fruit and vegetables and breakfast cereals. Collectively, these findings may reflect selective biases in their under-reporting behaviour.

Our study has a large sample size. Another strength of our study is that individually reported PALs were used to assess lowest plausible thresholds for PAL (Black, 2000a). This allowed for the identification of women who were deemed likely to be mis-reporters at an individual level i.e. if EI/BMR was less than the individual's lowest plausible threshold for PAL they were considered under-reporters. Many studies use a single PAL value to estimate the group's PAL which may be considered inaccurate as estimated habitual PALs among free living individuals vary greatly (Black *et al*., 1996). It has been suggested that to optimise the accuracy of data collected, a measure of physical activity should be collected, which allows individuals to be categorised into different activity levels for the purpose of stratified EI/BMR threshold calculation (Black, 2000b). Our study used bioelectric impedance to measure maternal weight and body composition. The accurate measurement of bodyweight is critical as women, in particular obese women, have been shown to underestimate their weight (Fattah *et al*., 2009).

3.4.2 Limitations of this study

A limitation of this study is that only one dietary assessment method was used to assess energy and nutrient intakes, and that this was a self-reported questionnaire. Studies have shown that the accuracy of the FFQ can be lower than other methods, with the FFQ containing a substantial amount of measurement error because it makes several assumptions about food portion size and may result in an underestimation of dietary intake where the list of food items used is not reflective of the dietary habits of the target population (Scagliusi *et al.,* 2009; Prentice *et al.,* 2011). Nonetheless, the FFQ can be reliably used to rank individuals according to their relative food or nutrient intakes, and thus, represents an appropriate tool to analyse the characteristics of mis-reporters. In addition the WFFQ we used was validated in a population of young Dublin women in 2013 (McGowan *et al.,* 2014).

Our study did not record nausea in the first trimester. Dietary intake should increase during pregnancy (Kaiser & Allen, 2002). However, common fluctuations in appetite, nausea and vomiting, may affect this anticipated increase (Robinson *et al.,* 1996). Thus, a specific period of pregnancy may not be representative of the whole gestation. It has been shown that a single FFQ administration around the time of delivery was able to capture dietary intake throughout the whole pregnancy among Portuguese pregnant women (Pinto *et al.,* 2010). These researchers found that the performance of their FFQ was not modified by the presence of nausea and/or vomiting, daily number of meals or weekly weight gain. Similarly, a recent Irish study administered the same FFQ used in our study to a cohort of Irish multigravidas on one occasion

between 12 and 34 weeks gestation, concluding that the resulting intake data was representative of dietary intake throughout the whole pregnancy (Walsh *et al*., 2012; McGowan *et al.,* 2014). The WFFQ used in this study is representative of the periconceptional period. Further studies are needed to assess the extent and characteristics of women who under-report EI throughout their whole gestation.

3.4.3 What is already known on this topic?

3.4.3.1 Under-reporting and the general population

Studies using DLW and urinary nitrogen have confirmed a higher prevalence of under-reporting among obese subjects, as well as differential under-reporting patterns with respect to different foods (Heitmann & Lissner, 1995; Prentice *et al*., 1996; Voss *et al.,* 1998). Other researchers have also reported that non-pregnant subjects who have higher BMI are more likely to under-report (Poslusna *et al.,* 2009), corroborating the findings of our own study where under-reporters were more likely to be overweight or obese.

The EPIC-Potsdam study found that EI/BMR ratios decreased with increasing BMI ($P<0.001$) (Voss *et al.,* 1998). In our study, the mean EI/BMR also decreased as BMI increased ($P<0.001$). EI was measured in the EPIC-Potsdam study using a semi-quantitative FFQ and BMR was calculated using standard equations including weight and age (Schofield, 1985). The EPIC-Potsdam study found that a higher percentage of under-reporters reported consuming a high proportion of energy from protein and carbohydrate, and a lower proportion of energy from fat (Voss *et al*., 1998). Similarly, our study also found that under-reporters reported a higher proportion of energy from carbohydrate.

Lower income levels have also been associated with more frequent under-reporting (Scagliusi *et al.,* 2009). As income decreases, an increase in energy dense, nutrient dilute foods can occur, possibly as a means to maintain EI at a lower cost. If income decreases further, households may decrease EI below daily requirements, resulting in overt deprivation (Drewnowski & Specter, 2004). The current study found that women who under-reported EI were more likely to be at risk of relative deprivation.

3.4.3.2 Under-reporting and the general female population

In a Canadian study, 43% of participants were classified as under-reporters when evaluated by the Goldberg technique. Female under-reporters were older (P=0.01), heavier (P=0.04), had a higher BMI (P=0.02) and were more likely to report intakes of foods containing a higher percentage of carbohydrate (P=0.02) or a lower percentage of fat (P=0.002), than plausible reporters (Bedard *et al.,* 2003). Other studies have also observed that older women were more likely to under-report EI than younger women (Shaneshin *et al.,* 2012), although one study in postmenopausal women identified no effect of age within that group on energy reporting levels (Mahabir *et al.,* 2006). Another study found that younger, postmenopausal women under-reported EI more frequently than older women (Horner *et al.,* 2002). Our study, like others in the obstetric setting, captures a relatively young cohort of women (18-43 years). However, even within this age group, under-reporters were more likely to be at the younger end of the age spectrum (P<0.001). There are few studies investigating the effect of age on energy under-reporting in the periconceptional period, and the interpretation of such data is further complicated by the socioeconomic gradient in primiparous age (McAvoy *et al.,* 2006; ESRI, 2013).

In 436 Australian middle aged women, the relationship between body fat using DEXA and the dietary characteristics of energy under-reporters was investigated (Samaras *et al.,* 1999). Women categorised as under-reporters had increased weight ($P<0.01$), BMI ($P<0.01$), FM ($P<0.05$) and FFM ($P<0.05$) than plausible reporters. However, % FM did not differ between the two groups. While higher % FM was seen in women with a lower EI/BMR ratio in the EPIC-Potsdam study ($P<0.001$), the calculation of % FM in this study was based on derivation using skin-fold measurements (Durnin & Womersley, 1974; Voss *et al*., 1998). In our study, under-reporters had a higher BMI, higher FM and higher % FM, as well as a lower FFM than plausible reporters, suggesting that both increased BMI and increased adiposity are associated with under-reporting.

3.4.3.3 Under-reporting and pregnant women

While the characteristics of under-reporters have been well documented in general populations, there are fewer studies investigating the characteristics of under-reporters in the periconceptional period. However, periconceptional nutrition is known to be crucial for an optimal onset and development of pregnancy (Cetin *et al.,* 2010). In 260 Irish multigravidas women, between 10 and 18 weeks gestation, a high proportion (44%) were classified as under-reporters (McGowan & McAuliffe, 2012; Walsh *et al.,* 2012). In 490 Indonesian women, the mean EI/BMR was 1.33, classifying 29.7% as under-reporters in the first trimester of pregnancy (Winkvist *et al.,* 2001). The authors believed that this percentage represented a group with inadequate dietary intake as opposed to under-reporting however, as many women reported nausea during the first trimester.

3.4.4 What this study adds

The observed dietary under-reporting bias in this study, as well as the biases introduced by the exclusion of dietary mis-reporters or the adjustment of their reported dietary intakes based exclusively on quantitative energy correction equations may generate misleading associations between dietary and nutrient intakes and obstetric outcome. The increased incidence of under-reporting in overweight and obese women in particular, may result in erroneous conclusions regarding the nutritional intake, status and risk profile of these women. The assessment of body composition allowed us investigate the association between body fat levels in early pregnancy and the likelihood of under-reporting, which as far as we are aware has not been investigated in any previous studies in pregnancy.

Women experiencing relative deprivation may be at particular risk of nutritional deficiencies. Maternal diet and nutritional status can be modified before conception, and given the importance of maternal diet in fetal programming and lifelong health, the associations between nutritional intake and status and gestational outcome need to be clearly and accurately articulated. On the basis of these findings, all women who are planning pregnancy or who may be at risk of nutritional deficiencies or excesses during pregnancy, need to be accurately identified so that effective interventions can be implemented. Development of specialised dietary assessment techniques for overweight and obese women in pregnancy may also be needed to ensure the collection of more robust nutritional intake data from these women.

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Chapter 4

Dietary Assessment Methods

4.0 Introduction

This chapter was based on the publication **(Appendix 6)**:

Mullaney L, O'Higgins AC, Cawley S, Kennedy R, McCartney D, Turner MJ (2016) Use of a Web-Based Dietary Assessment Tool in Early Pregnancy. *Ir J Med Sci* DOI: 10.1007/s11845-016-1430-x [Epub ahead of print].

The Ph.D. candidate's contribution was data collection, data preparation, statistical analysis, and preparation and finalisation of the manuscript.

4.0.1 Dietary assessment

Dietary assessment is a problematic area with accurate data often 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 addition, the assessment of food and nutrient intake in pregnant women is further complicated as gestation causes complex and sequential physiological changes. These changes alter maternal nutrient absorption and metabolism, energy and nutrient needs, appetite, and meal pattern (Picciano, 2003). The difficulties associated with accurate quantitative dietary assessment in pregnancy are important, as reliance on weak food and nutrient intake data may give rise to aberrant conclusions regarding the effects of maternal diet on the course and outcome of pregnancy.

Several methods for dietary assessment are currently used in clinical and research practice, with new technologies also beginning to emerge in this area. The appropriate tool for dietary assessment will depend on the purpose for which it is being used e.g. to measure nutrients, foods or eating habits; and the context in which it is deployed e.g. the research or clinical setting. Given the importance of maternal diet in fetal health (Zeisel, 2009) and in later infant and adult heath (Silveira *et al.,* 2007; Koletzko *et al.,* 2012), accurate dietary assessment and interpretation is crucial to enable the derivation of efficacious, evidence based nutritional interventions in this population.

4.0.2 Reductionist approach

Nutrition research has historically often favoured a reductionist approach which investigates the role of single nutrients in determining health outcomes (Messina *et al.,* 2001). This approach relies on the derivation of nutrient intake data from raw dietary intake data (collected by FFQ or other methods) using a nutrient analysis software package. This approach is subject to error at the respondent interface (e.g. recall bias), and at each stage of the data processing continuum (e.g. portion size estimation, dietary data recording, food composition analysis). Collectively, these challenges often mean that while precise nutrient intake data are generated, the accuracy of these data in representing the true or actual nutrient intake of study subjects often remains elusive.

4.0.3 Dietary patterns

In recent years, investigating "whole diet" patterns has emerged as a more holistic and potentially more useful methodology in terms of food based interventions than that previously described, as it is less subject to the iterative biases inherent in the more traditional approach.

Dietary patterns encompass a broad and integrative representation of food and nutrient intakes and therefore may be more predictive of diet related health risk than single nutrient intakes.

Two main methods are used to categorise dietary patterns: 'a priori', which calculates dietary scores based on existing hypotheses about the role of dietary factors in disease prevention, and 'a posteriori', which involves principal components or cluster analysis using available dietary data, often alongside health outcome data (Kant, 1996; Kant, 2004; Moeller *et al.*, 2007; Waijers *et al.*, 2007; Arvaniti & Panagiotakos, 2008). A limitation of investigating dietary patterns is that the health effects of individual nutrients, for example, different types of fat, folate, calcium, etc., can't be determined, as the quantitative estimation of such nutrient intakes can only be achieved by putting detailed raw dietary intake data through a nutrient analysis software package.

4.0.3.1 'A priori' approaches

Dietary quality scores or indexes have been used in many adult population studies to predict disease risk (Waijers *et al.*, 2007). These translate dietary intake data into a score to represent overall dietary quality. The premise for the use of diet quality scores/indexes in assessing health risk is that if the minimum number of recommended food servings from dietary guidelines is met, the majority of people will take in all of their required nutrients, thus maintaining health and preventing diet related chronic disease.

However, the health endpoints for pregnant women (e.g. the optimisation of specific micro-nutrient levels, the prevention of excessive GWG and GDM, the prevention of NTDs etc.) are different to those of the general adult female population. As nutrient requirements are

different in pregnant women than in non-pregnant women, it is unknown whether dietary indexes applied to the general adult population are directly applicable during pregnancy.

Pick *et al.*, (2005) investigated the validity of the Healthy Eating Index (HEI) in pregnancy in terms of meeting the explicit nutrient intake requirements of pregnancy. They found that the HEI scores for pregnant and non-pregnant women were not statistically different. However, when specific nutrients of concern in pregnancy were examined, folate and iron intakes were below the recommended intakes for pregnancy. The nutrient analyses in this 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. Pick *et al.*, (2005) concluded that a new HEI designed to target food choices and micro-nutrient intakes associated with enhanced maternal and fetal pregnancy outcomes would better reflect the dietary quality priorities of pregnant women.

Bodnar & Siega-Riz (2002) developed a Diet Quality Index for Pregnancy (DQI-P). Dietary intake was assessed using a FFQ between 26 to 28 weeks of gestation. The DQI-P score was then calculated from eight components derived from this FFQ data 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. In this sample of 2063 pregnant women from North Carolina, the DQI-P detected differences in dietary quality according to maternal socio-demographic factors. Women with a low poverty index, and those who were well-educated, nulliparous and older had higher DQI-P scores, reflecting a superior diet quality.

Watts *et al.,* (2007) used this DQI-P to compare diet quality in pregnant Native Americans and Caucasian Americans. The dietary differences between the two groups were minimal; however most of the women had suboptimal dietary quality and were categorised into the 'needs improvement' grouping as per their DQI-P scores. One limitation of the DQI-P is that the total fat component of the score may not adequately reflect the quality of the pregnant women's diet as it does not differentiate among types of fat. Rifas-Shiman *et al.,* (2009) generated an Alternate Healthy Eating Index (AHEI) for pregnancy (AHEI-P) model which does make reference to the different fat components e.g. trans-fats, and the ratio of polyunsaturated to saturated fats. Similar to the findings of Bodnar & Siega-Riz (2002), women who were younger, less educated, had more children, and who had higher pre-pregnancy BMI had poorer quality diets in pregnancy using this AHEI-P. However, as the DQI-P and AHEI-P relies partly on estimated nutrient intakes, they require the derivation of these nutrient intake data from dietary data using nutrient analysis software.

4.0.3.2 'A posteriori' approaches

Another method to investigate dietary patterns is Principal Component Analysis (PCA). PCA is a method of re-organising information in a data set of samples with a defined outcome variable. PCA formulates new independent variables from the original data set which account for the majority of variability in the outcome under investigation, and thus identifies predictive patterns in the data (Kant, 2004; Moeller *et al.,* 2007).

Using PCA, Northstone *et al.,* (2008) found 5 distinct dietary patterns amongst 12,053 pregnant women participating in a population based cohort study in the UK. The 'health conscious' pattern described a diet based on salad, fruit, rice, pasta, breakfast cereals, fish, eggs,

pulses, fruit juices, white meat and non-white bread. The 'traditional' pattern was characterised by large intakes of all types of vegetables, red meat and poultry. The 'processed' pattern was associated with a high consumption of high fat processed foods. The 'confectionery' pattern was characterised by an elevated intake of high sugar snack foods, while the 'vegetarian' pattern contained large amounts of meat substitutes, pulses, nuts and herbal tea and low amounts of red meat and poultry. Northstone *et al.,* (2008) found that the 'health conscious' pattern was positively associated with increasing formal education and age, lower parity, paid work in the third trimester, Caucasian ethnicity and the absence of tobacco use. There was also a negative association between the "health conscious" pattern and self-reported overweight pre-pregnancy (assessed by recall). Decreasing education and age were positively associated with the 'processed' dietary pattern, as were increasing levels of financial difficulty, parity and residence in local authority housing. Similar results were found by Volgyi *et al.,* (2013) in that healthy eating patterns were reflective of older and more educated individuals in their sample of 1,155 pregnant women from mid-south America.

Zhang *et al.,* (2006) identified two pre-pregnancy dietary patterns; the 'prudent diet' and the 'western diet' among 13,110 women. The western diet, and in particular the higher intakes of red meat and processed meat associated with this dietary pattern, were strongly associated with the development of GDM. This group concluded that several biological possibilities could account for this increased risk of GDM in those following a western dietary pattern e.g. the adverse effects of dietary saturated fat and cholesterol on insulin sensitivity, or possibly the increased consumption of nitrates, which have been used as a preservative in processed meats, causing beta cell toxicity. Similarly adherence to 'healthy' dietary patterns, for e.g. positive factor loadings for fruit, vegetables, fish etc. and negative factor loadings for French fries, soft

drinks, has been associated with decreased GDM (Karamanos et al., 2014; He *et al.,* 2015; Tryggvadottir *et al.,* 2016).

4.0.4 Computer based dietary assessment

Computing devices provide a potentially powerful means of collecting dietary information which reduces the burden on record keepers and study participants. Computer based dietary assessment is quick, easy, and cheap to administer. The major cost is incurred in the development of the system, but once the system is established, the additional cost of adding extra participants to the study is relatively small as there is no expense for printing, posting, manual check of incomplete answers, and transfer of data into an electronic format. Illustrations or sounds can also be included to clarify answers (e.g. portion size estimation), while computer based dietary assessment also has the ability to gather data from geographically and socially dispersed populations, potentially capturing groups which are traditionally difficult to sample.

The disadvantages of such tools can include the use of one computer address by more than one respondent. This could lead to the wrong individual being targeted or responding to the questions in the assessment. Additionally, socio-demographic variations in Information Technology (IT) literacy and the requirement for participants to have access to the internet can introduce systematic biases with regard to age, sex, SES and education (Atkinson & Gold, 2002).

A number of web based dietary assessment questionnaires have been evaluated and found to be feasible and acceptable to respondents (Boeckner *et al.,* 2002; Balter *et al.,* 2005; Vereecken *et al.,* 2005; Touvier *et al.,* 2010; Gonzalez Carrascosa *et al.,* 2011). There is a lack of studies investigating the use of computer based dietary assessment in pregnant women however. Fowles & Gentry (2008) assessed the feasibility of using a Personal Digital Assistant (PDA) to

collect dietary information in low SES pregnant women. They 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. However the small sample size of this study is a major limitation.

A recent meta-analysis investigated the use of technology supported lifestyle interventions for healthy pregnant women and their impact on maternal outcomes (O'Brien *et al.*, 2014). Seven articles (including five Randomised Control Trials (RCTs)) met the inclusion criteria. Lifestyle interventions in pregnancy included either telephone supported, video supported, internet supported or app supported interventions. Findings from this meta-analysis suggest that technology supported lifestyle interventions in pregnancy hold potential as a safe and sustainable adjunct to traditional health care models. However the quality and quantity of the evidence is limited, particularly data examining more modern technologies such as smart phone apps. There may also be an issue of uptake levels and sociocultural acceptance of such lifestyle interventions.

4.1 Aims

As technology increasingly dictates the way in which we collect and communicate information, future research into computer based dietary assessment methodologies in pregnancy is needed to evaluate the accuracy and effectiveness of these new technologies. Our aim was to compare dietary quality scores from a newly developed online DAT against nutrient intakes derived from the WFFQ previously validated amongst multigravidas pregnant women presenting for antenatal care in Dublin (McGowan *et al.*, 2014).

4.2 Methods

Women were recruited at their convenience in the first trimester of pregnancy as outlined in Chapter 2 and Chapter 3.

To collect habitual food and nutrient intakes, women were asked to complete the previously validated semi-quantitative WFFQ (Harrington, 1997; Kaaks *et al.*, 1997; Morgan *et al.*, 2008; McGowan *et al.*, 2014), and then the online DAT questionnaire (outlined in Chapter 2). Both questionnaires were completed within their first antenatal visit (~ two hours), with the WFFQ given to participants ~ one hour 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 0.1kg (Tanita MC 180, Tokyo, Japan) and BMI calculated (kg/m^2).

4.2.1 Inclusion and exclusion criteria

Women who booked for antenatal care and who had an ultrasound examination confirming a singleton ongoing pregnancy in the first trimester met the inclusion criteria. Exclusion criteria included the presence of multiple pregnancies or women less than 18 years of age so as to reduce the number of potential confounding variables. Respondents who had under- or over- reported their energy intakes using the WFFQ were also excluded. The methodology to determine EI under-reporters and the results of these analyses are outlined in Chapter 3. These respondents were excluded from the final nutrient intake analyses to enhance the integrity of our nutrient intake data (Livingstone & Black, 2003).

4.2.2 Statistical analysis

Data analyses were carried out using SPSS statistics version 20.0 (IBM Corporation, Armonk, New York). Plausible reporters based on EIs derived from the WFFQ dietary data, were dichotomized at an individual level (approach one) into those meeting and not meeting recommended intake guidelines for dietary fibre, macro- and micro- nutrients, and alcohol (DOH, 1991; FSAI, 1999; Strategic Taskforce on Alcohol, 2004; FSAI, 2005; FSAI, 2011). 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 (approach two) with dietary fibre, alcohol, carbohydrate and fat intake recommendations were also calculated and dichotomised into compliers and non-compliers (Wearne & Day, 1999; Harrington *et al.*, 2001). Approach two takes into account that dietary targets and recommendations are set as average intakes for the population and not as individual targets.

For nutrients where recommendation is less than (for example % fat < 35%) the nutrient is sorted in ascending order (low to high). Starting with the lowest intake, the mean is calculated until inclusion of the next individual will cause the mean of the group to be greater than the recommendation. For nutrients where the recommendation is greater than (for example % carbohydrate > 50%) the nutrient is sorted in descending order (high to low). Starting with the highest intake, the mean is calculated until inclusion of the next individual will cause the mean of the group to be less than the recommendation. The individuals in this group are categorized 'compliers'. Therefore 'non-compliers' are categorized into the other group.

Nutrient intakes per MJ of EI were calculated. As the nutrient intake data derived from the WFFQ were skewed, Spearman correlation analyses were used to test associations between the energy, dietary fibre, energy adjusted and energy unadjusted nutrient intakes derived from the WFFQ, and the diet and nutrition scores obtained from the DAT. Diet and nutrition scores were subsequently divided into quartiles (low (<51.4) to high (>66.6) scores). Kruskal Wallis tests were used to compare median WFFQ energy, dietary fibre, and energy adjusted and absolute nutrient intakes across the diet and nutrition score quartiles. Thus the Spearman correlation was used to determine the strength of the relationship between nutrient intakes and the DAT score, while Kruskal Wallis was used to assess differences in median nutrient intakes across different DAT scores.

4.3 Results

EI was under-reported 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 have been described in Table 3.1 Chapter 3.

Amongst the plausible reporters (*n*=402), the majority met their phosphate, niacin, copper and vitamin B_6 intake guidelines. However, a greater proportion of women did not met carbohydrate, fat, saturated fat, sodium, or vitamin D guidelines. Higher diet and nutrition scores were observed among those meeting the recommended intake guidelines for carbohydrate (*P*=0.02), dietary fibre (*P*<0.001), total fat (*P*<0.001), saturated fat (*P*=0.01), Non-Milk Extrinsic Sugars (NMES) (*P*<0.001), calcium (*P*=0.001), and iron (*P*=0.01) according to their WFFQ derived nutrient intake data (Table 4.1).

Table 4.1: Comparison of DAT scores between respondents meeting and not meeting nutrient intake recommendations (n=402)

Nutrients	Recommended daily intake	% meeting guideline[a]	% of compliers[b]	Median Diet & Nutrition score (IQR) for compliers	% not meeting guideline[a]	% of non-compliers[b]	Median Diet & Nutrition score (IQR) for non-compliers	P
Carbohydrate	>50% of energy[1]	35.3	89.3	60.4 (15)	64.7	10.7	57.4 (15)	0.02[c]
Dietary Fibre	>25g/d[1]	68.2	100	58.6 (15)	31.8	0.00	-	-
Non Milk Extrinsic Sugars	< 11% of energy[1]	88.5	100	58.6 (15)	11.5	0.00	-	-
Alcohol	0 units/week[2]	37.6	37.6	61.0 (14)	62.4	62.4	58.6 (15)	NS[c]
Total Fat	<35% of energy[3]	40.3	93.8	60.4 (14)	59.7	6.20	49.2 (16)	<0.001[c]
Saturated Fat	<10% of energy[3]	9.50	44.5	62.7 (14)	90.5	55.5	57.6 (16)	<0.001[c]
		% meeting guideline[a]		**Median Diet & Nutrition score (IQR)**	**% not meeting guideline[a]**		**Median Diet & Nutrition score (IQR)**	
Protein	54 g/d[4]	98.3		59.6 (15)	1.70		70.5 (28)	NS[d]
Sodium	<2400mg/d[5]	26.4		59.1 (16)	73.6		59.9 (16)	NS[d]
Calcium*	>615mg/d[4]	85.9		60.0 (15)	14.1		55.0 (14)	0.001[d]
Iron*	>10.8mg/d[4]	72.5		60.1 (15)	27.5		56.4 (16)	0.01[d]
Zinc*	>5.5 mg/d[4]	100		58.6 (15)	0.00		-	-
Vitamin B_{12}*	>1.0µg/day[4]	99.8		59.6 (15)	0.20		70.5 (-)	NS[d]
Vitamin D*	>10µg/day[4]	1.1		40.9 (34)	98.9		59.1 (15)	NS[d]
Vitamin C*	>46mg/day[4]	99.3		59.6 (15)	0.70		57.4 (-)	NS[d]

*Goals are for Estimated Average Requirements IQR: interquartile range, NS: Non-Significant, [1]DOH 1991, [2]DOH 2016, [3] Food Safety Authority of Ireland 2011, [4]Food Safety Authority of Ireland 1999, [5]Food Safety Authority of Ireland 2005. Approach one-individual level, [b]Approach two-population level. Mann Whitney U test used to test differences between median DAT scores of [c]compliers vs. non-compliers (approach two) and [d] % meeting guideline vs. % not meeting guideline (approach one).

Median fibre, folate, carotene, vitamin D, and vitamin C intakes derived from the WFFQ generally rose from the lowest to the highest quartile of diet and nutrition score (P<0.001) (Table 4.2). According to intake data derived from the WFFQ, dietary fibre per MJ and percentage of energy from protein rose (both P<0.001), while percentage of energy from NMES (P<0.001), total fat (P<0.001) and saturated fat (P=0.002) declined moving from the lowest to the highest dietary assessment score quartiles (Table 4.3).

A positive correlation was observed between respondents' diet and nutrition scores and their intakes of nutrients pertinent to fetal growth and development, for example, folate

(P<0.001), vitamin B_{12} (P=0.001), vitamin C (P<0.001), vitamin D (P<0.001), calcium (P=0.02) and magnesium (P=0.01) intakes all increased as diet and nutrition scores rose (Table 4.2). In addition, after micro-nutrient 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<0.001), zinc (P<0.001) and iodine (P<0.001) intakes per MJ of energy consumed (Table 4.3).

For macro-nutrients, negative correlation coefficients were observed between participants' diet and nutrition scores and their total energy intake (P=0.04) (Table 4.2), and their percentage energy from fat (P<0.001), saturated fat (P<0.001) and NMES (P<0.001) (Table 4.3).

Table 4.2: Comparison of median (IQR) FFQ nutrient intakes between diet and nutrition score quartiles; and correlation between diet and nutrition scores and FFQ nutrient intakes (*n*=402)

	Diet and Nutrition Score[1]					
	Low (*n*=100)	**Low-Medium (*n*=94)**	**Medium-High (*n*=103)**	**High (*n*=105)**	**Kruskal Wallis**	**Correlation Coefficient (*P*)**
Energy (kcal/d)	2388 (1094)	2236 (825)	2276 (985)	2293 (805)	*NS*	-0.1 (0.04)
Dietary Fibre (g/d)	26.0 (13.0)	27.0 (12.8)	31.5 (17.0)	34.0 (15.0)	<0.001	0.3 (<0.001)
Alcohol (units/week)	0.13 (0.6)	0.13 (0.6)	0.13 (0.4)	0.13 (0.3)	*NS*	-0.08 (*NS*)
Sodium (mg/d)	3058 (1604)	2831 (1342)	3051 (1150)	3053 (1497)	*NS*	-0.04 (*NS*)
Potassium (mg/d)	4354 (4879)	5680 (7382)	5076 (3984)	5141 (5569)	*NS*	0.1 (0.04)
Calcium (mg/d)	1135 (742)	1269 (694)	1331 (681)	1348 (583)	*NS*	0.12 (0.02)
Magnesium (mg/d)	349.8 (374.5)	496.5 (680.8)	455.9 (570.4)	439.8 (471.8)	0.03	0.13 (0.01)
Iron (mg/d)	15.3 (13.0)	16.2 (11.8)	18.1 (11.9)	18.0 (10.5)	*NS*	0.08 (*NS*)
Zinc (mg/d)	11.5 (6.0)	12.5 (5.0)	12.5 (5.0)	12.5 (5.0)	*NS*	0.07 (*NS*)
Iodine (µg/d)	173.8 (145.8)	167.1 (108.9)	184.5 (107.4)	204.8 (120.4)	0.03	0.14 (0.006)
Folate (µg/d)	334.0 (148.8)	330.8 (154.6)	391.6 (182.6)	416.0 (169.4)	<0.001	0.21 (<0.001)
Vitamin B_{12} (µg/d)	7.1 (4.3)	6.4 (3.9)	7.5 (3.9)	8.4 (4.3)	0.007	0.21 (<0.001)
Retinol (µg/d)	397.5 (354.8)	392.8 (385.1)	427.5 (405.3)	434.58 (334.4)	*NS*	0.03 (*NS*)
Carotene (µg/d)	4934 (3350)	6440 (3472)	8048 (5168)	8431 (6717)	<0.001	0.38 (<0.001)
Vitamin D (µg/d)	2.0 (2.0)	2.0 (1.0)	3.0 (1.8)	3.5 (3.2)	<0.001	0.25 (<0.001)
Vitamin C (mg/d)	155.5 (111.0)	216.6 (155.9)	240.9 (157.6)	264.5 (210.1)	<0.001	0.33 (<0.001)

[1]Median (Interquartile Ranges) Low score ≤51.4; Low-Medium score = 51.4-59.1; Medium-High score= 59.2-66.6; High score ≥66.6

Table 4.3: Comparison of median (IQR) energy adjusted FFQ nutrient intakes between diet and nutrition score quartiles and correlation between diet and nutrition scores and energy adjusted FFQ nutrient intakes (*n*=402)

	Diet and Nutrition Score[1]					
	Low (*n*=100)	**Low-Medium (*n*=94)**	**Medium-High (*n*=103)**	**High (*n*=105)**	**Kruskal Wallis**	**Correlation Coefficient (P)**
Fibre (g/MJ per day)	2.3 (1.0)	2.7 (1.1)	3.1 (1.0)	3.7 (1.2)	<0.001	0.48 (<0.001)
Protein (% of energy)	16.2 (5.2)	17.8 (4.9)	18.8 (4.5)	18.4 (3.5)	<0.001	0.25 (<0.001)
Carbohydrate (% of energy)	46.4 (11.7)	46.2 (7.7)	47.1 (8.6)	48.0 (7.8)	*NS*	0.08 (*NS*)
Total Fat (% of energy)	37.9 (8.7)	36.9 (6.6)	35.2 (6.9)	35.0 (7.7)	<0.001	-0.22 (<0.001)
Saturated Fat (% of energy)	14.3 (3.5)	13.2 (3.5)	13.2 (3.5)	12.6 (3.5)	0.002	-0.19 (<0.001)
Non-Milk Extrinsic Sugars (% of energy)	8.0 (6.6)	6.7 (4.2)	5.9 (3.9)	5.6 (3.5)	<0.001	-0.22 (<0.001)
Alcohol (units/MJ per day)	0.4 (0.5)	0.2 (0.6)	0.1 (0.3)	0.1 (0.3)	*NS*	-0.12 (0.02)
Sodium (mg/MJ per day)	289.9 (86.8)	288.5 (80.5)	315.0 (79.3)	309.3 (86.7)	0.02	0.11 (0.03)
Potassium (mg/MJ per day)	393.9 (211.4)	531.8 (578.4)	494.5 (496.5)	535.9 (277.6)	<0.001	0.26 (<0.001)
Calcium (mg/MJ per day)	105.6 (49.6)	116.9 (48.8)	132.4 (42.6)	130.9 (45.0)	<0.001	0.28 (<0.001)
Magnesium (mg/MJ per day)	33.0 (23.9)	43.4 (51.6)	43.0 (46.0)	45.6 (28.6)	<0.001	0.29 (<0.001)
Phosphorus (mg/MJ per day)	166.1 (50.4)	183.3 (58.1)	201.2 (49.4)	199.0 (45.6)	<0.001	0.30 (<0.001)
Iron (mg/MJ per day)	1.4 (0.7)	1.6 (0.8)	1.7 (0.9)	1.8 (0.7)	<0.001	0.25 (<0.001)
Zinc (mg/MJ per day)	1.1 (0.3)	1.2 (0.3)	1.3 (0.3)	1.3 (0.3)	<0.001	0.26 (<0.001)
Iodine (µg/MJ per day)	14.2 (9.2)	16.1 (8.0)	18.9 (11.5)	19.4 (9.9)	<0.001	0.25 (<0.001)
Folate (µg/MJ per day)	31.0 (9.9)	36.0 (8.4)	40.3 (13.1)	41.2 (12.7)	<0.001	0.43 (<0.001)
Vitamin B_6 (µg/g protein per day)	27.6 (13.2)	26.3 (11.3)	25.6 (10.8)	27.5 (7.8)	*NS*	-0.0007 (*NS*)
Vitamin B_{12} (µg/MJ per day)	0.6 (0.3)	0.7 (0.3)	0.8 (0.4)	0.8 (0.4)	<0.001	0.25 (<0.001)

Retinol (µg/MJ per day)	41.0 (24.5)	41.6 (26.6)	44.8 (25.5)	42.6 (25.8)	*NS*	0.06 (*NS*)
Carotene (µg/MJ per day)	438.3 (348.4)	667.9 (4.2.8)	762.4 (539.4)	888.9 (619.7)	<0.001	0.41 (<0.001)
Vitamin D (µg/MJ per day)	0.2 (0.2)	0.3 (0.2)	0.3 (0.2)	0.3 (0.3)	<0.001	0.30 (<0.001)
Vitamin C (mg/MJ per day)	14.7 (9.6)	22.3 (14.2)	24.3 (14.4)	29.0 (15.5)	<0.001	0.41 (<0.001)

[1] Median (Interquartile range) Low score ≤51.4; Low-Medium score = 51.4-59.1; Medium-High score= 59.2-66.6; High score ≥66.6

4.4 Discussion

4.4.1 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 birthweight and impaired cognitive development (Haider *et al.*, 2013; Radlowski & Johnson, 2013). In this study, the correlation coefficient between the diet and nutrition score and the WFFQ derived energy adjusted iron intake was 0.25 ($P<0.001$) 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 (MRC Vitamin Study Research Group, 1991). The correlation coefficient between the diet and nutrition score and WFFQ derived energy adjusted folate intake was 0.43 ($P<0.001$), showing that higher diet and nutrition scores were strongly associated with better dietary intakes of folate.

Maternal vitamin D intakes may influence fetal growth and cognitive development (Thorne-Lyman & Fawzi, 2012; Eyles *et al.*, 2013), while vitamin C intake has also been positively associated with birthweight (Mathews *et al.*, 1999). The correlation coefficients between the diet and nutrition score and participants' energy adjusted vitamin D and vitamin C intakes were 0.30 ($P<0.001$) and 0.41 ($P<0.001$) respectively.

Metabolic ill-health in pregnancy has been linked to excessive saturated fat and refined sugar intake (Bowers *et al.,* 2012; Regnault *et al.,* 2013); while frequent consumption of four or more units of alcohol per day during pregnancy can adversely affect childhood academic outcomes (Alati *et al.,* 2013). The correlation coefficient between the respondents' diet and nutrition scores and their WFFQ derived percentage of energy from saturated fat was -0.19 (P<0.001); for NMES intakes was -0.22 (P<0.001), and for alcohol intake was -0.12 (P=0.02), showing that lower diet and nutrition scores were associated with higher intakes of these potentially deleterious nutrients.

4.4.2 Interpretation

In evaluating a web based dietary assessment tool in pregnancy, the first issue to be addressed is the dietary assessment method by which the reference 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 (Baddour *et al.,* 2013; McGowan *et al.,* 2014). In a recent Irish study, the WFFQ used in the current study was validated against three day food records in 130 pregnant women (McGowan *et al.,* 2014). Energy adjusted Pearson's correlation coefficients for nutrient intakes estimated by the two methods 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 by both methods, showing reasonable to good agreement between the WFFQ and the three day food records 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 our study.

In the past, nutrition research has often favoured an approach which emphasises the role of single nutrients in diet-health relationships (Messina *et al.,* 2002). This approach has resulted in important advances, for example, in learning the basic pathology of vitamin deficiency disorders, and in identifying effective strategies for their prevention e.g. the role of folic acid in the prevention of NTD births (MRC Vitamin Study Research Group, 1991). 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 foods and nutrients is likely, not to mention the inter-individual and intra-individual variations which exist in nutrient effect at the metabolic interface (Messina *et al.*, 2002). Additionally, the physiological effect of a single nutrient may be too small to be detected, while statistically significant (but non-causal) associations between nutrient intakes and health outcomes may simply occur by chance when numerous nutrients and foods are analysed independently (Farchi *et al.*, 1989; Newby & Tucker, 2004).

Investigating "whole diet" patterns has emerged as a more holistic method of dietary assessment than the single nutrient approach. 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.

4.4.3 What this study adds

Currently, there is a dearth of research describing the use of online tools in the dietary assessment of pregnant women. It has been recommended that more research is undertaken to validate innovative web based dietary assessment tools (Illner *et al.,* 2012). The use of the internet has increased significantly in recent years, with latest figures from the CSO estimate that

82% of Irish households now have access to the internet at home (CSO, 2014). 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.

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 fruit and vegetables, breakfast cereals, oily fish, refined sugar and fructose, and alcohol (Snook-Parrott *et al.*, 2009; Bowers *et al.*, 2012; Alati *et al.*, 2013; Regnault *et al.*, 2013; Grieger & Clifton, 2015). The DAT employed also incorporates further key elements of evidence based dietary advice for pregnancy disseminated by national and international expert agencies (FSAI, 2011; HSE, 2013; National Health and Medical Research Council, 2013).

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 also collects 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.

In addition, web based DATs are 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 strong potential as more cost and time effective, less

laborious methods of dietary data collection which have been found to be feasible and acceptable to respondents (Illner *et al.,* 2012).

4.4.4 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 many FFQs containing a substantial amount of measurement error because they make several assumptions about food portion size. They may also underestimate dietary intake due to an inadequate list of food items (Prentice *et al.*, 2011). Nonetheless, while FFQs can therefore be a relatively imprecise tool to measure an individual's nutrient intakes, they can be reliably used in large 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 (McGowan *et al.,* 2014).

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 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 used the DAT. Further studies (for example a weighted randomisation study) 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 used in the current study. The DAT could therefore be used for nutritional screening and followed by more precise nutritional assessment. 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 (Atkinson & Gold, 2002).

4.5 Conclusions

Higher DAT 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. The technological advantages and potential interactive aspect of the DAT make it a useful tool for collecting dietary information and in the future could be linked to individualised advice on the subject's dietary intakes, physical activity and other lifestyle behaviours. In addition, the DAT scores may be used as an index of global dietary quality in obstetric populations, enabling clinicians and pregnant women alike to critically evaluate dietary practices, which is ultimately important for the derivation of efficacious, evidence based nutritional interventions.

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Chapter 5

The Relationship between Maternal Food Group and Macro-nutrient Intakes and Fasting Plasma Glucose Levels in Pregnancy

5.0 Introduction

This chapter was based on the publication **(Appendix 6)**:

Mullaney L, Brennan A, Cawley S, O'Higgins AC, McCartney D, Turner MJ (2016) The relationship between fasting plasma glucose levels and maternal food group and macronutrient intakes in pregnancy. *Nutr Diet* DOI: 10.1111/1747-0080.12278 [Epub ahead of print].

The Ph.D. candidate's contribution was data collection, data preparation, statistical analysis, and preparation and finalisation of the manuscript.

GDM is defined as any degree of glucose intolerance with onset or first recognition during pregnancy (Metzger & Coustan, 1998; ADA, 2008). In Ireland, based on the International Association of Diabetes and Pregnancy Study Group (IADPSG) diagnostic criteria, GDM is estimated to affect 12.4% of pregnancies (O'Sullivan *et al.,* 2011). Women with GDM and their offspring are at risk of adverse complications in pregnancy and poorer long-term health. For example, GDM has been associated with increased caesarean section rates and pre-eclampsia (Wendland *et al.,* 2012), while women who develop GDM are also at increased risk of type 2 diabetes later in life (Buchanan *et al.,* 2012). In the offspring it may contribute to fetal macrosomia and associated birth complications like shoulder dystocia, as well as obesity and type 2 diabetes later in life (Buchanan *et al.,* 2012; Wendland *et al.,* 2012).

The cost of obstetric care in the US is higher in women with GDM versus non diabetic women from the start of their pregnancy to three months postpartum (Jovanovic *et al.*, 2015). In Ireland, GDM has been associated with higher total costs of care, with an estimated €817.60 increase in maternity care costs during pregnancy and a €680.50 increase in annual health care costs in the 2-5 years post pregnancy (Danyliv *et al.*, 2015). Diet and exercise have been suggested as modifiable behaviours which can ameliorate the risk of developing GDM (Zhang *et al.*, 2006; Ley *et al.*, 2011; Tobias *et al*., 2011; Bowers *et al.*, 2012; Walsh *et al.*, 2012; Bao *et al.*, 2013; Russo *et al.*, 2015). However a recent meta-analysis (13 trials, *n*=4983 women) found no difference between diet and exercise intervention groups and their respective control populations in the development of GDM (Bain *et al.*, 2015). Effective interventions to prevent and treat GDM are needed to reduce adverse maternal and infant health outcomes, and to reduce the associated costs of the condition to the healthcare system.

5.0.1 Diagnosis and treatment of GDM

The exact level of glucose intolerance which defines GDM has been a contentious issue for some time (Wendland *et al*., 2012; Farrar *et al.*, 2015). In addition, screening practices for GDM vary within and across European countries, with some offering universal screening to all pregnant women and others only to selective high risk groups. In the 1960s, the National Diabetes Data Group (NDDG) opted to designate the 3-hour 100g Oral Glucose Tolerance Test (OGTT), largely used and evaluated in the USA, as their standard diagnostic method (O'Sullivan & Mahan, 1964). The American Diabetes Association (ADA) and many other medical associations around the world subsequently adopted this 3-hour 100g OGTT protocol. In the 1980s, the WHO adopted the 2-hour 75g OGTT to detect hyperglycaemia in pregnancy, recommending the use of the same diagnostic cut points established for the diagnosis of Impaired

Glucose Tolerance (IGT) outside of pregnancy (WHO, 1980). In 1999, WHO clarified that GDM encompassed both IGT (FPG ≥ 7.0 mmol/l; 2-hour plasma glucose ≥ 7.8 mmol/l) and diabetes (FPG ≥ 7.0 mmol/l; 2-hour plasma glucose ≥ 11.1 mmol/l) (WHO, 1999), and these diagnostic criteria have been retained since then.

More recently, the IADPSG, after extensive analyses of the Hyperglycemia and Adverse Pregnancy Outcomes (HAPO) study (HAPO *et al*., 2008), recommended that new diagnostic criteria for GDM be adopted (IADPSG, 2010). This group recommended that, based on a 2-hour 75g OGTT; a FPG level ≥ 5.1 mmol/L, or a 1-hour post-prandial result of ≥ 10.0 mmol/L, or a 2-hour post-prandial result of ≥ 8.5 mmol/L should be considered diagnostic of GDM.

Currently, evidence is lacking to conclusively define the best way to identify women who have GDM (Farrar *et al.,* 2015). The HAPO study found a linear association between maternal plasma glucose levels and adverse perinatal outcomes across the whole distribution of plasma glucose levels in pregnancy (HAPO *et al.,* 2008). Thus, there is no clear plasma glucose threshold above which women and their offspring are at high clinical risk and below which they are at low risk. Criteria for the diagnosis of GDM have been developed however, in an attempt to identify thresholds which best predict adverse maternal and neonatal outcomes. Unfortunately, clear evidence demonstrating improved clinical outcomes through the use of one criterion over another has remained elusive. This has led to the use of different criteria for the diagnosis of GDM which are arbitrary and often based on expert opinion (Farrar *et al.,* 2015). Diagnosis of GDM can be further complicated by poorly controlled pre-analytical handling of the fasting glucose sample. In one 2015 study, it was observed that GDM was under diagnosed in obese women unless maternal FPG samples were transported on ice and analysed immediately in the laboratory (Daly *et al.,* 2015).

The primary aims of treatment for GDM are to optimise glycaemic control and improve pregnancy outcomes (Alwan *et al.,* 2009). For women who have been diagnosed with GDM, dietary and lifestyle advice can be effective (Crowther *et al.,* 2005; Landon *et al.,* 2009) and is usually recommended as the primary therapeutic strategy to achieve acceptable glycaemic control (Hoffman *et al.,* 1998; ACOG, 2001; NICE, 2008). As part of the treatment for GDM, women are also encouraged to start or continue moderate intensity exercise as long as they have no medical or obstetric contraindications (Hoffman *et al.,* 1998; NICE, 2008; Alwan *et al.,* 2009). If these interventions alone are not enough to achieve good maternal glycaemic control, insulin therapy may be indicated (Hoffman *et al.,* 1998; ACOG, 2001; NICE, 2008), although oral hypoglycaemics such as glyburide and metformin have been used as alternatives to insulin therapy (Simmons *et al.,* 2004; Silva *et al.,* 2010). As part of GDM management, maternal glucose monitoring and ultrasonography are advised to assess treatment effectiveness and to guide care for birth (Hoffman *et al.,* 1998; ACOG, 2001; NICE, 2008).

5.0.2 Factors influencing the development of GDM

5.0.2.1 Maternal anthropometric and socio-demographic factors and GDM

It is now well established that the risk of developing GDM is increased in women with higher pre-pregnancy BMI, and that this risk significantly and progressively increases across the BMI categories of overweight, obesity, and morbid obesity (Torloni *et al.,* 2009; Morisset *et al*., 2010; Heude *et al.,* 2012). Non Caucasian ethnicity has also been shown to be an independent risk factor for GDM (Ben-Haroush *et al.,* 2004), with Asian, Hispanic, and Native American women all having a greater risk of GDM than their non Hispanic Caucasian peers (DeSisto *et al.,* 2014). These ethnic differences in GDM risk have been shown to persist even after adjusting for

maternal age, education, smoking status and pre-pregnancy weight (Savitz *et al.*, 2008). Advanced maternal age, parity and positive family history are associated with an increased risk of GDM (King, 1998; DeSisto *et al.*, 2014).

Studies examining socioeconomic variations in GDM cannot be easily compared because of the different criteria used to define SES. Some studies have used indices such as relative deprivation defined by area of residence. For example, a UK study found no association between deprived area of residence and GDM risk (Janghobani *et al.*, 2006), while an Australian study showed that living in a deprived area was positively associated with GDM risk (Anna *et al.*, 2008). Education and current employment status have also been used as markers of SES in GDM research, with higher levels of education and paid employment linked to lower rates of GDM (Bo *et al.*, 2002).

5.0.2.2 Physical activity and GDM

Exercise is associated with improved insulin sensitivity and glucose uptake in cells (Ryder *et al.*, 2001); improvements in beta cell and epithelial function in insulin synthesis (Venkatasamy *et al.*, 2013), and with a reduction in excess adipose tissue which favourably influences the hormonal and inflammatory environment (Makki *et al.*, 2013). Increased blood glucose levels and an associated increase in insulin production are a natural part of late pregnancy. In such circumstances, pregnant women with underlying insulin resistance may have difficulty producing enough insulin to lower blood glucose to safe levels (Buchanan & Xiang, 2005). In these instances, exercise induced improvements in insulin sensitivity, cellular glucose uptake and insulin production may therefore help to prevent the excessive blood glucose levels associated with GDM (Russo *et al.*, 2015).

Observational studies have noted that higher levels of physical activity before pregnancy and during early gestation are associated with a lower prevalence of GDM (Tobias *et al.,* 2011). However, RCTs have yielded conflicting results in this area, with some showing no association between physical activity and GDM prevention (Han *et al.,* 2012; Yin *et al.,* 2014). A 2013 meta-analysis which included data from four trials of exercise intervention and one of a yoga intervention revealed no significant association between exercise and GDM risk (Yin *et al.,* 2014). However, only one of the trials included in this meta-analysis began their intervention in the first trimester, while the other four studies started their intervention in the second trimester. Also, this study excluded women with a history of GDM. Together, these study limitations may partially explain why these trials yielded non-significant results. Conversely, a systematic review and meta-analysis in 2015 which included 10 RCTs and which did not exclude women with a previous history of GDM, demonstrated a 28% lower risk of GDM among those assigned to a physical activity intervention compared with those in a control group (Russo *et al.,* 2015). However, again physical activity interventions may have been initiated in the first or second trimester. The authors concluded that more research is needed to evaluate which types, durations, and intensities of physical activity are associated with a reduction in risk of GDM, and to assess the effectiveness of various intervention models.

5.0.2.3 Diet and GDM

A recent meta-analysis of 20 RCTs reviewed the role of nutritional intervention in pregnancy in preventing GDM (Rogozinska *et al.,* 2015). Nutritional manipulation based on diet or diet and lifestyle did not appear to prevent GDM. There was a trend towards beneficial effects in women who undertook mainly diet-based interventions however, with a potentially significant reduction in GDM risk when the effectiveness of these dietary interventions was assessed in

obese and overweight women only. From this meta-analysis, three RCTs showed beneficial effects of dietary intervention, including reduced incidence of GDM; among their overweight and obese subjects (Wolff *et al.,* 2008; Thornton *et al.,* 2009; Quinlivan *et al.,* 2011).

The Australian RCT (*n*=124) in this meta-analysis (Quinlivan *et al.,* 2011) involved a four step care model consisting of i) continuity of care provider ii) weighing on arrival iii) brief dietary intervention at every antenatal visit and iv) psychological assessment and intervention if needed. The intervention group reported increases in water, fresh fruit and vegetable intake and home cooked meals, and decreases in fizzy drink, juice and fast food consumption compared to the control group.

The American RCT (*n*=232) involved energy restriction and food diary record keeping. There was no difference in GDM incidence between the intervention and the control groups. However, women in the intervention group who did adhere to the nutritional advice were less likely to develop GDM compared with women who did not adhere to the nutritional advice, although these findings should be interpreted with caution due to the small sample sizes in these sub categories (Thornton *et al.,* 2009).

In the Danish study (*n*=50) (Wolff *et al.,* 2008), the intervention involved ten one hour consultations throughout pregnancy with a dietician providing advice on healthy eating and energy restriction based on individual estimated energy requirements. The intervention group successfully limited their EI and decreased their % of energy from fat and carbohydrate and increased their % of energy from protein compared with the control group. In so doing, the intervention group limited their GWG which in turn, attenuated their pregnancy induced increases in fasting insulin, leptin and blood glucose.

5.0.3 Macronutrient intakes and blood glucose levels

5.0.3.1 Carbohydrate intake and GDM - Glycaemic Index, fibre and fructose

Maternal diet, and particularly the type and content of carbohydrate in the diet, influences maternal blood glucose concentrations (Walsh *et al.,* 2012). Jenkins developed the Glycaemic Index (GI) in 1981 as a method for assessing glycaemic responses to different foods and carbohydrates (Jenkins *et al.,* 1981). Consumption of carbohydrate containing foods typically results in a rise, peak and decline of blood glucose. Foods which induce a gradual increase in blood glucose due to slow digestion and absorption have a low GI. Carbohydrate containing foods that produce a rapid rise in blood glucose are referred to as high GI. A review in 2008 (Tieu *et al.,* 2008), showed that low GI versus high GI diets during pregnancy were not effective in preventing GDM or improving maternal fasting blood glucose levels. However, this review was limited by the small number of studies included (n=3).

In other studies, the benefits of low GI diets have been shown for individuals being treated for type II diabetes (Brand-Miller *et al.,* 2003), while some evidence also exists to suggest that low GI diets may confer similar benefits in women with GDM (Cheung, 2009). The ROLO study carried out in Ireland on multigravidas women, found that a low GI dietary intervention in pregnancy had no effect on infants' birthweight compared to no dietary intervention in a group at increased risk of fetal macrosomia. The low GI intervention, did however, have a significant beneficial effect on GWG and on maternal glucose intolerance. Despite these favourable effects, there was no difference between the two groups in terms of GDM incidence (Walsh *et al.,* 2012). Because of such conflicting data, confusion still exists surrounding the potential beneficial impact of a low GI diet in pregnancy. Better powered RCTs

are therefore warranted to further investigate the effects of the low GI diet on maternal food and nutrient intakes, maternal weight gain and pregnancy outcomes.

In a large prospective study of women, pregravid consumption of dietary total fibre and in particular, cereal and fruit fibre was inversely associated with GDM risk. This association remained after adjustment for several possible confounding factors for example BMI, PAL, family history of GDM, and parity (Zhang *et al.,* 2006).

Fructose is an increasingly common constituent of the Westernised diet due to its intense sweetness, low cost and ease of production. Over the past two decades, human and animal studies have highlighted that excessive fructose intake may be associated with adverse metabolic effects (Stanhope *et al.*, 2009; Stanhope, 2012; InterAct Consortium, 2013; Stanhope *et al.*, 2013). Excessive intake of fructose is often the combined result of increased total energy consumption and increased portion sizes of foods which incorporate the fructose containing sugars sucrose or high fructose corn-syrup (Regnault *et al.,* 2013).

Sugars added to processed food, particularly fructose, can contribute to obesity, but also appear to have properties which increase diabetes risk independent of their effects on obesity (Malik & Hu, 2012). Findings from one meta-analysis show a clear link between Sugar Sweetened Beverages (SSB) consumption and risk of metabolic syndrome and type II diabetes. Based on three prospective cohort studies including 19,431 participants and 5,803 cases of metabolic syndrome, participants in the highest category of SSB intake had a 20% greater risk of developing metabolic syndrome than those in the lowest category of intake. For type II diabetes, based on data including 310,819 participants and 15,043 cases of type II diabetes, participants in

the highest category of SSB intake had a 26% greater risk of developing type II diabetes than participants in the lowest category of intake (Malik *et al.,* 2010).

There is currently a lack of studies investigating the relationship between fructose intake and risk of GDM. In the Nurses' Health Study II, after adjustment for age, parity, race, physical activity, smoking, alcohol intake, pre-pregnancy BMI, and Western dietary pattern (high intake of red meat, processed meat, refined grain products, sweets, french fries, and pizza); intake of sugar sweetened cola was positively associated with the risk of GDM, whereas no significant association was shown for other sugar sweetened beverages and diet beverages. Compared with women who consumed one serving/month, those who consumed five servings/week of sugar-sweetened cola had a 22% greater GDM risk (relative risk: 1.22; 95% CI: 1.01, 1.47, *P*=0.04) (Chen *et al.,* 2009).

5.0.3.2 Protein intake and GDM

Dietary proteins and amino acids are important modulators of glucose metabolism, and a diet high in protein may impact glucose homeostasis by promoting insulin resistance and increasing gluconeogenesis (Tremblay *et al.,* 2007). Moreover, emerging data suggest that dietary protein actions may vary depending on their amino acid profiles and food sources. For instance, a prospective cohort study among Europeans showed that long-term high intake of animal protein, but not vegetable protein, was associated with an increased risk of type II diabetes (Sluijs *et al.,* 2010).

In a recent large prospective cohort study, it was shown that pre-pregnancy intake of animal protein, in particular red meat, was significantly and positively associated with GDM risk; while vegetable protein intake, specifically nuts, was significantly and inversely associated

with GDM risk. Replacing 5% of energy from animal protein with vegetable protein, and replacement of red meat with poultry, fish, nuts, or legumes were both associated with lower GDM risk. The distinct effects of animal protein on the incidence of GDM could be attributable to the presence of other nutrients such as cholesterol and saturated fat which co-occur in these protein rich foods. However, in the study cited, the association of animal protein and GDM risk remained significant even after adjustment for dietary cholesterol and saturated fat intakes (Bao *et al*., 2013).

5.0.3.3 Fat intake and GDM

Fatty acids play a vital role in glucose homeostasis. Increased plasma free fatty acids may cause a dose dependent inhibition of insulin stimulated glucose uptake and, therefore, contribute to insulin resistance (Boden *et al.,* 1994). In a prospective cohort study, after adjusting for BMI, age and race, higher maternal total fat intake in pregnancy increased the risk of IGT and GDM when accompanied by a decrease in carbohydrate intake, while carbohydrates were protective when fat intake reciprocally decreased. However, these investigators did not examine the effect of types of fat or quality of carbohydrate (Saldana *et al.,* 2004). A large US (*n*=13,475) prospective study identified no significant association between total fat intake and GDM risk; however, a significantly higher risk of GDM was associated with greater consumption of dietary cholesterol and animal fat. Furthermore, it was suggested that the replacement of carbohydrate derived energy with animal fat was associated with an increased risk of GDM, whereas the replacement of energy derived from animal fat with vegetable fat was associated with a reduced risk (Bowers *et al.,* 2012).

A further US prospective study investigated dietary quality and risk of abnormal glucose tolerance among a cohort of pregnant women (*n*=1173) enrolled in the Project Viva study (Radesky *et al.,* 2008). With the possible exception of an adverse effect of n-3 fatty acid intake in normal weight women, there was no evidence that diet quality in early pregnancy, namely, the intake of macro-nutrients, fat subtypes, whole grains, fibre, glycaemic load, red or processed meats, or dietary patterns; was associated with risk of developing IGT or GDM. The authors concluded that previously established risk factors for GDM, including pre-pregnancy BMI, age, race/ethnicity, history of GDM and family history of diabetes, are strong independent predictors of glucose tolerance.

Finally, in a Canadian study (*n*=205), higher total fat and lower carbohydrate intake in the second trimester was associated with later risk of GDM, after adjusting for confounders including age, ethnicity, previous GDM, SES, pregravid PAL and smoking status. Higher saturated fat and trans-fat as a percentage of energy, added sugar in tea and coffee, and lower fruit and vegetable intakes were individually associated with increasing maternal FPG levels (Ley *et al.,* 2011).

5.1 Aims

Effective interventions to prevent and treat GDM are important to reduce the short- and long-term adverse health consequences of the condition for women and their infants, and to mitigate their substantial attendant healthcare costs. The aim of the present study was to investigate the association between maternal dietary intake in terms of food groups and macro-nutrients in the first trimester of pregnancy and FPG levels, after adjustment for the effects of bodyweight and other potential confounders.

5.2 Methods

Women were recruited at their convenience in the first trimester of pregnancy as outlined in Chapter 2 and Chapter 3. The main inclusion criteria were women booking for antenatal care after an ultrasound confirmation of a singleton ongoing pregnancy in the first trimester. Exclusion criteria included multiple pregnancies, women with pre-existing diabetes or women who subsequently delivered in another hospital.

To collect habitual food and nutrient intakes, women were asked to complete the previously validated semi-quantitative WFFQ (Harrington, 1997; Kaaks *et al.*, 1997; Morgan *et al.*, 2007; McGowan *et al.*, 2014), and then the online DAT questionnaire (both outlined in Chapter 2). Respondents who under- and over-reported EI were excluded from the final food and nutrient intake datasets to enhance the integrity of the food and nutrient intake analyses (Livingstone & Black, 2003) as outlined in Chapter 3.

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 BMI calculated.

5.2.1 Oral Glucose Tolerance Test (OGTT)

OGTTs were performed between weeks 24-28 of gestation on women with risk factors for GDM according to national guidelines (NICE, 2008). These risk factors included a BMI ≥30 kg/m^2, maternal age ≥40 years, family history of diabetes in a first degree relative, GDM in a previous pregnancy, long-term steroid use, current glycosuria, polycystic ovarian syndrome, previous unexplained perinatal death, previous delivery of a macrosomic baby weighing ≥4.5 kg,

polyhydramnios in the current pregnancy and certain specific ethnicities (Indian/ Pakistani/ Bangladeshi/ Black Caribbean/ Saudi Arabian/ United Arab Emirates/ Iraqi/ Jordanian/ Syrian/ Omani/ Qatari/ Kuwaiti/ Lebanese/Egyptian) (NICE, 2008). FPG levels were collected from the hospital database on study participants who had had an OGTT.

5.2.2 Statistical analysis

Descriptive analyses were initially carried out to characterise the cohort with respect to their age, parity, ethnicity, gestational age, SES, smoking status, and PALs. One-way ANOVA tests were used to compare mean values for normally distributed continuous variables between the FPG tertiles. Cross-tabulation with Chi-square analyses were used to test differences in categorical variables such as SES and health behaviours (e.g. smoking status) across the FPG tertiles. Respondent data for weight, BMI, FM, % FM, and FFM were non-normally distributed, and Kruskal Wallis tests were used to compare medians for these parameters between the FPG tertiles. Nutrient and food group intake data were also non-normally distributed, therefore Kruskal Wallis tests were used to compare median energy adjusted food group and macro-nutrient intakes between women in each FPG tertile. Binary logistic regression analysis was used to assess factors associated with FPG levels >4.5 mmol/L.

5.3 Results

OGTTs were undertaken by 180 women. The social and demographic characteristics of this study population both overall, and according to FPG level are shown in Table 5.1. GDM was diagnosed in 16 women (8.9%) according to the IADSPG guidelines (IADPSG, 2010). Weight, BMI, FM, % FM, and FFM all increased with increasing FPG levels (all P=0.001) (Table 5.2).

EI under-reporting was observed in 57 (31.7%) women. There were no EI over-reporters in the sample. EI under-reporters in this sample had a higher weight [87.1 ± 19.3 vs. 73.9 ± 15.2 kg (*P*=0.001)], BMI [32.0 ± 7.1 vs. 26.9 ± 5.5 kg/m^2 (*P*=0.001)], % FM [37.1 ± 7.4 vs. 32.4 ± 7.4 % (*P*=0.001)], and FFM [53.6 ± 7.4 vs. 49.0 ± 5.9 kg (*P*=0.001)] compared to plausible reporters of EI. No differences were seen in energy adjusted food group and macro-nutrient intakes across the FPG tertiles (Table 5.3 & Table 5.4).

There was no difference in self-reported PAL between obese and non-obese women [1.76 ± 0.2 vs. 1.75 ± 0.2, (*P*=0.598)]. On logistic regression, only antenatal obesity (OR 8.8, *P*=0.006) was associated with a FPG level >4.5 mmol/L (Table 5.5). Obese plausible reporters (*n*=35) had a higher EI [3254.9 vs. 2281.5 kcal/d, (*P*=0.009)], higher starch intake [28.2 vs. 24.2 % total energy, (*P*=0.03)] and lower fructose intake [3.88 vs. 3.37 % total energy, (*P*=0.03)] compared to non-obese women as shown in Table 5.6.

Table 5.1: Differences in socio-demographic and health behavioural characteristics between respondents in differing FPG tertiles (*n*=180)

	Total (*n*=180)	**Low FPG (≤4.3 mmol/L) (*n*=63)**	**Moderate FPG (4.31-4.60 mmol/L) (*n*=63)**	**High FPG (≥4.61 mmol/L) (*n*=54)**	***P***
Age[1] (years)	30.6 ± 5.5	30.4 ± 5.4	30.2 ± 5.8	31.2 ± 5.1	*NS*
Nulliparous %(*n*)	41.1 (74)	38.1 (24)	39.7 (25)	46.3 (25)	*NS*
Relative income poverty [a] %(*n*)	21.7 (39)	19.1 (12)	20.6 (13)	25.9 (14)	*NS*
Relative deprivation %(*n*)	32.2 (58)	33.3 (21)	31.8 (20)	31.5 (17)	*NS*
Consistent poverty[a] %(*n*)	10.6 (19)	11.5 (7)	8.2 (5)	14.0 (7)	*NS*
Under-reporters %(*n*)	31.7 (57)	25.4 (16)	34.9 (22)	35.2 (19)	*NS*
Gestational Age[1] (weeks)	12.6 ± 2.8	12.5 ± 2.6	12.6 ± 3.3	12.6 ± 2.5	*NS*
Irish %(*n*)	74.4 (134)	69.8 (44)	74.6 (47)	79.6 (43)	*NS*
Current Smoker %(*n*)	11.1 (20)	11.1 (7)	11.1 (7)	11.1 (6)	*NS*
Physical Activity Level[1] (METS)	1.75 ± 0.30	1.70 ± 0.2	1.70 ± 0.2	1.8 ± 0.2	*NS*

[1]Mean ± SD, [a] data available on *n*=172

One and two hour post glucose load Plasma Glucose (PG) levels also showed no association with maternal food and macronutrient intakes. The one hour PG levels also increased as maternal weight, BMI and body composition increased. Interestingly the two hour PG levels were not as significant as the FPG or one hour PG levels. Only BMI increased as the two hour PG levels increased (*P*=0.03).

Table 5.2: Univariate comparison of maternal anthropometric characteristics according to FPG level (*n*=180)

	Low FPG (≤4.3 mmol/L) (*n*=63)	**Moderate FPG (4.31-4.60 mmol/L) (*n*=63)**	**High FPG (≥4.61 mmol/L) (*n*=54)**	***P***
Weight[1] (kg)	70.9 ± 15.4	80.2 ± 16.4	84.2 ± 18.9	<0.001
BMI[1] (kg\m^2)	25.8 ± 5.7	29.4 ± 6.5	30.7 ± 6.3	<0.001
% Body Fat[1]	31.1 ± 7.6	35.1 ± 7.6	35.8 ± 7.0	<0.001
Fat Free Mass[1]	47.9 ± 6.0	51.0 ± 5.8	53.0 ± 7.5	<0.001

[1]Mean ± Standard Deviation

Table 5.3: Comparison of energy adjusted food group intakes in plausible dietary reporters analysed by FPG tertiles (*n*=123)

Food group (g/MJ energy)	**Low FPG (≤4.3 mmol/L) (*n*=47)**	**Moderate FPG (4.31-4.60 mmol/L) (*n*=41)**	**High FPG (≥4.61 mmol/L) (*n*=35)**	***P***
Breads	4.7 (7.1)	4.5 (5.2)	4.1 (7.1)	*NS*
Breakfast Cereals	4.1 (8.2)	4.1 (5.5)	3.9 (4.9)	*NS*
Rice/Pasta	9.0 (8.8)	10.2 (9.8)	11.4 (9.9)	*NS*
Eggs	1.9 (1.7)	1.9 (1.5)	2.2 (1.9)	*NS*
Potatoes	10.1 (7.1)	10.6 (6.4)	9.7 (7.8)	*NS*
Fats/Oils	0.6 (1.0)	0.6 (0.7)	0.5 (0.5)	*NS*
Alcoholic drinks	1.9 (9.4)	0.8 (6.2)	1.2 (4.3)	*NS*
Sugar Groups	12.2 (11.0)	15.5 (13.4)	12.3 (11.5)	*NS*
Fruit &Vegetables	62.2 (36.2)	54.8 (46.3)	51.1 (35.9)	*NS*
Milk/cream/cheese	4.0 (5.5)	3.1 (3.6)	4.4 (4.7)	*NS*
Fish	2.89 (4.6)	5.01 (6.93)	2.09 (3.97)	*NS*
Meat	13.3 (6.6)	13.4 (6.4)	14.6 (9.3)	*NS*
Other drinks	61.3 (64.4)	60.0 (59.5)	54.2 (67.1)	*NS*
Other foods	11.6 (9.9)	12.8 (12.5)	10.5 (13.7)	*NS*

All values reported are median (IQR)

Table 5.4: Energy adjusted macro-nutrient intakes in plausible dietary reporters analysed by FPG tertiles (*n*=123)

Nutrient	**Low FPG (≤4.3 mmol/L) (*n*=47)**	**Moderate FPG (4.31-4.60 mmol/L) (*n*=41)**	**High FPG (≥4.61 mmol/L) (*n*=35)**	***P***
Energy (MJ/day)	10.0 (5.8)	9.8 (4.7)	9.5 (3.3)	*NS*
Carbohydrate (% TE)	45.2 (8.3)	48.6 (8.9)	47.1 (9.4)	*NS*
Sugars (% TE)	18.9 (6.2)	21.2 (7.6)	19.0 (7.1)	*NS*
Starch (% TE)	25.2 (10.2)	26.9 (9.2)	27.0 (7.8)	*NS*
NMES (% TE)	5.6 (2.5)	6.5 (4.9)	6.7 (4.1)	*NS*
Fructose (% TE)	3.8 (2.4)	3.7 (2.9)	3.6 (2.0)	*NS*
Sucrose (% TE)	5.9 (3.4)	6.5 (2.8)	6.1 (3.4)	*NS*
Lactose (% TE)	0.7 (0.7)	0.5 (0.5)	0.6 (0.5)	*NS*
Maltose (% TE)	0.5 (0.7)	0.5 (0.6)	0.5 (0.6)	*NS*
Oligosaccharides (% TE)	0.02 (0.1)	0.06 (0.1)	0.06 (0.2)	*NS*
Fat (% TE)	36.4 (7.8)	34.7 (6.2)	35.6 (10.3)	*NS*
Saturated fat (% TE)	13.4 (4.2)	13.1 (2.8)	13.3 (4.2)	*NS*
Monounsaturated fat (% TE)	11.3 (2.3)	10.9 (2.7)	10.8 (3.1)	*NS*
Polyunsaturated fat (% TE)	6.5 (2.8)	7.2 (3.1)	6.8 (2.4)	*NS*
Dietary Fibre (per MJ energy)	5.0 (1.8)	4.8 (2.9)	4.6 (2.4)	*NS*
Protein (% TE)	18.0 (5.8)	18.2 (4.2)	18.4 (4.7)	*NS*
Alcohol (g/day) (% TE)	0.4 (2.0)	0.3 (1.2)	0.4 (1.6)	*NS*

All values reported are median (IQR)

Table 5.5: Logistic regression for factors associated with blood glucose >4.5 mmol/l in plausible dietary reporters (*n*=119)

		n	**Odds Ratio**	**95.0% C.I.**		***P***
Antenatal Obesity	Non-Obese	84	1.0[a]			
	Obese	35	8.80	1.85	41.79	0.006
Weight	Linear variable	119	1.11	0.77	1.655	*NS*
Body Fat %	Linear variable	119	0.90	0.69	1.16	*NS*
Fat Free Mass	Linear variable	119	0.86	0.52	1.42	*NS*
Visceral Fat Level	Linear variable	119	0.97	0.44	2.17	*NS*
Age	Linear variable	119	1.06	0.94	1.19	*NS*
Nulliparous	Yes	46	1.0[a]			
	No	73	0.89	0.33	2.39	*NS*
Smoking Status	Never\Former	106	1.0[a]			
	Current	13	0.72	0.17	3.00	*NS*
Ethnicity	Non-Irish	30	1.0[a]			
	Irish	89	2.83	0.93	8.6	*NS*
Energy (MJ)	Linear variable	119	0.90	0.78	1.03	*NS*
Sugar Food Groups (g/MJ energy)	Linear variable	119	1.02	0.93	1.12	*NS*
Carbohydrate (% TE)	Linear variable	119	0.84	0.65	1.09	*NS*
Protein (% TE)	Linear variable	119	0.84	0.62	1.14	*NS*
Fat (% TE)	Linear variable	119	0.87	0.65	1.14	*NS*
Dietary Fibre (per MJ energy)	Linear variable	119	1.12	0.81	1.55	*NS*
Glycaemic Index	Linear variable	119	0.98	0.88	1.09	*NS*

Data for *n*=119 for which all variables available, 1.0[a] denotes reference category

Table 5.6: Comparison of energy adjusted macro-nutrient intakes in plausible reporters analysed by obesity (BMI ≥30 kg/m^2) status (*n*=122)

Nutrient	Non-Obese (*n*=87)	Obese (*n*=35)	*P*
Energy (kcal/day)	2281.5 (838.8)	3254.9 (1591.0)	0.009
Carbohydrate (% TE)	47.14 (7.90)	47.58 (10.11)	*NS*
Sugars (% TE)	19.58 (7.86)	19.01 (6.73)	*NS*
Starch (% TE)	24.82 (9.54)	28.24 (8.29)	0.03
NMES (% TE)	5.63 (3.50)	6.50 (4.38)	*NS*
Fructose (% TE)	3.88 (2.51)	3.37 (2.04)	0.03
Sucrose (% TE)	6.23 (3.41)	6.24 (3.17)	*NS*
Lactose (% TE)	0.62 (0.59)	0.57 (0.48)	*NS*
Maltose (% TE)	0.45 (0.61)	0.65 (0.52)	0.04
Oligosaccharides (% TE)	0.04 (0.14)	0.07 (0.15)	0.02
Fat (% TE)	36.54 (7.29)	34.43 (7.53)	*NS*
Saturated fat (% TE)	13.45 (3.90)	12.78 (3.32)	*NS*
Monounsaturated fat (% TE)	11.33 (2.71)	10.77 (2.74)	*NS*
Polyunsaturated fat (% TE)	6.75 (2.88)	6.97 (2.69)	*NS*
Dietary Fibre (per MJ energy)	4.76 (2.09)	4.76 (1.66)	*NS*
Protein (% TE)	18.30 (3.83)	18.3 (5.12)	*NS*
Alcohol (% TE)	0.36 (1.71)	0.37 (1.36)	*NS*
Glycaemic Index	48.00 (7.00)	46.93 (9.00)	*NS*

All values reported are median (IQR), TE: Total Energy

5.4 Discussion

This study found that food group and macro-nutrient intakes in the periconceptional period were not associated with FPG levels at 24-28 weeks gestation. Obesity in early pregnancy remained associated with higher FPG levels after adjusting for important confounding variables. These findings suggest that weight management interventions should be targeted at women of child bearing age, especially obese women, in the pre-pregnancy period; in order to most effectively prevent abnormal blood glucose levels arising during pregnancy. These interventions

should focus on reduced total energy and starch intakes, as higher intakes of both were observed among obese women

This study has a number of strengths. Firstly, maternal weight was measured, not self-reported. Participants' weights and heights were measured by a trained professional and BMI calculated from these measured data. While the accurate assessment of bodyweight is critical, women, particularly those who are obese, have been shown to commonly underestimate their weight, which may lead to BMI misclassification (Fattah *et al.,* 2009; Turner, 2011).

The present study also used advanced BIA to measure maternal weight and body composition. The maternal weight was taken in the first trimester, which has been shown to be the optimal time for assessment, as maternal weight and body composition only begin to change after 18 weeks of gestation (Fattah *et al.,* 2010; O'Higgins *et al.,* 2014). The availability and use of participants' body composition data (e.g. body fat percentage) in more fully articulating the anthropometric risk factors for GDM is another strength of this study.

A possible limitation of this study is the difficulty associated with accurate assessment of dietary intake. The WFFQ is a semi-quantitative FFQ and therefore does not facilitate portion size estimation for individuals. Nonetheless, the WFFQ has been validated as a dietary data collection instrument in several Irish population studies, including a recent study on pregnant women in Dublin (Kaaks *et al.,* 1997; Harrington, 1997; Morgan *et al.,* 2007; McGowan *et al.,* 2014). Women who under-reported their EI were excluded from the final food and nutrient intake datasets to enhance the integrity of the study population's nutrient intake data (Livingstone & Black, 2003). Under-reporting of EI is more common amongst women in higher BMI categories, and therefore needs to be considered when conducting research into GDM as

increased BMI is strongly associated with the development of GDM. Under-reporting of EI may result in bias and erroneous conclusions regarding the dietary and nutritional predictors of increased GDM risk amongst obese women.

It is now well established that the risk of developing GDM is increased in women with higher pre-pregnancy BMI, and that this risk significantly and progressively increases across BMI categories of overweight, obesity, and morbid obesity (Torloni *et al.,* 2009; Morisset *et al.,* 2010; Heude *et al.,* 2012). Visceral fat and total body fat mass have also been linked to insulin resistance (Gastaldelli *et al.,* 2002; Mackay *et al.,* 2009), with data from a 2012 European cross-sectional study including 4,828 participants indicating that body fat plays a key role in the development of insulin resistance (Gomez-Ambrosi *et al.,* 2011). Studies in this area have also found that overall adiposity strongly predicts risk of type 2 diabetes mellitus (Wang *et al.,* 2005; MacKay *et al.,* 2009; Bigs *et al.,* 2010). However, despite the compelling data linking obesity and increased adiposity to metabolic syndrome and diabetes in the general population, there is a lack of studies investigating body fat mass in pregnancy and risk of GDM. One small cross-sectional study (*n*=79) found that women with GDM had higher FM levels (measured using BIA) compared to women with normal blood glucose levels (Moreno Martinez *et al.,* 2009). Univariate analysis in our study suggested that increased adiposity in early pregnancy was associated with higher FPG levels. However, after controlling for important confounding factors, only antenatal obesity as measured by BMI remained associated with higher FPG levels.

A recent meta-analysis (13 trials, *n*=4983 women) found no difference in the likelihood of developing GDM between women receiving diet and exercise interventions, and those allocated to their respective control groups (Bain *et al.,* 2015). However, another recent meta-analysis of 20 RCTs reviewed whether nutritional intervention during pregnancy was associated

with the prevention of GDM (Rogozinska *et al.*, 2015). While nutritional manipulation based on diet or diet and lifestyle changes did not appear to prevent GDM, there was a trend towards beneficial effects among women receiving primarily diet based interventions; with a potentially significant reduction in GDM risk observed when these interventions were confined to obese and overweight women. Our study showed no association between food group intakes or energy adjusted macro-nutrient intakes and higher FPG. However as women who under-reported EI were excluded from the final nutrient analysis, and these excluded women were more likely to be obese and have higher body fat levels, this is a biasing factor in GDM research which needs to be considered in future studies.

Previous studies investigating dietary intakes in early pregnancy and the risk of developing GDM have yielded inconsistent findings. In relation to macro-nutrients, some studies have shown that the type and content of carbohydrate (e.g. the GI) influences maternal blood glucose concentrations (Walsh *et al.*, 2012). In non-obstetric populations, high fructose intake has been linked with adverse metabolic effects including the development of type 2 diabetes (Stanhope *et al.*, 2009; Stanhope, 2012; InterAct Consortium, 2013; Stanhope *et al.*, 2013) however there is a lack of studies investigating fructose consumption and the development of GDM. GI and absolute or energy adjusted carbohydrate or fructose intakes in this study were not associated with FPG levels in pregnancy. It may be that a more specific FFQ, aimed specifically at assessing fructose containing foods, is required to accurately determine the association (if any) between increased fructose intakes and elevated blood glucose levels, including abnormal blood glucose levels in pregnancy.

From our findings, weight management in the preconceptional period may have a more beneficial effect on FPG than altering maternal diet in early pregnancy, as obesity was the main

predictor of higher FPG levels in this obstetric population. Obese women in our study had higher energy and starch intakes than non-obese women however, suggesting that preconceptional weight loss in obese women, possibly through a reduction in energy and starch intakes, may be more effective in preventing maternal hyperglycaemia than dietary adjustments initiated in early pregnancy.

5.5 Conclusions

Obesity is associated with increased FPG levels during pregnancy. While higher maternal bodyweight and adiposity were associated with increased plasma glucose levels upon univariate analysis, this association persisted only for increased BMI upon multivariate analysis. We also found that food group and macro-nutrient intakes in the periconceptional period were not associated with FPG levels at 24-28 weeks gestation. Our results suggest that effective weight management in the preconceptional period is critical in alleviating the risk of GDM, and that dietary interventions focused on energy and starch restriction should be targeted specifically at obese women in order to most effectively prevent abnormal glycaemia arising during pregnancy.

5.6 References

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Chapter 6

Weight and Body Composition Changes at Four and Nine Months Postpartum

6.0 Introduction

This chapter is based on the publication **(Appendix 6)**:

Mullaney L, O'Higgins AC, Cawley S, Daly N, McCartney D, Turner MJ (2016) Maternal Weight Trajectories between Early Pregnancy and Four and Nine Months Postpartum. *Public Health* DOI: 10.1016/j.puhe.2016.02.017 [Epub ahead of print].

The Ph.D. candidate's contribution was data collection, data preparation, statistical analysis, and writing of the manuscript.

Weight retention related to pregnancy is highly variable among women (Gore *et al.*, 2003). However, effective weight management following childbirth may reduce the long-term risks of heart disease, cancer, obesity and diabetes among women of child bearing age, as well as reducing their risk of entering future pregnancies overweight or obese. The 2006 NICE Obesity Guidelines identified the postpartum period as a vulnerable life stage for weight gain (NICE, 2006). This may be because women often receive little or no advice on weight management after childbirth. In addition, the postpartum period has been associated with an increase in food intake and a decrease in PAL (Sadurskis *et al.*, 1988; Clark & Ogden, 1999; Symons Downs & Hausenblas, 2004).

The postnatal period for many women is also an inter-partum or preconceptional period for their next baby. One long-term, retrospective UK study (n=740,628), found that BMI

increased significantly in women following the birth of each child, independent of SES group, PAL, region of residence, and smoking status (Bobrow *et al.,* 2013). An Irish longitudinal study (*n*=1,220) further found that two thirds of fist time mothers had gained weight when they re-attended for antenatal care on their next pregnancy, and that as a result, one in five women had moved into a higher BMI category, and one in twenty had become obese during this period (Crosby *et al.,* 2015). Another Irish study (*n*=10,524) found that increasing parity in socioeconomically disadvantaged women was associated with obesity at nine months postpartum (Turner & Layte, 2013).

There is a paucity of studies which investigate changes in body composition over the postpartum period using advanced BIA. Any studies available have relied on small sample sizes (Butte *et al.,* 2003; IoM, 2009; Cho *et al.,* 2011). It has been suggested that more evidence in the area of weight management during the postpartum period is needed (Messina *et al.,* 2009). The IoM have also stated that there are gaps in the surveillance of PPWR, and that results should be reported by BMI category (IoM, 2009).With regard to weight management before, during and after pregnancy, NICE (2010) recognise that a population based approach is needed in reaching all women of childbearing age, as many pregnancies are unplanned. This body also highlighted the lack of evidence describing the most effective time for women to start managing their weight after childbirth, and the optimal rate of weight loss to be targeted in this postpartum period.

6.0.1 Pre-pregnancy BMI, GWG and postpartum weight and body composition changes

Concerns about the adverse lifelong health consequences of maternal obesity led the IoM in the US to review the evidence linking pregnancy outcomes with GWG and subsequently, to revise downwards the recommended GWG for obese women (IoM, 2009; Rasmussen *et al.,*

2010) (Table 6.1). This has led to a number of interventional research studies targeting decreased maternal weight gain. However, these heterogeneous interventions have generated inconsistent outcomes to date (O'Higgins *et al.,* 2013).

Nonetheless, GWG has been frequently cited as a predictor of PPWR. In a meta-analysis of 12 studies (*n*>68,000 women), inadequate GWG was associated with decreased PPWR and this association was independent of the postpartum time span. Excess GWG, while associated with increased PPWR, was dependent on the postpartum follow-up time, with a U-shaped trend observed between 6 months to 21 years postpartum. Only five of these studies reported on postpartum BMI and its categories as an outcome of GWG. Those women with inadequate GWG, when compared with women with adequate GWG, had a decline in BMI of -2.42 kg/m^2 (95% CI, -3.03 to -1.80 kg/m^2). In contrast, those with excess GWG gained an additional 3.78 kg/m^2 (95% CI, 3.14 to 4.41 kg/m^2) over a postpartum period of 21 years. There was, however, considerable heterogeneity in the BMI figures included in this analysis, and thus while the trend is clear, exact losses or gains are difficult to assess (Mannan *et al.,* 2013).

Table 6.1: Institute of Medicine GWG recommendations by BMI category (IoM, 2009)

BMI category	**BMI (kg/m^2)**	**GWG recommendation (kg)**
Underweight	<18.5	12.7-18.1
Normal	18.5-24.9	11.3-15.9
Overweight	25.0-29.9	6.8-11.3
Obese	>30.0	5.0-9.1

A meta-analysis of 17 studies the following year (Rong *et al.,* 2015), also associated PPWR with excess GWG, and further suggested the presence of a U-shaped trend; where there is a decline in weight in the early postpartum period (1 year) and then an increase lasting ≥15 years.

Ten of the studies (*n*=116,735 women) analysed PPWR according to pre-pregnancy BMI from one month to 15 years postpartum. Changes in postpartum BMI were not assessed. Mean PPWR decreased with increasing pre-pregnancy BMI. Compared with normal weight women, underweight women retained more weight, while overweight and obese women retained less weight, independent of postpartum timespan.

These meta-analyses were limited in that they only assessed studies which categorized GWG according to IoM guidelines (Table 6.1). In addition, many of the studies relied on self-reported estimates of pre-pregnancy weight, which are subject to bias, particularly in obese women (Fattah *et al.*, 2009; Turner, 2011). These meta-analyses also did not investigate changes in postpartum body composition with regard to GWG. Breastfeeding, maternal education and parity may have a role in PPWR (Mannan *et al.*, 2013). However, it is unclear whether these and other potential confounders such as diet, exercise and lifestyle may be more relevant to PPWR than GWG, as not all studies adjusted for these confounders.

There is a lack of studies where both pre-pregnancy and postpartum maternal weights are measured. In one American study (*n*=795), BMI measured in early pregnancy was not associated with differences in weight changes at 6 months or 8.5 years postpartum. The most significant predictors of weight change at 8.5 years postpartum were GWG and weight retention at 6 months postpartum. However, the analysis was not adjusted for initial BMI and did not assess changes in postpartum BMI categorization (Rooney & Schauberger, 2002). In a second study, these women were followed, on average, for 14.7 years (range, 10.1 to 16.3 years). The authors overcame the limitation of the initial study by controlling the analysis for pre-pregnancy BMI. They concluded that excessive GWG and failure to lose pregnancy related weight by 6 months postpartum constitute important predictors of obesity in midlife (Rooney *et al.*, 2005).

In a small American study (*n*=63), measured pre-pregnancy BMI was not associated with measured weight changes at 27 weeks postpartum, however postpartum weight changes did positively correlate with GWG (Butte *et al.,* 2003). In another small UK study (*n*=47), obese women were heavier at 6 months postpartum in comparison to their measured weight at 13 weeks gestation, demonstrating weight retention in this obese cohort (Soltani & Fraser, 2000). However these studies are limited by their small sample sizes in conclusively determining whether PPWR differs according to baseline BMI.

In relation to postpartum changes in body composition, data is even scarcer. One South Korean study (*n*=41), which used MF BIA (InBody 720; Biospace, Seoul, Korea) to measure maternal body composition, found that although weight decreased at 6 weeks postpartum, FM increased by 9.7%, which led to an increase in overall percentage body fat (Cho *et al.,* 2011). This study, however, did not analyse changes in postpartum body composition by early pregnancy BMI category or GWG.

A further small study used a four component body composition model to compute FM in 63 non-smoking, physically active (20-30 minutes of moderate exercise at least three times per week) women (Butte *et al.,* 2003). They found that although there was a tendency for women in the high pre-pregnancy BMI group (≥26.0 kg/m^2) to retain more weight and FM at 27 weeks postpartum than the normal (19.8-26.0 kg/m^2) and low-BMI (≤19.8 kg/m^2) groups, the differences were not significant. PPWR correlated positively with GWG however (r = 0.67, *P*=0.001), and with total FM gain (r = 0.61, *P*=0.001). Postpartum fat retention correlated positively with GWG (r = 0.56, *P*=0.001) and with total fat mass gain (r = 0.57, *P*=0.001). Maternal fat retention at 27 weeks after delivery (5.3 kg) was significantly higher in women who gained above IoM recommendations for weight gain compared with those women who gained

within (2.3 kg) or below (0.5 kg) recommendations. However this study relied on a small sample size and assessed postpartum weight and body composition changes according to the IoM categorization for BMI and GWG.

Infant feeding method, SES, PAL, and dietary practices may play a role in postpartum weight and body composition changes and the literature regarding these topics is discussed in further detail in Chapter 7 and Chapter 8.

6.1 Aims

It has been highlighted that research in the area of postpartum weight and body composition changes is needed. There is a lack of studies where postpartum changes in BMI category are examined. Studies investigating changes in postpartum body composition rely on small sample sizes. Thus our aims were to examine trajectories in maternal weight and body composition between the first antenatal visit and four and nine months postpartum and to analyse these trajectories according to baseline (early pregnancy) BMI category.

6.2 Methods

Women were recruited at their convenience between February and August 2013 after an ultrasound examination confirmed an ongoing singleton pregnancy as outlined in Chapter 2. Height was measured to the nearest centimetre using a Seca wall-mounted digital height measure with the woman standing in her bare feet. Weight and body composition were measured using 8-electrode BIA (Tanita MC 180, Tokyo, Japan) and BMI was calculated. Written informed consent was obtained. Women were invited back to the hospital at approximately four and nine months postpartum.

6.2.1 Inclusion and exclusion criteria

The main inclusion criterion was presentation for antenatal care following ultrasound examination and confirmation of a singleton ongoing pregnancy in the first trimester. To reduce the number of confounding variables, the exclusion criteria were multiple pregnancies, maternal age < 18 years, and booking gestational age >18 weeks. Women, who delivered elsewhere, usually due to emigration, were also excluded, because follow-up details were not available.

6.2.2 Statistical analysis

Data analysis was carried out using SPSS version 20.0 (IBM Corporation, Armonk, New York). The characteristics of the women who returned for their second follow-up visit were compared to those who did not return using independent samples t-tests and Chi-square analyses.

Longitudinal changes in weight and body composition between early pregnancy, four months postpartum and nine months postpartum were analysed using the Friedman test and the Wilcoxon signed rank test, conducted with a Bonferroni correction. The Friedman test is a non-parametric test used to assess changes in the same sample over three or more time points. The Wilcoxon signed rank test assesses where, if any the significant difference occurs. Bonferroni correction is used to avoid Type one error.

Analyses between early pregnancy BMI and weight and body composition changes at four and nine months postpartum were displayed graphically using multiple line charts. Kruskal Wallis was used to assess if changes in weight and body composition at four and nine months postpartum varied according to early BMI status. Wilcoxon signed rank test were used to assess changes in weight and body composition at four and nine months postpartum according to early

pregnancy BMI status. Changes in postpartum BMI categorization were assessed using cross-tabulation with Chi-square analyses and displayed graphically using a bar chart.

6.3 Results

The number of women initially enrolled in the first trimester was 1035. Of the 1035 women, 98% (*n*=1018) delivered a live born baby in the Hospital. Women returned for their four month postpartum appointment (*n*=494) at 18.0 ± 2.2 weeks postpartum and their nine month postpartum appointment (*n*=328) at 39.8 ± 3.6 weeks. The characteristics of the study population who returned for their four and nine month postpartum appointments compared with women who did not attend are shown in Table 6.2.Women who did not attend at four and nine months were more likely to be younger and more likely to be current smokers.

Table 6.2: Characteristics of attendees versus non-attendees at four months and nine months postpartum (*n*=494)

	Comparison of Antenatal Characteristics between Attendees versus Non-Attendees at Four months Postpartum			Comparison of Four months Postpartum Characteristics of Attendees versus Non-Attendees at Nine months Postpartum		
	Attendees (*n*=494)	Non-Attendees (*n*=524)	*P*	Attendees (*n*=328)	Non-Attendees (*n*=166)	*P*
Age (years)[1]	30.9 ± 5.1	28.9 ± 5.6	0.001	32.0 ± 4.9	30.9 ± 5.2	0.02
Weight (kg)[1]	69.4 ± 15.0	69.8 ± 15.1	*NS*	71.0 ± 14.2	70.5 ± 14.1	*NS*
BMI (kg/m^2)[1]	25.3 ± 5.3	25.8 ± 5.6	*NS*	25.8 ±4.8	25.9 ± 5.2	*NS*
Birthweight (g)[1]	3.5 ± 0.5	3.4 ± 0.6	0.01	3.5 ± 0.5	3.5 ± 0.5	*NS*
Smoking in Early Pregnancy % (*n*)	9.7 (48)	20.8 (109)	0.001	11.7 (37)	20.2 (32)	0.02
Primiparous % (*n*)	43.9 (217)	38.2 (200)	*NS*	46.3 (152)	36.8 (61)	0.04
Living in Dublin % (*n*)	67.4 (333)	73.9 (387)	*NS*	59.4 (195)	72.3 (120)	*NS*

[1] mean ± SD

Table 6.3 shows the longitudinal changes in maternal weight and body composition which occurred between early pregnancy and four and nine months postpartum (*n*=328). Wilcoxon signed rank tests, conducted with a Bonferroni correction, showed significant increases in weight (r=0.46; z=-8.5 (*P*<0.001)), BMI (r=0.47; z=-8.43 (*P*<0.001)), % FM (r=0.17; z=-3.07 (*P*<0.001)) and FM (r=0.43; z=-5.50 (*P*<0.001)) between early pregnancy and four months postpartum. Conversely, significant decreases in weight (r=0.43; z=-7.9 (*P*<0.001)), BMI (r=0.40; z=-7.4 (*P*<0.001)), % FM (r=0.44; z=-8.1 (*P*<0.001)) and FM (r=0.45; z=-8.2 (*P*<0.001)) were observed between four months and nine months postpartum. A significant increase in FFM was observed between early pregnancy and four months postpartum (r=0.42; z=-7.7 (*P*<0.001)) and between early pregnancy and nine months postpartum (r=0.31; z=-5.6 (*P*<0.001)). However, there was no significant change in FFM between four and nine months postpartum.

Table 6.3: Longitudinal changes in body weight and composition (*n*=328)

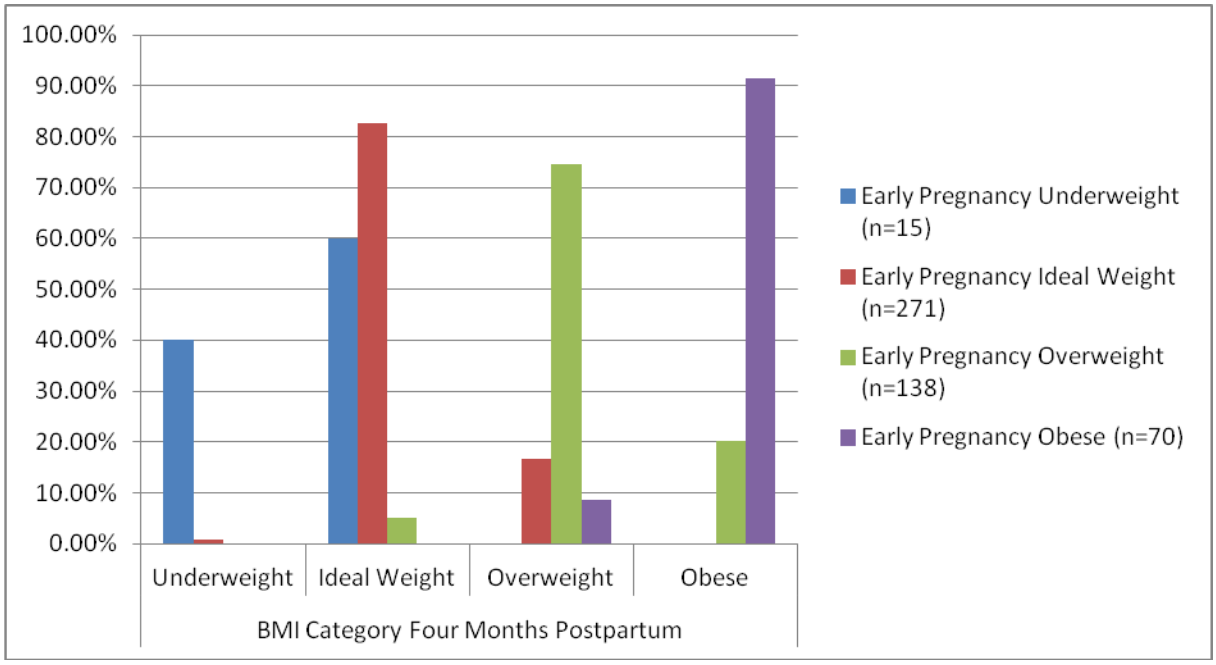
	Early Pregnancy[1]	**4 Months Postpartum**[1]	**9 Months Postpartum**[1]	**X^2**	***P***
Weight (kg)	66.7 (18.2)	68.5 (19.3)	66.0 (20.2)	81.2	(<0.001)
BMI (kg/m^2)	24.1 (6.1)	24.6 (6.7)	24.0 (6.0)	77.4	(<0.001)
% Fat Mass	30.8 (10.0)	31.4 (10.9)	30.0 (11.5)	46.6	(<0.001)
Fat Mass (kg)	20.1 (12.8)	21.5 (13.5)	19.2 (13.7)	53.4	(<0.001)
Fat Free Mass (kg)	46.8 (8.1)	47.5 (7.7)	47.4 (8.3)	39.2	(<0.001)

[1] median (IQR), P value analysed using Friedman test (significant change in the same women occurring over the three time points)

At four months postpartum the median change in weight from the first antenatal visit was +1.5 (IQR 4.8) kg (mean +1.6 ± 4.2 kg) the median change in BMI was +0.5 (IQR 1.8) kg/m^2 (mean +0.6 ± 1.5 kg/m^2), and 19.2% were obese. Of the 494 women who returned at this time, 330 (66.8%) had gained weight between their booking visit and their four month postpartum

follow-up. At nine months postpartum, the median change in weight from early pregnancy was 0.0 (IQR 5.2) kg (mean +0.2 ± 4.7 kg), the median change in BMI from early pregnancy was -0.1 (IQR 2.1) kg/m^2 (mean -0.06 ± 1.8 kg/m^2), and 16.8% were obese. Of the 328 women who returned, 166 (33.6%) had gained weight between their booking visit and their nine month postpartum follow-up.

Changes in BMI categorization between early pregnancy, four months postpartum and nine months postpartum are shown in Figure 6.1. Of the women who had an ideal BMI in early pregnancy, 16.6% and 11.1% were overweight at four and nine months postpartum respectively. Of the women who were overweight in early pregnancy, 20.3% and 14.3% had become obese at four and nine months postpartum respectively. Ninety percent of women who were obese in early pregnancy remained obese at four and nine months postpartum.



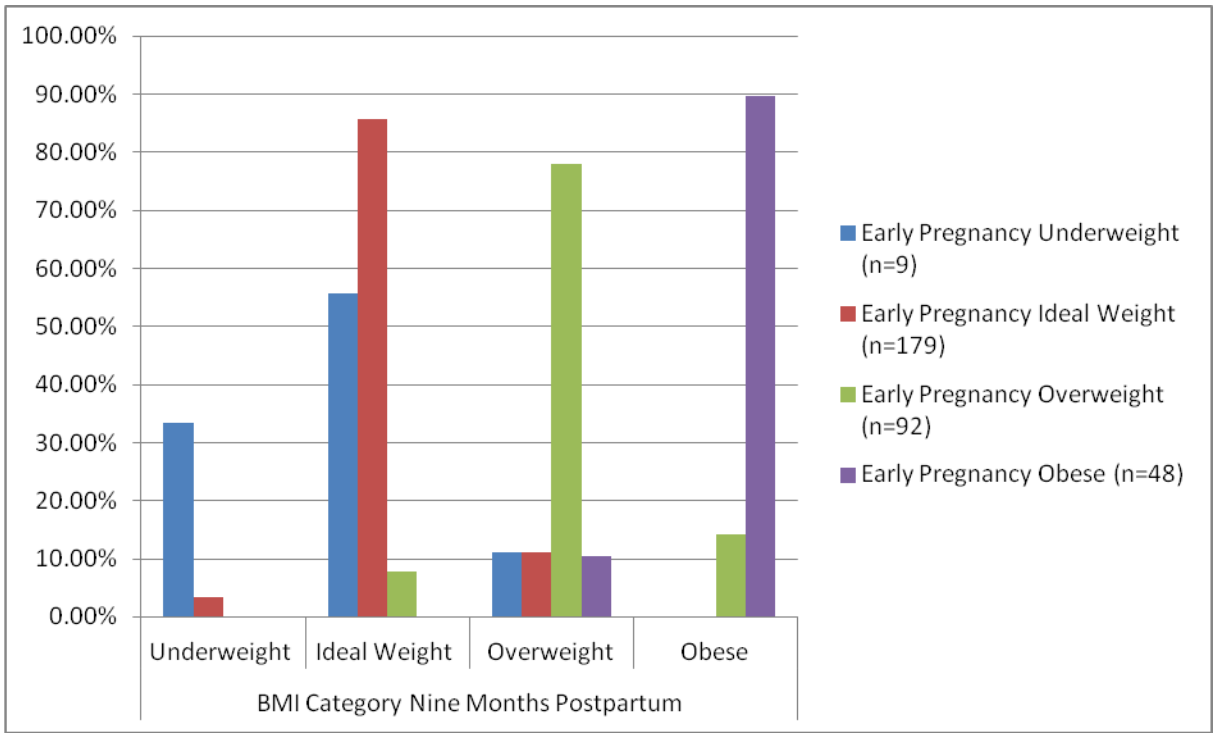


Figure 6.1: The change in BMI categorization at four and nine months postpartum according to early pregnancy BMI

Women who had ideal weight in early pregnancy had mean gains in weight (P<0.001), BMI (P<0.001), % FM (P=0.016), FM (P<0.001), and FFM (P<0.001) between early pregnancy and four months postpartum. Women who were overweight in early pregnancy had mean gains in weight (P<0.001), BMI (P<0.001), % FM (P=0.008), FM (P<0.001), and FFM (P<0.001) between early pregnancy and four months postpartum. It is notable that women who were obese in early pregnancy (n=48) however, experienced mean losses of weight (P=0.01), BMI (P=0.01), %FM (P=0.001), FM (P=0.003) and FFM (P=0.743) loss from early pregnancy to four months postpartum (-1.6 kg, -0.65 kg/m^2, -1.1%, -1.6 kg, -0.2 kg respectively) (Figures 6.2-6.6).

Between four and nine months postpartum, 233 women (71%) lost weight. Women who had ideal weight in early pregnancy had mean losses in weight (P<0.001), BMI (P<0.001), FM (P<0.001), % FM (P<0.001), and FFM (P=0.04) between four and nine months postpartum. Women who were overweight in early pregnancy had mean losses in weight (P<0.001), BMI (P<0.001), FM (P<0.001), % FM (P<0.001), and FFM (P=0.398) between four and nine months postpartum. Women who were obese in early pregnancy however, experienced mean increases in weight, BMI, and FFM gain (0.3 kg, 0.1 kg/m^2 and 0.5 kg respectively), as well as a reduction in FM (-0.15 kg) and % FM (-0.5%) between four and nine months postpartum (all P=NS) (Figures 6.2-6.6).

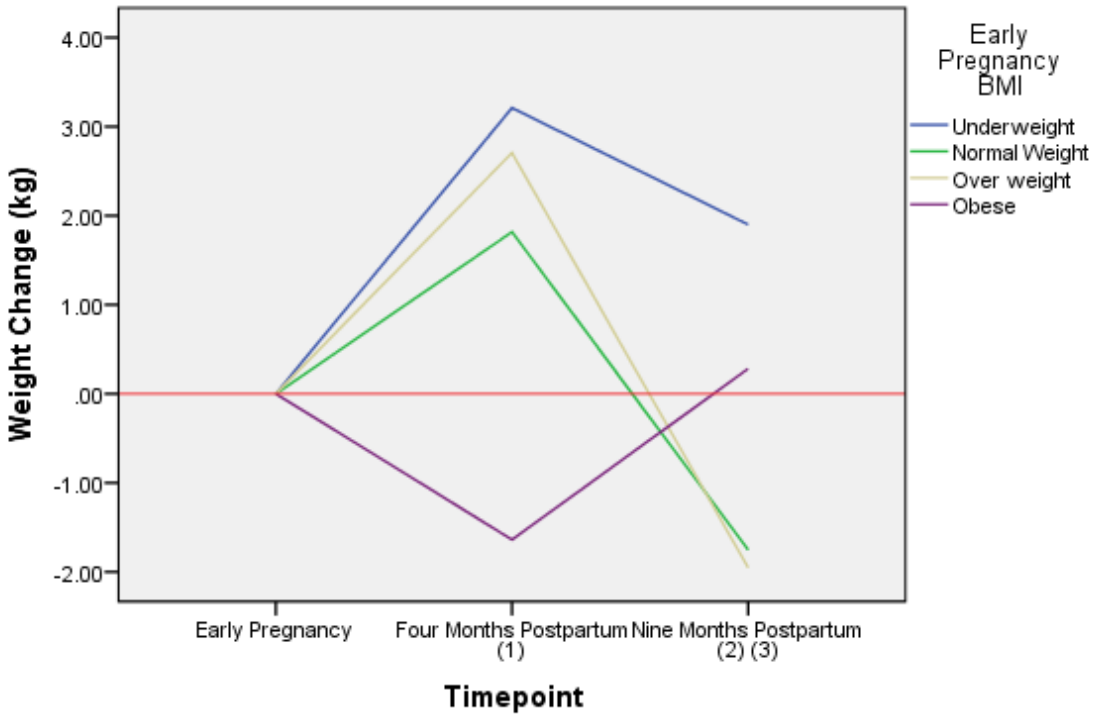


Figure 6.2: Changes in weight between four and nine months postpartum analysed by early pregnancy BMI (*n*=328)
(1) *P*<0.001 between BMI categories between early pregnancy and four months postpartum

(2) *P*=0.001 between BMI categories between four and nine months postpartum

(3) *P*=0.01 between BMI categories between early pregnancy and nine months postpartum

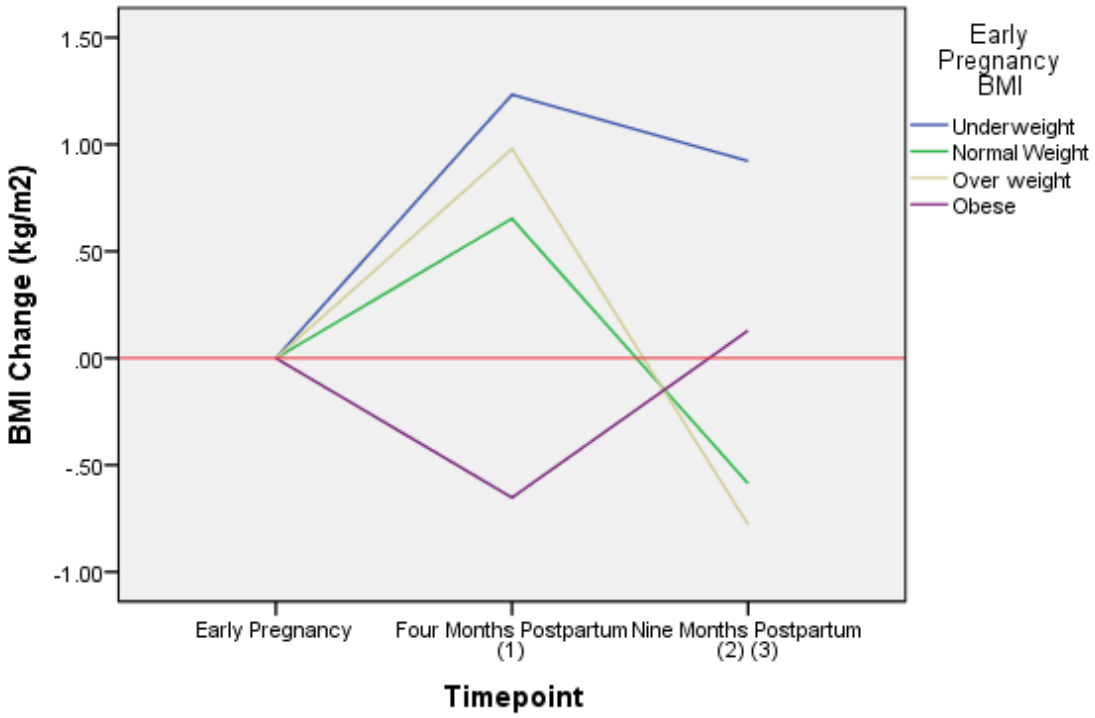


Figure 6.3: Changes in BMI between four and nine months postpartum analysed by early pregnancy BMI (*n*=328)

(1) *P*<0.001 between BMI categories between early pregnancy and four months postpartum

(2) *P*=0.001 between BMI categories between four and nine months postpartum

(3) *P*=0.02 between BMI categories between early pregnancy and nine months postpartum

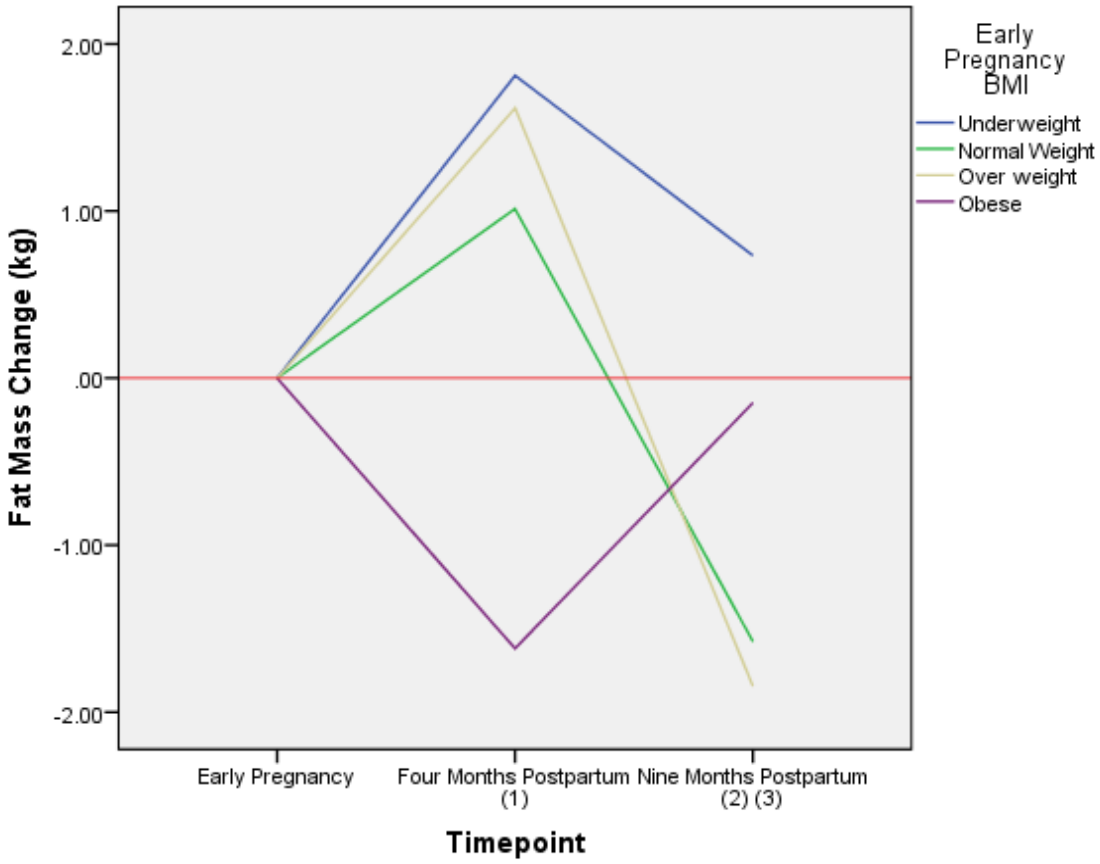


Figure 6.4: Changes in fat mass between four and nine months postpartum analysed by early pregnancy BMI (*n*=328)

(1) *P*<0.001 between BMI categories between early pregnancy and four months postpartum

(2) *P*=0.01 between BMI categories between four and nine months postpartum

(3) *P*=0.054 between BMI categories between early pregnancy and nine months postpartum

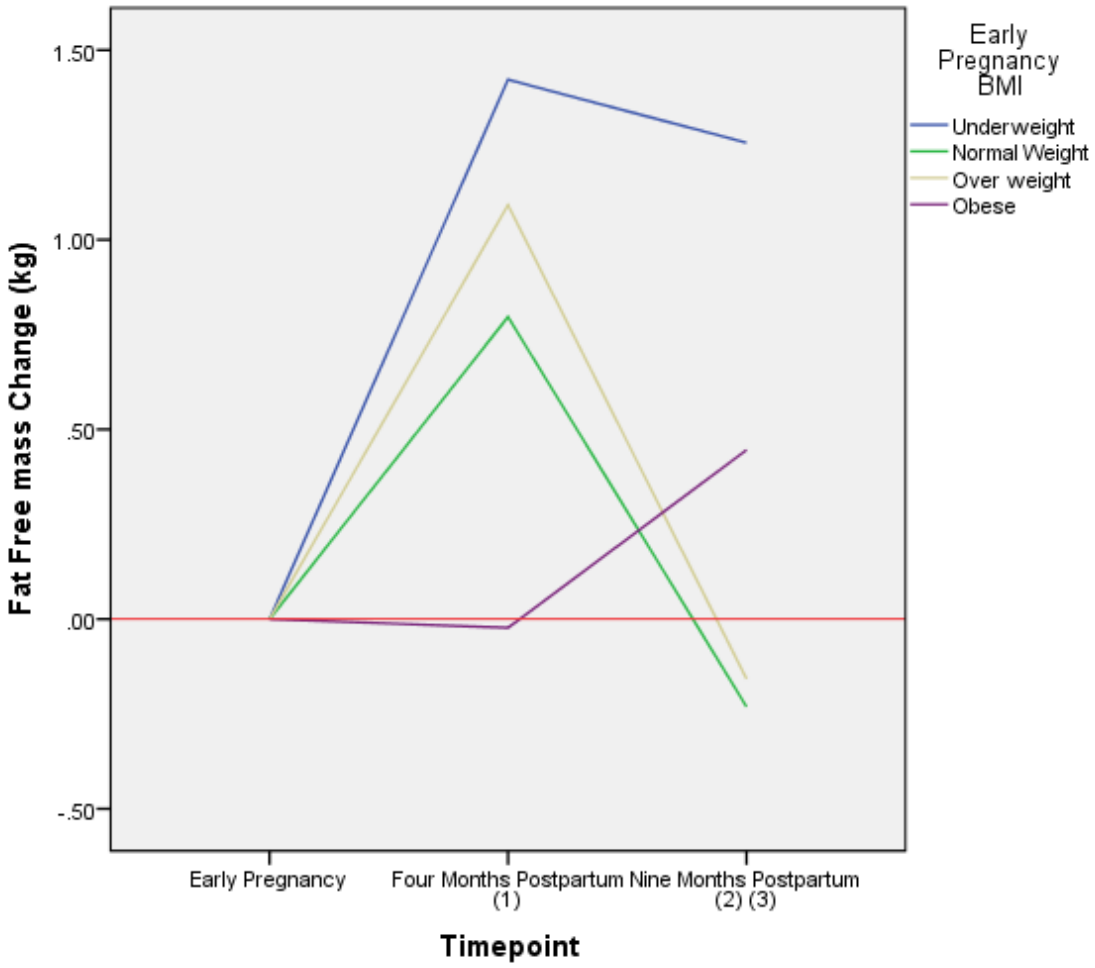


Figure 6.5: Changes in fat free mass between four and nine months postpartum analysed by early pregnancy BMI (*n*=328)

(1) *P*=0.006 between BMI categories between early pregnancy and four months postpartum

(2) *P*=0.102 between BMI categories between four and nine months postpartum

(3) *P*=0.07 between BMI categories between early pregnancy and nine months postpartum

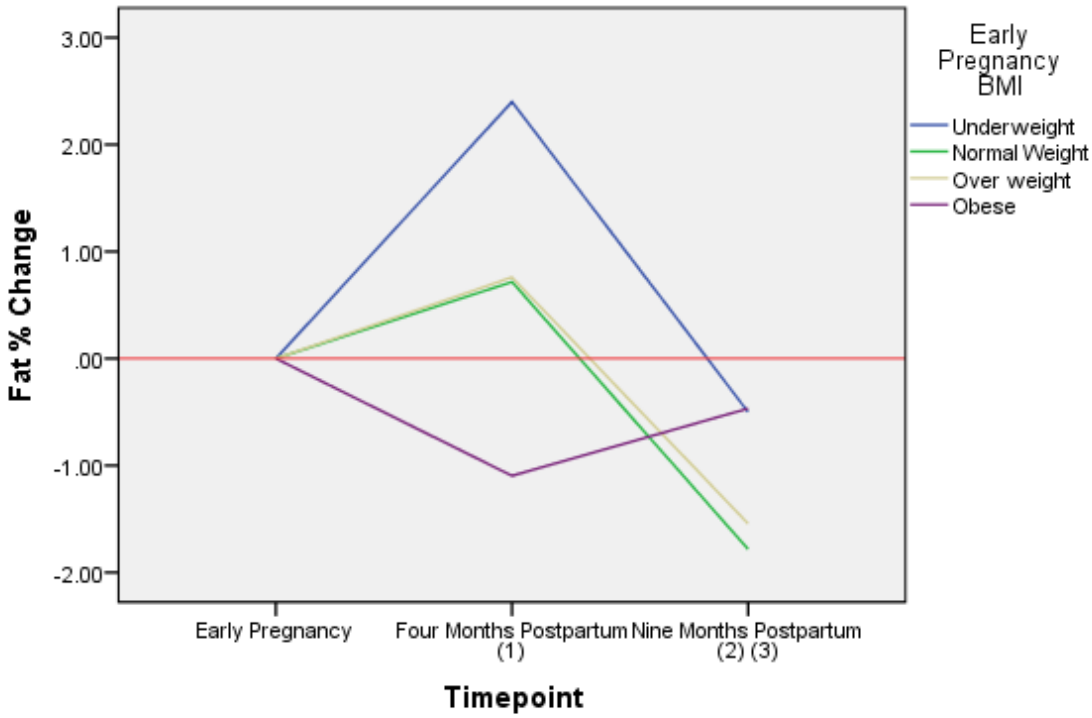


Figure 6.6: Changes in fat percentage between four and nine months postpartum analysed by early pregnancy BMI (*n*=328)

(1) *P*=0.001 between BMI categories between early pregnancy and four months postpartum

(2) *P*=0.04 between BMI categories between four and nine months postpartum

(3) *P*=0.239 between BMI categories between early pregnancy and nine months postpartum

6.4 Discussion

This large, longitudinal observational study found that maternal weight trajectories after pregnancy are not linear and that there are different trajectories in obese compared with non-obese women. Furthermore, changes in maternal body composition post pregnancy are not linear, and also differ between obese compared and non-obese women. These novel findings have important implications for the design of future research studies and public health interventions targeting PPWR.

A strength of this paper is that we cannot find a larger sample of women where maternal weight trajectories have been based on accurate measurement, and not self-reporting, which has been shown to be unreliable (Fattah *et al*., 2009; Turner, 2011). The study also fills a knowledge gap by assessing weight and body composition trajectories according to participants' WHO BMI categorization at the first antenatal visit.

Its longitudinal design means that exact weight gains and losses could be tracked according to BMI category in early pregnancy. If assessed cross-sectionally at each of the three time points it would appear that weight goes up in the initial four months postpartum but reverts to early pregnancy levels by nine months postpartum. However when assessed longitudinally, underweight and obese women are gaining weight between early pregnancy and nine months postpartum and end up heavier, whereas ideal and overweight women are losing weight. These findings would not be captured by simply examining cross-sectional data at these three time points. Furthermore, longitudinal changes in maternal body composition postpartum measured using advanced BIA have not previously been reported.

A potential weakness of the study is the large number of women who did not re-attend their scheduled postpartum visits. This attrition may be explained by the fact that women were re-attending on a voluntary basis without any financial incentive. This loss to follow-up may also be attributable to the logistical challenges of returning to the maternity hospital for a research study, for a mother with a new baby and/or other children. Some of the women may also have migrated outside the hospital catchment area or may have left the country within nine months of delivery. The follow-up of women in the first year after delivery of their baby in a population based research study is particularly challenging, which may explain why there are such large gaps in our knowledge on postpartum weight changes (NICE, 2010).

A previous Irish longitudinal study found that two thirds of first time mothers had gained weight when they re-attended for antenatal care on their next pregnancy and as a result, one in 5 women had moved into a higher BMI category, and one in 20 women had become obese, according to their WHO BMI categorization (Crosby *et al.,* 2015). In an American study (*n*=550) where the IoM guidelines were used to categorize BMI, 14.2% of women who started pregnancy with an ideal weight (BMI 19.8 to 26.0 kg/m^2) became overweight by 12 months postpartum (Siega-Riz *et al.,* 2010). Among women who were overweight (BMI >26.0 to 29.0 kg/m^2), 40% became obese (>29.0 kg\m^2) by 12 months postpartum. However, this study relied on maternal self-reporting of pre-pregnancy weight. In our study, 90% of women who were obese in early pregnancy remained obese at nine months postpartum. Of ideal weight women, 16.6% and 11.1% were overweight at four and nine months postpartum respectively. Of overweight women, 20.3% and 14.3% had become obese at four and nine months postpartum respectively. Interventions are, therefore, required to help prevent all women with a BMI > 18.5 kg/m^2 from moving into a higher BMI category in the postpartum period.

There is a paucity of studies tracking postpartum body composition changes from early pregnancy according to BMI status. A small study of 63 women measured maternal weight changes and used a four component body composition model to compute fat mass, and the IoM guidelines to categorise BMI (IoM, 1990; Butte *et al.,* 2003). This study found that although there was a tendency for women in the high BMI (≥26.0 kg/m^2) (*n*=12) group to retain more weight and fat mass at 27 weeks postpartum than the ideal (19.8-26.0 kg/m^2) (*n*=34) and low (≤19.8 kg/m^2) (*n*=17) BMI groups, these differences were not significant. To our knowledge, our study is the largest to date measuring postpartum changes in maternal body composition in women of all WHO BMI categories.

Interventions to reduce maternal weight in the postpartum period have shown mixed results. Some studies show that diet and exercise interventions in this period are associated with improved postpartum weight loss (Lovelady *et al.,* 2000; O'Toole *et al.,* 2003; Craigie *et al*., 2011; Davenport *et al.,* 2011; Bertz *et al.,* 2012; Colleran *et al*., 2012). However, the majority of these trials have relied on small sample sizes and are not representative of the broader population as their participants were either overweight or obese and/or breastfeeding. In addition, these trials did not analyse changes in individual maternal postpartum BMI category among their participants.

The Active Mothers Postpartum (AMP) trial was a dietary, physical activity and behavioural change intervention for 9 months postpartum among overweight (*n*=180) and obese (*n*=270) women. This US trial is one of the largest interventions to date in this area, and did not detect improvements in postpartum weight loss, or improvements in diet or exercise levels in the intervention group. The authors attributed the lower than expected participation rates in this study to women's inability to attend classes or other group format interventions while caring for

an infant during this challenging period of life (Ostbye *et al.*, 2009). NICE (2010) recognize that for weight management before, during and after pregnancy, a population based approach is needed to reach all women of childbearing age because many pregnancies are unplanned (NICE, 2010). Our data further support the need for effective postpartum interventions to reduce PPWR in women of all BMI categories.

There is also a lack of data concerning the most effective time for women to initiate weight management after childbirth (NICE, 2010). Obese women in this study increased their weight between four and nine months postpartum. However, weight gained by these obese women between four and nine months was disproportionately FFM, with a decline in % FM, highlighting the importance of body composition analysis in assessing weight trajectories in the postpartum period. Women with a normal BMI had weight, BMI, % FM, and FFM gains up to four months postpartum, however, these women had a FFM loss between four and nine months postpartum. This information is important for the design of research studies and public health interventions intended to tackle the clinical challenges of maternal obesity. For example, weight loss interventions in previously ideal weight mothers might emphasise physical activity and perhaps other measures known to preserve lean tissue mass, while those targeted at obese women might emphasise dietary calorie restriction. In light of our findings, the behavioural and other characteristics of women who gained weight or fat mass postpartum such as dietary practices, PALs, infant feeding practices and SES need to be examined.

6.5 Conclusions

Collectively, weight, BMI, % FM, FM and FFM all appeared to increase between early pregnancy and four months postpartum, and to decrease between four and nine months

postpartum in this obstetric cohort. However, when analysed by BMI category, obese women, in aggregate, lost weight until four months postpartum, and experienced a "re-bound" in weight gain between four and nine months postpartum. However, our data indicate that the weight gained by these obese women between four and nine months is disproportionately FFM, with a decline in % FM during this time. Conversely, the ideal and overweight women in this cohort gained weight between early pregnancy and four months postpartum, and subsequently lost weight between four months and nine months postpartum. In this instance however, the apparently favourable weight loss observed among these women is characterised by a disproportionate loss of FFM, which ultimately yielded a higher % FM among these women. These findings highlight the value of body composition analysis in measuring weight trajectories in the postpartum period.

Maternal obesity has emerged as one of the most important challenges in contemporary obstetrics because it is associated with an increase in both adverse fetal and maternal outcomes. To date, interventions to manage body weight in pregnancy and improve obstetric outcomes have had little or no success. Our finding that maternal weight changes in the first nine months postpartum are not linear, that they differ between obese and non-obese women, that a significant number of women become obese within nine months of delivery, and that weight changes experienced in the postpartum period need to be qualified by assessment of body compositional changes during this time, should all help to inform the design of future interventions aimed at addressing PPWR.

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Chapter 7

Breastfeeding and Weight and Body Composition Changes at Four Months Postpartum

7.0 Introduction

This chapter is based on the publication **(Appendix 6)**:

Mullaney L, O'Higgins AC, Cawley S, Kennedy R, McCartney D, Turner MJ (2015) Breast-feeding and postpartum maternal weight trajectories. *Public Health Nutr* e-pub ahead of print 2015/10/15.

The Ph.D. candidate's contribution was data collection, data preparation, statistical analysis, and writing of the manuscript.

7.0.1 Benefits of breastfeeding and breastfeeding recommendations

The multiple maternal and infant benefits of breastfeeding are widely established (IoM, 1991; AAP, 2012). Breastfeeding has been associated with benefits for the mother including reduced risk of type 2 diabetes, breast and ovarian cancer, and postpartum depression; and also with benefits for the infant including reduced risk of obesity, type 1 and 2 diabetes, asthma, and non-specific gastroenteritis. The risks of not breastfeeding therefore include increased rates of infant and maternal morbidity and mortality, increased health care costs, and significant economic losses to families and employers (IoM, 1991; Bartick & Reinhold, 2010; AAP, 2012; Bartick, 2013; Bartick *et al.*, 2013).

As a result, breastfeeding continues to be recommended by multiple national and international health organisations and agencies (WHO, 2003; AAP, 2012; FSAI, 2011; RCPI, 2014). In the US, the American Academy of Pediatrics (AAP) recommends that infants be EBF to 6 months of age, at which point appropriate complementary foods should be introduced and breastfeeding should continue until the infant is at least one year of age or as long as mutually desired by mother and infant (AAP, 2012). The WHO extends this recommendation to two years or beyond (WHO, 2003). The Academy of Nutrition and Dietetics in the US recommends 'that exclusive breastfeeding provides optimal nutrition and health protection for the first 6 months of life, and that breastfeeding with complementary foods from 6 months until at least 12 months of age is the ideal feeding pattern for infants'(Academy of Nutrition and Dietetics, 2015).

7.0.2 Factors influencing breastfeeding

In Ireland, breastfeeding rates (either exclusive or complimentary breastfeeding) on discharge from hospital/within the first 48 hours after birth, increased from 48% to 54% between 2005 and 2010 (McAvoy *et al.*, 2014). Analysis of nationally representative data from the Growing Up in Ireland (GUI) survey has provided a snapshot of breastfeeding duration for infants born in Ireland in 2007/2008. Of those women who initiated breastfeeding (both EBF and partial breastfeeding *n*= 6,580), half were still breastfeeding at three months and one in four were still breastfeeding at 6 months, with a sharp decline at the 6 month point. Among mothers who practiced partial breastfeeding soon after birth, a sharp decline in breastfeeding was observed within the first three months. Thus, breastfeeding duration in Ireland fell considerably below the WHO recommendations on EBF for the first six months of life. Around 97% of mothers of 9 month olds reported that their infant had received an infant formula product at some stage (McAvoy *et al.*, 2014).

7.0.2.1 High pre-pregnancy and postpartum BMI and breastfeeding practices

Pre-pregnancy overweight and obesity has been shown to be associated with early termination of breastfeeding (Oddy *et al.,* 2006; Mok *et al.,* 2008; Liu *et al.,* 2010; Guelinckx *et al.,* 2012). As pre-pregnancy BMI increases, there is a progressively higher risk of terminating full or partial breastfeeding earlier (Baker *et al.,* 2007; Liu *et al.,* 2010; Krause *et al.,* 2011). Correspondingly, high maternal BMI is negatively associated with breastfeeding duration and intensity (Krause *et al.,* 2011).

7.0.2.2 Pregnancy and labour complications and breastfeeding practices

Obese and overweight women are at increased risk of pregnancy related complications (Ramachenderan *et al.,* 2008). Kitsantas & Pawloski (2010) found that women with medical complications during pregnancy and/or labour complications who were overweight or obese pre-pregnancy were less likely to initiate breastfeeding than their ideal weight counterparts. Also, women in this group who did initiate breastfeeding were more likely to cease breastfeeding earlier than their ideal weight counterparts. Interestingly, no difference in breastfeeding initiation was detected between overweight and obese women with no medical or labour complications, and their ideal weight counterparts. However these overweight and obese women ceased breastfeeding earlier than their ideal weight peers, showing that while overweight and obese women with no medical or labour complications may be able to initiate breastfeeding, they may need additional continued support to maintain breastfeeding.

7.0.2.3 Socio-demographic variables and breastfeeding practices

Significant risk factors for early cessation of breastfeeding include young maternal age (Lande *et al.,* 2003; Kehler *et al.,* 2009), lower maternal education (Baker *et al.,* 2007; Kehler *et*

al., 2009), lower SES (Donath & Amir, 2007; Amir & Donath, 2008), and not being married (Lande *et al.,* 2003). In the US, black women are observed to have lower breastfeeding initiation rates and shorter breastfeeding durations than white women suggesting psychosocial and cultural barriers to breastfeeding among black women (Liu *et al.,* 2010). Conversely, being born in an Asian country is associated with a longer duration of breastfeeding (Forster *et al.*, 2006). It has also been consistently shown in studies that smoking is negatively associated with breastfeeding duration (Lande *et al.,* 2003; Giglia *et al.,* 2006; Baker *et al.,* 2007; Kehler *et al.,* 2009).

7.0.2.4 Biological variables and breastfeeding practices

Overweight and obesity is associated with delayed lactogenesis (Dewey *et al.,* 2003; Hilson *et al.,* 2004). Rasmussen & Kjolhede (2004) found that overweight and obese women have a lower prolactin response to suckling at 48 hours postpartum than women of ideal bodyweight. During this early stage of lactogenesis, prolactin response is more important for milk production than later on in lactation, thus a lower prolactin production in overweight and obese women may be a reason for early cessation of full breastfeeding.

Mok *et al.* (2008) found that a greater proportion of obese women who breastfed reported difficulties e.g. cracked nipples, fatigue, and difficulty initiating breastfeeding; versus ideal weight breastfeeding mothers. Fewer obese mothers perceived milk supply as adequate and a greater proportion of obese mothers reported feeling uncomfortable breastfeeding in the presence of others compared to their ideal weight peers.

Caesarean section rates are higher among obese mothers (Oddy *et al.,* 2006; Kitsantas & Pawloski, 2010). This is relevant because caesarean sections are associated with delayed onset of lactation and poor breastfeeding performance (Dewey *et al.,* 2003; Baker *et al.,* 2007). They also

result in longer recovery periods and often in increased complications which can compromise the mother's ability to breastfed by increasing mother child separation and forcing the mother to concentrate more on her own recovery than on breastfeeding (Perez-Rios *et al.,* 2008).

Numerous studies have investigated the effect of parity on breastfeeding duration. Some studies show a longer duration of breastfeeding with increased parity (Lande *et al.,* 2003; Simard *et al.,* 2005). For example, Kronborg & Vaeth (2004) found that among multiparous women, previous experience of extended breastfeeding had a significant positive impact on the duration of the current breastfeeding period. Relative to mothers who breastfed the previous child for more than 17 weeks, mothers who breastfed the previous child for less than 5 weeks had an earlier cessation rate. The cessation rate was almost 8 times higher among women who breastfed their previous child for a shorter duration. They also found that higher breastfeeding knowledge among primiparous women was associated with longer breastfeeding duration.

7.0.2.5 Psychosocial variables and breastfeeding practices

Krause *et al.,* (2011) found that in a 12 month postpartum follow-up of women who had ever or were still breastfeeding their infant, reasons for doing so included weight loss for the mother, improved infant health, bonding with the infant, lower feeding costs and convenience. Although women stated that one of the reasons for breastfeeding was weight loss, this belief did not affect women's breastfeeding initiation and intensity (combining the duration and exclusivity of breastfeeding). Expectations regarding weight loss decreased from 6 weeks to 12 months postpartum. A higher expectation of weight loss over time and at 12 months postpartum was associated with lower breastfeeding intensity. Krause *et al.,* (2011) hypothesized that this may be

because women with persistently high, unrealistic expectations of achieving better weight loss with breastfeeding gave up on breastfeeding earlier.

Low maternal self-efficacy (a mother's confidence in her ability to carry out breastfeeding) has also been negatively associated with breastfeeding duration (Kronborg & Vaeth, 2004). A history of depression and/or anxiety during pregnancy has been shown to negatively affect breastfeeding duration (Taveras *et al.,* 2003; Forster *et al.,* 2006; Kehler *et al.,* 2009); however some studies show no association with depression and/or anxiety and breastfeeding duration in overweight and obese women (Mehta *et al.,* 2012).

Women who return to work or education early have also been shown to have shorter breastfeeding durations (Kehler *et al.,* 2009; Ogbuanu *et al.,* 2011), while women who breastfeed female infants, have been shown to have longer breastfeeding durations than those who breastfeed male infants (Lande *et al.,* 2003; Baker *et al.,* 2007).

7.0.3 Breastfeeding and postpartum weight changes

Breastfeeding has been suggested to promote postpartum weight loss, due to the caloric expenditures required for lactation (Dewey, 1997) or metabolic changes that are favourable to weight loss (Stuebe & Rich-Edwards, 2009). However studies have shown that women may compensate for the extra energy requirements of lactation by increasing EI and decreasing their energy expenditure by reducing PAL (Butte *et al.,* 1984; Goldberg *et al*., 1991; Butte *et al.,* 1999).

Thus the role of breastfeeding in postpartum weight changes is not clear. Some studies suggest that breastfeeding aids postpartum weight loss while others challenge that belief (Neville *et al.,* 2014). EBF has been associated with greater weight loss postpartum however, this

relationship has not been consistently demonstrated in all studies (Neville *et al.*, 2014). In an early US study (*n*=56), no differences in measured 6 month postpartum weight and body fat changes were observed between women who EBF, partially breastfed, and formula fed their infants. Mean daily EIs estimated from two 3-day food records were higher in women who EBF compared to women who partially breastfed or formula fed (Brewer *et al.*, 1989). A further study in Montreal (*n*=236) found no difference in self-reported nine months postpartum weight loss according to whether a woman predominantly breastfed or formula fed, or partially breastfed, even after adjusting for potential confounding variables e.g. GWG, smoking status, breastfeeding duration (Haiek et al., 2001). Several other studies have also reported that infant feeding practices are not associated with postpartum weight changes up to 18 months postpartum (Dugdale & Evans, 1989; Walker, 1996; Motil *et al.*, 1998; Butte *et al.*, 2003).

However, in the Danish National Birth Cohort study, a lactation score which reflected the energy requirements of lactating women was formulated (IoM, 2002). This lactation scale which captured both breastfeeding intensity and duration, was negatively associated with PPWR (calculated using self-reported pre-pregnancy and postpartum weights) in all women apart from those in the heaviest BMI categories (≥35.0 kg/m^2) at 6 (*n*=36,030) and 18 (*n*=26,846) months postpartum (Baker *et al.*, 2008). This study thus concluded that breastfeeding can contribute to maternal health by reducing PPWR.

In the Danish Lifestyle in Pregnancy (LiP) trial (*n*=360), obese women (BMI ≥ 30.0 kg/m^2) were randomized to either a diet and physical activity intervention (including individualised dietetic counselling performed by trained dieticians on four separate occasions during pregnancy) or to a control group (standard hospital care). The overall percentage of women initiating ‘full’ breastfeeding was 92%, and was comparable between the intervention

and control groups. 'Full' breastfeeding was defined as breastfeeding at 6 months postpartum without the introduction of formula feeding or solid food. For women with insignificant measured PPWR at six months postpartum, the percentage who initiated breastfeeding was higher than in women with significant PPWR (> 5 kg) (94% vs. 85%, P=0.034). A negative correlation was observed between full breastfeeding until 6 months postpartum and PPWR. However, neither breastfeeding initiation nor breastfeeding duration was associated with less weight retention at six months (Vinter *et al.*, 2014).

In one small study (n=104), women who breastfed for >16 weeks had lower measured postpartum weight gain at 6 to 8 months postpartum compared to women who did not breastfeed (To *et al.*, 2009). An Australian study (n=152) further found that for each additional week of any breastfeeding, 0.04 kg less weight was retained at 12 months postpartum (Martin *et al.*, 2014). This study however, relied on self-reporting of pre-pregnancy weight which is subject to bias (Fattah *et al.*, 2009; Turner, 2011).

A recent US study (n=2,102) examined if EBF for at least three months was associated with increased postpartum weight loss at six, nine and 12 months postpartum in comparison to women who had not breastfed or who had breastfed for less than three months. The main outcome of this study was self-reported weight change from the women's highest pregnancy weight to postpartum weights at six, nine and 12 months postpartum. Women who EBF for at least three months had a 0.59 kg (P<0.05), 1.68 kg (P<0.01) and 1.45 kg (P<0.05) greater weight loss at six, nine and 12 months postpartum respectively, in comparison to women who had not breastfed or who had breastfed for less than 3 months. EBF also increased the likelihood of returning to self-reported pre-pregnancy BMI. Additionally, EBF in the first 3 months postpartum led to a 2.7 percentage point greater weight loss at 12 months postpartum, relative to

not breastfeeding or breastfeeding non-exclusively, after adjusting for a range of confounding variables such as maternal education, age, parity, pre-pregnancy obesity and smoking status. This study however did not take into account maternal dietary and physical activity practices (Jarlenski *et al.,* 2014).

Similarly, an Australian study (*n*=2,231) found that women who breastfed for more than three months, had a reduced chance of high PPWR at 12 months postpartum compared to non-breastfeeding women (Ng *et al.,* 2014). All outcomes for these studies were based on self-reported weights. An American study (*n*=540), where early pregnancy weight and one year postpartum weight were measured however, found that women who breastfed for one year had decreased PPWR at one year postpartum (Olson *et al.,* 2003). This study also adjusted for maternal food intake and exercise levels. Women who exercised often ($P<0.001$) and ate less food ($P=0.04$) also retained less postpartum weight at one year. However any breastfeeding and the breastfeeding score (considers breastfeeding intensity and duration) at 6 months postpartum was not associated with PPWR at one year postpartum. Interestingly, ideal and low BMI women who exercised often retained less weight (-1.80 kg, $P=0.03$), however overweight and obese women who exercised often retained even less weight (-5.41 kg, $P=0.006$).

7.0.4 Breastfeeding and postpartum body composition changes

It has been hypothesised that fat may be accumulated during pregnancy and evidence from animal and human research suggests that lactation plays a role in mobilizing stored fat after delivery (Stuebe & Rich-Edwards, 2009). However, conflicting findings have emerged with regard to breastfeeding and its effect on maternal body composition. The majority of studies

report little or no association between breastfeeding and body composition changes. However, many of these studies rely on small sample sizes (Neville *et al.,* 2014).

In one study, body composition was measured using anthropometry and whole body potassium counting in 30 non-smoking women. This investigation found that lean body mass was preserved in well-nourished women who breastfed their infants exclusively between 6 and 24 weeks postpartum (Motil *et al.,* 1998). This observation presumably reflects the finding that the EBF women consumed >55% more protein and 40% more energy than non-lactating women suggesting that the metabolic needs of milk protein production were met solely by the higher protein and EIs of the lactating women. However other uncaptured differences (in PAL for example) may have existed between the groups which might have influenced these outcomes (Motil *et al.,* 1998). Lean body mass was also preserved in non-lactating women between 6 and 24 weeks postpartum. Fat mass between 6 and 24 weeks postpartum was lower in non-lactating women than EBF women, however this difference was not statistically significant. In this study, the thigh was the major site of fat mobilization not only in EBF women, but also non-lactating women.

Another small study used a four component body composition model to compute fat mass in 63 women (Butte *et al.,* 2003), and found no association between breastfeeding and body composition changes up to 27 weeks postpartum. Breast feeders however, had lower total body potassium than non-breastfeeders, which may suggest lean protein losses between 6 and 26 weeks postpartum (Butte *et al.,* 2003). A larger study (n=104) which used BIA (Tanita Corp, Tokyo, Japan) to measure postpartum weight changes, found no difference in body fat changes at 6 to 8 months postpartum in women who breastfed for >16 weeks compared to women who did not breastfed (To *et al.,* 2009). This study did not investigate changes in lean body mass and

pertinently used a broad categorisation for breastfeeding (e.g. women as either breastfeeding or not breastfeeding) without any consideration of EBF, mixed feeding rates or breastfeeding intensity.

7.1 Aims

The current study aimed to examine whether breastfeeding, and in particular EBF, was associated with maternal weight and body composition changes after delivery, independent of other variables such as diet, physical activity, smoking, SES and demographic differences.

7.2 Methods

Women were recruited at their convenience in the first trimester of pregnancy as outlined in the previous chapters. Socioeconomic, health behavioural, PAL, and dietary quality data were collected using the online tool as previously described. Height was measured to the nearest centimetre using a Seca wall-mounted digital height measure with the woman standing in her bare feet. Weight and body composition were measured using 8-electrode BIA (Tanita MC 180, Tokyo, Japan) and BMI was calculated. Written informed consent was obtained.

Women were invited back to the hospital at approximately four months postpartum. Socioeconomic, health behavioural, PAL and dietary quality data were again gathered at this visit, and the woman's weight, body composition and BMI.

7.2.1 Inclusion and exclusion criteria

The main inclusion criteria were attendance for antenatal care following ultrasound examination and confirmation of an ongoing singleton pregnancy in the first trimester. To reduce the number of confounding variables the main exclusion criteria were multiple pregnancies,

women < 18 years of age, and women with a booking gestation > 18 weeks at the first visit. Women who delivered elsewhere were also excluded.

7.2.2 Infant feeding practices

When they returned for their four month postpartum visit, women were asked, using the online tool, whether they had breastfed after delivery. Breastfeeding women were also asked at this postpartum visit, whether they had EBF (only breast milk, no formula) or engaged in partial breastfeeding (breast milk and formula combined). Women were asked how long they had breastfed for, with options ranging from '0 to 3 days', '4 to 6 days', '1 week' with weekly options up to '12 weeks'; '3 months' with monthly options to '5 months' to finally whether they were 'still breastfeeding'.

To capture both the intensity and duration of breastfeeding, we used a scale which reflects the energy costs of full and partial breastfeeding (IoM, 2002; Baker *et al.*, 2008). Women were assigned one point/week for EBF and 0.5 point/week for partial breastfeeding. The breastfeeding scale was used as a continuous scale.

7.2.3 Statistical analysis

Data analysis was carried out using SPSS version 20.0 (IBM Corporation, Armonk, New York). Baseline anthropometric characteristics of the women who returned for follow-up were compared to those of the total original sample using independent samples t-tests, to ensure that the final prospective cohort were representative of the broader study population. Age and anthropometric characteristics of the exclusive breast feeders were compared to those of the women who formula fed using independent samples t-tests. Cross-tabulation with Chi-square

analyses were used to test differences between the proportions of exclusive breast feeders and women who formula fed in different socioeconomic and health behavioural groups.

Binary logistic regression was performed to assess the unconfounded association between a number of putative influencing factors and participants' self-reported EBF and formula feeding practices. The final model comprised six independent variables (nativity, obesity, relative income poverty, relative deprivation, consistent poverty, nulliparity and current smoking status). Factors were included in the multivariate model based on a statistically significant association with infant feeding method upon univariate analyses ($P<0.05$).

Changes in maternal body weight and body composition between baseline and four months postpartum were compared between women who EBF and women who formula fed using Mann Whitney U tests as these data were non-normally distributed. PAL and dietary quality at four months postpartum were compared between the EBF women, partial breastfeeding women and those who formula fed using the Kruskal Wallis test.

Binary logistic regression was performed to assess the association between a number of factors and maternal weight gain and body fat percentage gain postpartum. The model contained eight independent variables (antenatal obesity status, nulliparity, stage of gestation at booking visit, dietary quality score, breastfeeding scale, PAL, EBF and infant birthweight).

7.3 Results

The total sample recruited initially in the first trimester was 1035 women and 98% (n=1018) delivered a live born baby in the Hospital between November 2012 and March 2014. At four months postpartum, 470 women agreed to return for repeat measurements for research purposes and completed the breastfeeding questionnaire. Women who returned for follow-up

(*n*=470) did not differ from the full baseline sample (*n*=1035) in weight, BMI or stage of gestation at booking visit. However, women who did not return were younger (28.9 vs. 30.9 years, *P*=0.001), and more likely to be current smokers (20.2 vs. 9.7%, *P*=0.001) than women who returned.

The mean stage of gestation at booking (*n*=470) was 12.4 ± 1.7 weeks and mean postpartum follow-up was at 18.0 ± 2.2 weeks. The mean age at recruitment was 30.8 ± 5.0 years. The mean antenatal weight was 69.2 ± 14.2 kg, and mean antenatal BMI was 25.3 ± 5.1 kg/m^2 with 14.9% of participants (*n*=70) obese. Forty-three per cent (*n*=213) of the women were nulliparous.

Table 7.1: Characteristics of the study population at 4 months postpartum analysed by postpartum infant feeding method (*n*=470)

	Formula Feeding (*n*=164)		**Partial Breastfeeding (*n*=114)**		**Exclusive Breastfeeding (*n*=192)**		***P***
Age (years)[1]	30.5	5.6	32.9	4.6	31.7	4.4	*NS*
Weight (kg)[1]	72.2	15.5	70.9	14.6	70.1	12.6	*NS*
BMI (kg/m^2)[1]	26.4	5.6	25.9	5.1	25.4	4.4	<0.05
Obese %	25.0		17.5		15.1		0.01
Nulliparous %	34.8		53.5		43.8		0.03
Irish Nativity %	94.5		63.2		60.4		<0.002
Currently Smoking %	22.6		10.5		9.9		<0.001
Caesarean Section %	17.7		24.6		20.3		*NS*
Risk of Poverty %[a]	23.8		6.2		11.5		0.002
Relative Deprivation %	29.3		18.4		13.0		<0.002
Consistent Poverty %	10.4		3.5		2.6		0.002
Any breastfeeding duration (days)[1]	0		56.8	43.5	86.0	46.6	<0.001**

[1] mean, standard deviation [a] Data available on *n*=469, *P* value testing significant difference between formula feeding and exclusive breastfeeding, ** *P* value testing significant difference between partial breastfeeding and exclusive breastfeeding, *P* value tested using independent samples t-test (continuous variables) and chi-square analyses (categorical variables).

The women's mean dietary quality score was 68.3 ± 26.0. Women who EBF had a mean breastfeeding scale score of 11.8 ± 5.2, and women who partially breastfed had a breastfeeding scale score of 4.1 ± 3.1. The mean postpartum weight was 70.9 ± 14.2 kg and the mean BMI was 25.9 ± 5.0 kg/m^2. The characteristics of the study population analysed by postpartum infant feeding method are shown in Table 7.1. Women who EBF reported breastfeeding for 86.0 ± 46.6 days (range 1.5 to 168 days using mid interval duration estimates), whereas women who partially breastfed reported breastfeeding for 56.8 ± 43.5 days (range 1.5 to 168 days using mid interval duration estimates) (P<0.001). When binary logistic regression was performed to assess the association between a number of maternal factors and the likelihood that women would EBF or not breastfeed; relative income poverty (P=0.04), deprivation (P=0.02), Irish nativity (P<0.001) and current tobacco use (P=0.01) remained negatively associated with EBF (Table 7.2).

Table 7.2: Binary logistic regression of postpartum factors associated with exclusive breastfeeding compared to formula feeding (*n*=356)

		n	**Odds Ratio**	**95.0% C.I.**		***P***
Nativity	Non-Irish	85	1.0[a]			
	Irish-born	271	0.085	0.04	0.2	<0.001
Obesity	Obese	70	1.0[a]			
	Non-obese	286	1.523	0.9	2.9	*NS*
Relative Income Poverty	Yes	61	0.421	0.2	1.0	0.04
	No	295	1.0[a]			
Relative Deprivation	Yes	73	0.458	0.2	0.9	0.02
	No	283	1.0[a]			
Consistent Poverty	Yes	22	1.715	0.4	7.6	*NS*
	No	334	1.0[a]			
Nulliparous	No	214	1.0[a]			
	Yes	142	1.225	0.8	2.0	*NS*
Smoking Currently	Former/Never	299	1.0[a]			
	Current	57	0.385	0.2	0.8	0.01

1.0[a] denotes reference category, C.I. confidence interval

There was no difference in maternal weight change from baseline to four months postpartum between women who EBF and those who did not breastfeed (Table 7.3). Women who EBF, however, had a greater increase in FM (*P*=0.03) and a greater increase in % FM (*P*=0.02) between early pregnancy and four months postpartum compared with non-breast feeders. We found no relationship between infant feeding method and postpartum changes in fat distribution (Table 7.4).

Table 7.3: Differences in maternal body weight and body composition changes between early pregnancy and four months postpartum according to infant feeding practices (*n*=470)

	Formula Feeding[1] (*n*=164)		**Partial Breastfeeding[1] (*n*=114)**		**Exclusive Breastfeeding[1] (*n*=192)**		***P*[a]**
Weight (kg)	+1.1	(-18.8 to 17.8)	+1.7	(-7.6 to 10.2)	+2.0	(-8.2 to 17.9)	*NS*
Fat Mass (kg)	+0.4	(-14.8 to 13.3)	+0.8	(-9.1 to 9.2)	+1.2	(-6.3 to 10.8)	0.03
Percentage Body fat (%)	-0.03	(-9.8 to 9.1)	+0.4	(-8.5 to 8.7)	+1.0	(-11.0 to 12.4)	0.02
Fat Free Mass (kg)	+0.7	(-7.2 to 7.0)	+0.9	(-4.5 to 6.0)	+0.7	(-4.9 to 11.3)	*NS*
Total Body Water (kg)	+0.5	(-5.0 to 5.0)	+0.6	(-3.2 to 4.2)	+0.6	(-3.5 to 8.0)	*NS*
Bone Mass (kg)	+0.04	(-0.3 to 0.3)	+0.04	(-0.2 to 0.3)	+0.04	(-0.3 to 0.6)	*NS*
Visceral Fat Level	+0.2	(-4.0 to 3.0)	+0.3	(-2.0 to 2.0)	+0.3	(-2.0 to 3.0)	*NS*

[1] Mean (Range) [a] *P* value testing significant difference between formula feeding and exclusive breastfeeding using Mann Whitney U

Table 7.4: Difference in maternal segmental body composition changes between early pregnancy and four months postpartum according to infant feeding practices (*n*=467)

	Formula Feeding[1] (*n*=167)		Partial Breastfeeding[1] (*n*=114)		Exclusive Breastfeeding[1] (*n*=186)		*P*[a]
Right Arm Fat (kg)	+0.001	(-1.0 to 0.8)	+0.02	(-0.5 to 0.7)	+0.05	(-0.5 to 0.8)	*NS*
Right Arm Fat (%)	-1.02	(-12.8 to 9.9)	-1.1	(-12.6 to 8.3)	-0.2	(-14.0 to 17.3)	*NS*
Left Arm Fat (kg)	-0.01	(-1.2 to 1.0)	+0.01	(-0.4 to 0.7)	+0.04	(-0.7 to 1.0)	*NS*
Left Arm Fat (%)	-1.3	(-12.5 to 10.4)	-1.2	(-12.6 to 10.6)	-0.5	(-16.1 to 11.6)	*NS*
Right Leg Fat (kg)	+0.2	(-3.6 to 4.1)	+0.4	(-3.5 to 3.5)	+0.3	(-2.3 to 5.0)	*NS*
Right Leg Fat (%)	+1.3	(-18.8 to 33.0)	+2.5	(-23.2 to 31.4)	+1.9	(-20.1 to 37.9)	*NS*
Left Leg Fat (kg)	+0.2	(-5.7 to 3.0)	+0.3	(-2.8 to 3.1)	+0.4	(-2.3 to 3.8)	*NS*
Left Leg Fat (%)	+1.0	(-31.6 to 26.5)	+1.7	(-18.7 to 25.1)	+2.0	(-17.4 to 29.0)	*NS*
Trunk Fat (kg)	-0.01	(-5.4 to 7.4)	+0.005	(-4.8 to 5.2)	+0.3	(-5.4 to 5.7)	*NS*
Trunk Fat (%)	-0.6	(-10.9 to 13.9)	-0.8	(-14.4 to 8.7)	+0.1	(-17.0 to 14.7)	*NS*

[1] Mean (Range) [a] *P* value testing significant difference between formula feeding and exclusive breastfeeding using Mann Whitney U

Women who EBF had a better dietary quality score than women who did not breastfeed or those who partially breastfed (*P*<0.001). There was no relationship between PAL and infant feeding practices (Table 7.5).

Table 7.5: Dietary quality scores and physical activity levels according to infant feeding practices (*n*=450)

	Formula Feeding[1] (*n*=157)		Partial Breastfeeding[1] (*n*=109)		Exclusive Breastfeeding[1] (*n*=184)		*P*
Dietary Quality Score	60.5	25.4	68.1	26.9	75.4	24.0	<0.001
Physical Activity (METS)	1.79	0.2	1.78	0.13	1.76	0.2	*NS*

METS: Metabolic Equivalents [1]Mean, standard deviation, *P* value tested using Kruskal Wallis

After controlling for breastfeeding, breastfeeding scale, nulliparity, stage of gestational booking, infant birthweight and PAL, only early pregnancy BMI < 30 kg\m^2 and diet quality score remained associated with weight and % FM gain at four months postpartum (Table 7.6).

Table 7.6: Logistic regression of factors associated with maternal weight gain and body fat percentage gain at four months postpartum

			Weight Gain				Body Fat Percentage Gain			
		n	Odds Ratio	95.0% C.I.		*P*	Odds Ratio	95.0% C.I.		*P*
Antenatal Obesity	Obese	52	1.0[a]				1.0[a]			
	Non-Obese	285	3.778	2.0	7.2	<0.001	2.729	1.4	5.3	0.003
Physical Activity Level	Linear Variable	337	3.679	0.8	17.4	*NS*	1.747	0.4	7.4	*NS*
Exclusive Breastfeeding	No	156	1.0[a]				1.0[a]			
	Yes	181	0.901	0.4	2.2	*NS*	0.752	0.3	1.7	*NS*
Breastfeeding Scale	Linear Variable	337	1.015	1.0	1.1	*NS*	1.047	1.0	1.1	*NS*
Booking Gestation	Linear Variable	337	0.955	0.8	1.1	*NS*	0.939	0.8	1.1	*NS*
Diet Quality	Linear Variable	337	1.011	1.0	1.1	0.03	1.011	1.0	1.1	0.02
Infant Birthweight	Linear Variable	337	0.944	0.6	1.5	*NS*	1.085	0.7	1.7	*NS*
Nulliparous	No	203	1.0[a]				1.0[a]			
	Yes	134	1.311	0.8	2.2	*NS*	1.059	0.7	1.7	*NS*

Data for *n*=337 for which all variables were available, 1.0[a] denotes reference category, C.I. confidence interval. C.I. confidence interval. Breastfeeding scale combines breastfeeding duration and intensity. Booking gestation is the gestational age at the first antenatal visit.

7.4 Discussion

We found in this longitudinal observational study that upon univariate analysis, obese women were less likely to breastfeed. Univariate analyses also revealed that EBF was associated with an increase in average maternal bodyweight and an increase in maternal adiposity. Women who breastfed were more likely to put on weight and to become fatter even though their diet quality was superior and their PALs were similar to women who formula fed. Exclusive breast feeders were also less likely to smoke, less likely to be socially deprived and less likely to have been born in Ireland. Infant feeding method was not associated with postpartum maternal bodyweight or % FM changes after adjusting for prenatal maternal obesity status, breastfeeding duration, PAL, booking gestation, diet quality, infant birthweight and nulliparity. Therefore, we found no evidence to support the promotion of breastfeeding on the basis of improving maternal weight loss postpartum. As part of a public health strategy to promote breastfeeding there are more convincing reasons why a woman should breastfeed exclusively (IoM, 1991; AAP, 2012).

Our study has strengths. The study population is well characterised. The clinical and socio-demographic details were computerised as usual at the first antenatal visit and after delivery, but additional data was collected at each visit using detailed questionnaires which gathered information on breastfeeding, dietary quality, physical exercise and social disadvantage.

A further strength of this study was the clinical measurement (rather than self-reporting) of early pregnancy weight. The baseline weight measurement and BMI calculations were obtained before 18 weeks gestation which is optimal (O'Higgins *et al.*, 2014). There are few studies investigating measured differences in weight and BMI between early pregnancy and the postpartum period, with many studies relying on self-reported pre-pregnancy weight which is

unreliable and leads to BMI misclassification (Turner, 2011). Self-reporting of weight in obese women may be particularly subject to error (Fattah *et al*., 2009). To our knowledge, this is one of the largest studies to measure maternal body composition directly using advanced BIA, which means that trajectories in FM and FFM can be tracked over time and analysed by infant feeding practices.

Another strength of the study is that its prospective design minimises recall bias which is a potential problem with post pregnancy research (Rockenbauer *et al*., 2001). The study also highlights the advantage of longitudinal studies. Based on a cross-sectional analysis postpartum, maternal obesity was associated with formula feeding; however, on univariate longitudinal analysis, maternal weight gain and adipose gain were associated with breastfeeding. Our longitudinal study design overcomes this critical inability of cross-sectional studies to measure changes in anthropometric status within individuals between the antenatal and postpartum time points.

A potential weakness of the study is that recall bias may have occurred at four months postpartum when women reported their breastfeeding duration. Women were asked how long they had breastfed. While the inability of this question to differentiate between EBF and partial breastfeeding introduces a degree of imprecision, this limitation is mitigated by the use of a scale which captures the intensity and duration of breastfeeding (and hence estimates the overall bio-energetic cost of breastfeeding during the postpartum period) for both EBF and partial breastfeeding mothers. Another potential weakness of the study is that convenience recruitment may introduce an unforeseen self-selection bias which was not addressed in the multivariate analysis. However, consecutive recruitment is practically challenging in a longitudinal study whose time frame spans early pregnancy until four months following a woman's discharge home

with her newborn baby. We are also uncertain whether our observations are applicable in the developing world. We did not have GWG information for the women. This is a possible limitation as GWG has been linked with PPWR (Rong *et al.,* 2015).

The benefits of breastfeeding for mother and child are well established (IoM, 1991; AAP, 2012). Many factors have been associated with breastfeeding including nationality, SES, education, smoking status, maternal age and pre-pregnancy weight (Amir & Donath, 2008; Kehler *et al.,* 2009; Tarrant *et al*., 2009; Krause *et al*., 2011). In this study, multivariate analysis showed that women who smoked, who were Irish, and who were living in relative income poverty and deprivation were less likely to EBF.

It has been suggested that common lifestyle risk factors cluster among adults (Schuit *et al.,* 2002), particularly those of low SES (Layte & Whelan, 2006). In this context, our study suggests a clustering of poorer health behaviours among women who choose to formula fed. This suggestion is further strengthened by our finding that women who EBF had better dietary quality scores than women who partially breastfed or formula fed. Insight into the prevalence of clustering is important, because it can potentially help in locating high risk groups where multicomponent health promotion initiatives may yield extra benefit (Schuit *et al.,* 2002). Our study findings have public health implications as they show that additional emphasis on breastfeeding promotion may be needed in women of low SES who have other adverse health behaviours such as smoking and poor diet.

There is insufficient evidence to assert a benefit for breastfeeding in postpartum weight loss (Neville *et al.,* 2014), yet this remains a commonly held belief (Murimi *et al*., 2010; Krause *et al*., 2011; AAP, 2012). Many studies in this area rely on self-reporting of maternal bodyweight

which has limitations (Turner, 2011). Consequently, it has been suggested that more robust studies are needed to reliably assess the impact of breastfeeding on postpartum weight management (Neville *et al.*, 2014). In our study, there was no difference in weight change from early pregnancy to four months postpartum between women who EBF and those who formula fed. The perception that breastfeeding aids postpartum weight loss may therefore, not be true for all women. Overweight and obese women with persistently high, unrealistic expectations of breastfeeding and weight loss have been shown to give up on breastfeeding earlier (Krause *et al*., 2011). For this reason, evidence based breastfeeding promotion strategies may need to focus on health benefits to the mother and child other than weight loss. In addition a longer follow up would be beneficial to examine if longer breastfeeding durations are associated with decreased PPWR in the later postpartum period.

In our study, women who EBF had a greater increase in postpartum FM and % FM compared to women who formula fed. Conflicting findings have also been reported in relation to breastfeeding and its effect on maternal body composition, with the majority of studies identifying little or no association between breastfeeding and body compositional changes postpartum. However, many of these studies rely on small sample sizes (Neville *et al.*, 2014). When DEXA was used to measure body composition in a US study (n=168), non-breastfeeding women lost whole body, arm and leg fat at a faster rate than breastfeeding women (those who intended to breastfed for up to or greater than 6 months and to provide no more than one formula feeding per day) between two weeks and 6 months postpartum (Wosje & Kalkwarf, 2004).

It has been reported that body fat deposition during lactation occurs at central sites, for example, on the trunk and thighs (Butte & Hopkinson, 1998). Although no difference in body fat distribution between lactating and non-lactating women was observed in our study; it may be that

lactating women have an overall physiological increase in body fat to support the extra energy costs of lactation. Further longitudinal studies are needed to clarify whether postpartum changes in fat distribution are influenced by breastfeeding.

7.5 Conclusions

This study found that exclusive breastfeeding was not associated with postpartum maternal weight or % FM changes after adjusting for important confounders. Breastfeeding promotion strategies may need to focus on women of low SES. These women, who may be subject to a clustering of poor lifestyle behaviours, such as smoking and poorer dietary quality, may benefit from interventions which promote the established advantages of breastfeeding to mother and child. The perception that breastfeeding aids postpartum weight loss is not true for all women however. Clinicians should be cautious when advising mothers about expected rates of weight and fat loss during lactation. Breastfeeding promotion strategies should instead focus on health benefits to mother and child other than maternal weight loss.

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Chapter 8

Diet, physical activity, socioeconomic factors and maternal weight, BMI and body composition trajectories postpartum

8.0 Introduction

Chapter 6 and Chapter 7 have briefly discussed gaps in the evidence surrounding PPWR and changes in postpartum weight. Diet, PAL, SES and smoking status have all been associated with differences in PPWR and postpartum weight change. The IoM recommend that counselling on diet and exercise be offered to women to reduce or eliminate PPWR. However, they have also stated that existing evidence is inadequate to establish the characteristics of effective interventions for the avoidance of PPWR (IoM, 2009). This chapter explores the relationship between these lifestyle, behavioural and socioeconomic variables and PPWR amongst a cohort of young Irish women.

8.0.1 Diet and physical activity interventions and postpartum weight changes

There are numerous methodological shortcomings of the diet and PAL intervention studies previously undertaken in pregnancy and the postpartum period. Of the small number of trials which examined the outcome effects of diet, physical activity or both, many had small sample sizes; and there was significant diversity in the nature, duration and frequency of the interventions. Also, many of these trials were poorly representative of their broader obstetric peer group, as many included only overweight/obese and/or breastfeeding women. Furthermore, as far as we are aware, none of these studies initiated a lifestyle intervention during pregnancy which was continued into the postpartum period (Choi *et al.*, 2013). Some large multi centered

studies are currently underway which will investigate lifestyle interventions in pregnancy and postpartum weight changes, however their results have not yet been published (Dodd *et al.,* 2011; Briley *et al.,* 2014).

8.0.1.1 Diet and physical activity interventions in pregnancy and postpartum weight changes

Diet and physical activity interventions during pregnancy vary widely. They can include face to face or telephone sessions on healthy eating and exercise (Dodd *et al.,* 2011; Walsh *et al.,* 2012; Harrison *et al.,* 2014; Briley *et al.,* 2014). Some studies incorporate a behavioural change aspect (Dodd *et al.,* 2011; Harrison *et al.,* 2014). Mailed material can be an adjunct to the intervention (Phelan *et al.,* 2011). Specific, measurable, achievable, relevant and time specific (SMART) goals and self-monitoring can also form important aspects of interventions (Phelan *et al.,* 2011; Briley *et al.,* 2014).

In one Australian RCT, overweight (BMI $\geq$ 25 kg/m^2) and obese (BMI $\geq$ 30 kg/m^2) women, and women at increased risk of GDM, were randomised to an intervention (*n*=121) or a control group (*n*=107) in early pregnancy (Harrison *et al.,* 2014). At six weeks postpartum, measured weight and BMI changes in the control group were 1.96 ± 5.74 kg and 0.78 ± 2.26 kg/m^2 respectively, compared with the intervention group who retained less weight (0.51 ± 4.48 kg) and whose BMI returned further towards baseline (0.22 ± 1.72 kg/m^2). The between group difference in retained weight was 1.45 ± 5.1 kg (*P*<0.05). Similarly in a US study (*n*=358; BMI 19.8-40.0 kg/m^2) 30.7% women in an intervention group had returned to their preconception weight at six months postpartum, compared to only 18.7% of the control group (*P*=0.005) (Phelan *et al.,* 2011). However in an Irish study no difference was observed in maternal weight

change at three months postpartum between women in a low GI intervention during pregnancy and a control group (Horan *et al.*, 2014).

Allocation to the intervention group, higher baseline BMI, GDM diagnosis, and older age have been shown to be independent predictors of lower weight retention at 6 weeks postpartum (Harrison *et al.*, 2014). The intervention effect may differ between BMI groups with evidence that weight retention postpartum was greater in the overweight control group compared to the overweight intervention group, however no difference observed between the obese intervention and obese control groups (Harrison *et al.*, 2014). This perhaps indicates that such lifestyle interventions are most effective in preventing postpartum weight gain amongst moderately overweight women. However when investigating women in a broad range of BMI categories, no difference was observed on the intervention effect in different BMI categories (Phelan *et al.*, 2011).

8.0.1.2 Diet and physical activity interventions postpartum and postpartum weight changes

Postpartum interventions also vary widely, particularly in their delivery, content, and duration (Ostbye *et al.*, 2009; Craigie *et al.*, 2011; Colleran *et al.*, 2012; Stendell-Hollis *et al.*, 2013). Interventions to reduce maternal weight in the postpartum period have shown mixed results. Some studies do show that diet and exercise interventions in the postpartum period are associated with improved postpartum weight loss however (Lovelady *et al.*, 2000; O'Toole *et al.*, 2003; Davenport *et al.*, 2010; Bertz *et al.*, 2012; Colleran *et al.*, 2012; Craigie *et al.*, 2012). Several reviews evaluating interventions in the postpartum period to reduce PPWR show that diet combined with exercise (Amorim & Linne, 2013; van der Pligt *et al.*, 2013; Berger *et al.*,

2014) or diet alone (Amorim & Linne, 2013) compared with usual care can enhance weight loss during the postpartum period (up to 24 months postpartum).

The Active Mothers Postpartum trial was an RCT involving healthy eating, increased physical activity and behavioural change intervention in 450 overweight and obese women (pre-pregnancy BMI > 25.0 kg/m^2) for nine months postpartum (Ostbye *et al.,* 2009). This US trial is one of the largest postpartum investigations to date and did not result in an improvement in diet or exercise levels or improved postpartum weight loss in the intervention group.

However, in a small American RCT (*n*=31), lactating women group (BMI 25-30 kg/m^2) assigned to the intervention decreased their body weight by 5.8 ± 3.5 kg compared with 1.6 ± 5.4 kg in the control group (*P*=0.03) by 20 weeks postpartum. The decrease in PPWR in the intervention group was possibly achieved through an improvement in diet quality through a reduction in EI, saturated fat and percentage energy from sugars (Colleran *et al.,* 2012).

Positive results with a postpartum intervention and weight changes were also observed in women with a BMI > 25.0 kg/m^2 living in deprived areas in the UK (Craigie *et al.,* 2011). However loss to follow-up is an issue with postpartum interventions and raises concerns about the ability of women in this challenging, transitional period of life to attend classes or other group format interventions while caring for an infant (Ostbye *et al.,* 2009; Craigie *et al.,* 2011).

8.0.2 Diet and physical activity and postpartum body composition changes

There is a lack of studies investigating diet and postpartum body composition changes, and the majority of studies are limited by their inadequate representation of the general population, and by their small sample sizes (McCrory *et al.,* 1999; Lovelady *et al.,* 2000; O'Toole *et al.,* 2003; Davenport *et al.,* 2010; Bertz *et al.,* 2012). One US study compared a

postpartum dietary intervention (35% energy deficit based on individual energy requirements), and a diet and exercise intervention (35% net energy deficit, 60% by dietary restriction and 40% by additional exercise) versus usual care on short-term postpartum weight change (11 days) amongst a small sample of EBF women (*n*=67) (McCrory *et al.,* 1999). Weight loss did differ between the control and intervention groups (both $P<0.05$). However, weight loss did not differ between the intervention groups. Loss of FFM was reduced and FM loss enhanced in the diet and exercise group, when measured using either hydrostatic weighing or air-displacement plethysmography.

Similar results were also found in a Canadian RCT were healthy non-smoking, sedentary women with a BMI ≥ 25.0 kg/m^2 and/or who had retained ≥ 5.0 kg from pregnancy (based on pre-pregnancy weight recall) were randomised into either a nutrition plus low intensity (*n*=20) or moderate intensity (*n*=20) exercise intervention group (Davenport *et al.,* 2010). The low and moderate intensity exercise groups lost more weight (-4.2 ± 4.0 and -5.0 ± 2.9 kg, respectively) compared to a control group (-0.1 ± 3.3 kg, $P<0.001$) at the end of the intervention. Based on DEXA, the loss in weight was predominantly from a loss in FM and preservation in lean muscle mass. Based on three day food diaries, there was no difference in dietary intake before and after the intervention, suggesting that the favourable effects on body composition were likely mediated by the exercise elements of the intervention alone.

However no associations with exercise lifestyle interventions, but a positive association with a dietary intervention, and postpartum body composition changes, have also been observed (Bertz *et al.,* 2012). A loss of both FM and FFM in the intervention group in lactating women with a BMI between 25 to 30 kg/m^2 has also been observed postpartum (Lovelady *et al.,* 2000).

The authors concluded that this loss in FFM may have reflected changes in body composition which occur naturally during the early postpartum period however.

Having reviewed the literature, it is difficult to draw conclusions from the lifestyle intervention studies conducted in both pregnancy and the postpartum period, due to their conflicting findings. It is also challenging to compare results between studies as samples and interventions vary, while small sample sizes and the self-reporting of maternal weights further compromise our ability to synthesise coherent, consensus findings in these areas.

8.0.3 Diet quality and postpartum weight changes

As discussed in Chapter 4, dietary quality scores, for e.g. the HEI have been used in many adult population studies to predict disease risk (Waijers *et al.,* 2007). In one American study, dietary quality scores from the HEI-2005 were shown to be significantly related to weight change from five to fifteen months postpartum, based on self-reported pre-pregnancy weights in overweight and obese postpartum women (Wiltheiss *et al.*, 2013). This relationship did not persist after controlling for confounders such as household income, postpartum maternal weight, parity, education, age, and smoking status. However, postpartum EI, an element of overall dietary quality, remained negatively associated with weight change.

Similarly, a US study (*n*=1136) examining diet patterns using two dietary quality scores (the alternate Mediterranean Diet Score (aMED) and the Alternative Healthy Eating Index-2010 (AHEI-2010)) found no association with either of the scores and self-reported postpartum weight changes at 14 months postpartum (Boghossian *et al.,* 2013). However, total maternal EI was a strong predictor of weight retention. The Stockholm Pregnancy and Weight Development Study (*n*=1423) identified risk factors for PPWR (Ohlin & Rossner, 1994). Weight retention one year

postpartum was greater in women who increased their EI during and after pregnancy, those who increased their snack eating after pregnancy to three or more snacks per day, and those who decreased their lunch frequency starting during or after the pregnancy. Women who had retained ≥5 kg one year postpartum were less frequently physically active in their leisure time throughout the study period compared with women who had a smaller weight gain.

These studies suggest that dietary quality indices may be enhanced by a greater focus on overall EI restriction, especially in predicting weight changes postpartum. However it remains unclear whether dietary quality in the postpartum period, at least as measured by existing dietary quality indices, is associated with postpartum weight changes. Differences in the measurement of dietary quality, the small sample sizes commonly captured by such studies, and reliance on self-reported maternal weights and heights further complicate comparisons between studies, making it difficult to draw conclusions from the existing literature in this area.

8.0.4 Socioeconomic status (SES) and postpartum weight changes

In many countries, women of lower SES are more likely to be overweight or obese (McLaren *et al.,* 2014; Ng *et al.,* 2014). Disparities in PPWR between SES groups have been observed in a number of studies (Dugdale & Eaton-Evans, 1989; Parker & Abrams 1993; Ohlin & Rossner, 1994; Gunderson *et al.,* 2000; Kac *et al.,* 2004; Gunderson, 2009; Shewsbury *et al.,* 2009). However, there is a paucity of studies which investigate SES differences in postpartum body composition changes. Of the studies which have investigated changes in postpartum body composition, none focus on differences in SES within their samples (McCrory *et al.,* 1999; Lovelady *et al.,* 2000; O'Toole *et al.,* 2003; Davenport *et al.,* 2010; Bertz *et al.,* 2012).

In early studies, variable results were found regarding SES and PPWR. In the 1988 US National Maternal and Infant Health Survey, white and black women in the highest SES group who began their pregnancy with an ideal weight, had the lowest prevalence of excess PPWR (defined as more than 9.1 kg) when assessed at an average 16 months postpartum (Parker & Abrams, 1993). Similarly, in a Brazilian study (*n*=266) the odds ratio of retaining >7.5 kg at 9 months postpartum was 3.3 (*P*=0.01) for low compared with high income women (Kac *et al.*, 2004). However, other early studies reported no association (Dugdale & Eaton-Evans, 1989) or mixed associations at one year postpartum (Ohlin & Rossner, 1994) between weight retention and SES indicators.

In one UK study (*n*=896), education level was used as a proxy for SES to assess if there was an SES gradient in self-reported PPWR at 7.6 months postpartum (Shrewsbury *et al.*, 2009). Higher SES women (university degree or higher degree) retained less weight (1.8 kg) compared to women of middle SES (3.2 kg) ('AS' level, 'A' level or National Diploma) or low SES (3.2 kg) (no qualifications or School Certificate, GCSE, 'O' level) (*P*=0.008). Furthermore, higher SES women in this study believed that they would return to their pre-pregnancy weight in a year, unlike medium or low SES groups. Higher SES women also weighed themselves more regularly and had lower ideal and target body sizes.

In a more recent US study, low income overweight (BMI $\geq$ 25.0 kg/m^2) postpartum women were randomly assigned to an ethnic specific weight loss intervention group [White/Anglo (*n*=23), African American (*n*=25), or Hispanic (*n*=23)] or to a control group (*n*=37) between 6 weeks and 12 months postpartum (Walker *et al.*, 2012). Participants in the ethnic specific intervention and control groups did not differ in terms of weight change or percentage weight change from the start of the intervention to week 13 of the study. Two further

weight trials targeting low income mothers of infants and young children also reported no difference in weight change between their intervention and control groups (Chang *et al.,* 2010; Krummel *et al.,* 2010). Low income mothers of young children have typical attrition rates of 45 to 55% from weight management programs (Jordon *et al.,* 2008; Chang *et al.,* 2009; Krummel *et al.,* 2010). This limitation makes it difficult to draw conclusions from weight management intervention studies conducted among low income women and mothers.

8.0.5 Smoking and postpartum weight and body composition changes

Given the relationship between smoking and body weight, postpartum smoking practices may be important in further understanding postpartum weight changes. Weight gain after smoking cessation has been linked with withdrawal of the acute metabolic effect of smoking, superimposed on a transient increase in eating and no change in physical activity (Perkins, 1993; Levine *et al.,* 2012a).

However, the relationship between smoking status and postpartum weight change is complicated as it may depend on smoking duration, intensity, cessation, and on the accurate reporting of smoking status (Gorber *et al.,* 2009; Shipton *et al.,* 2009). In addition, smoking related weight concerns have been noted to decrease the likelihood of women quitting smoking during pregnancy, or of remaining abstinent in the postpartum period (Berg *et al.,* 2008).

In one American study (n=183), smoking cessation once pregnant was associated with increased PPWR (Levine *et al.,* 2012b). Abstinent women were 2.9 ± 1.8 kg (P=0.01) and 3.6 ± 2.0 kg (P=0.02) heavier than women who had resumed smoking at 12 and 24 weeks postpartum respectively. Interestingly, the women who relapsed back to smoking during the postpartum

period in this study retained less weight than abstinent women, even after adjusting for important confounders (age, GWG, pregravid BMI, and breastfeeding).

In low income, ethnic minority women (*n*=427) aged 14 to 25 years, greater smoking intensity one year prior to pregnancy, and lower current smoking intensity, resulted in increased GWG and PPWR up to 12 months postpartum (Rothberg *et al.*, 2011). Similarly, in a large sample of low income primigravidous women (*n*=32,920) from the North Carolina Special Supplemental Nutrition Program for Women, current smokers retained less weight when booking for antenatal care on their next pregnancy (mean time between pregnancies 2.8 years) (Ostbye *et al.*, 2010).

There is a lack of studies investigating the association between postpartum body composition change and maternal smoking status. However there is increasing evidence to suggest that smoking predisposes to greater visceral fat accumulation and greater insulin resistance, and that smoking increases the risk of metabolic syndrome and type 2 diabetes in the general population (Chiolero *et al.*, 2008). Cross-sectional studies have shown that smokers have a higher waist circumference (a measure of central adiposity) and lower BMI than non-smokers (Barret-Connor *et al.*, 1989; Jee *et al.*, 2002; Bamia *et al.*, 2004; Canoy *et al.*, 2005; Pisinger *et al.*, 2007).

8.1 Aims

The relationships, if any, between maternal diet, exercise, smoking status and SES; and postpartum weight and body composition changes remain unclear. Thus the aim of this paper is to investigate the dietary, physical activity and socioeconomic factors associated with postpartum weight, BMI and body composition changes from early pregnancy to nine months postpartum.

8.2 Methods

Women were recruited at their convenience in the first trimester of pregnancy as outlined in previous chapters. The women's weight and body composition were measured and their BMI calculated. Socioeconomic, health behavioural, PAL, and dietary quality data were collected using the online tool as previously described. Women were invited back to the hospital at approximately four and nine months postpartum. Socioeconomic, health behavioural, PAL, and dietary quality data were again gathered at these visits, and the woman's weight, body composition and BMI re-measured. At each visit, habitual food and nutrient intakes were assessed using the WFFQ as previously described.

8.2.1 Inclusion and exclusion criteria

Inclusion and exclusion criteria have been described in Chapter 6. In addition women who under- and over-reported EI according to the WFFQ were also excluded from statistical analyses on data derived from the WFFQ as outlined in Chapter 3.

8.2.2 Statistical analysis

Cross-tabulation and Chi-square analyses were used to assess the proportions of women in different population groups who gained and lost weight, BMI, % FM, FM, and FFM between early pregnancy and nine months postpartum according to early pregnancy obesity status. Independent samples t-tests were also used to test differences in mean age, PAL, and dietary quality score between women who gained and lost weight, BMI, % FM, FM, and FFM between early pregnancy and nine months postpartum. Mann Whitney U tests were used to assess differences in median EI and percentage energy from macronutrients in women who gained and lost weight, BMI, % FM, FM, and FFM between early pregnancy and nine months postpartum.

Changes in diet quality score between early pregnancy and nine months postpartum, and between four and nine months postpartum were calculated. These median changes in diet quality score were then compared between participants who had experienced increases and decreases in weight and BMI using Mann Whitney U tests. The above statistical tests were also conducted with a Bonferroni correction, to avoid type one error. Binary logistic regression analyses were finally used to assess factors associated with weight gain postpartum.

8.3 Results

The characteristics of women who returned at four and nine months postpartum have been described in Chapter 6. Postpartum weight, BMI and body composition data for the 328 women who attended all three appointments have also been outlined in Chapter 6.

PAL, dietary quality and SES data were available on 286 women at 9 months postpartum. Current smoking was more prevalent in the 9 month postpartum weight loss group than in the weight gain group (P=0.04). Consistent poverty was more prevalent among women in the FFM loss group, and higher diet quality scores were also observed in this group **(Appendix 8).** The proportion of women in different population groups, who gained and lost postpartum weight and BMI by early pregnancy obesity status, are also shown in Appendix 8. On univariate analysis, early pregnancy obese women who had a 9 month postpartum BMI loss were more likely to be ≥30 years of age (P=0.03). Early pregnancy non-obese women who had a 9 month postpartum weight loss were more likely to be at risk of consistent poverty (P=0.04). However, these associations no longer remained after adjusting for type one error.

There was no association between change in diet quality from early pregnancy to nine months postpartum and weight and BMI changes over this period. Similarly, there was no

association between change in diet quality from four to nine months postpartum and weight and BMI changes between early pregnancy and nine months postpartum.

The WFFQ was completed by 205 women at nine months postpartum. Under-reporting of EI was observed in 86 women (42.0%) and over-reporting of EI was observed in 9 women (4.4%). Amongst plausible EI reporters (*n*=110), EI and percentage energy from macronutrients did not differ between women who gained or lost weight at 9 months postpartum. Women who gained BMI and fat mass during this time however, had a higher % of their EI from fat **(Appendix 8)**. Again these dietary associations no longer existed after conducting a Bonferroni correction.

Factors associated with weight gain at 9 months postpartum are shown in Table 8.1. BMI>29.9 kg/m^2 in early pregnancy (*P*=0.04) and currently smoking (*P*=0.03) are both associated with increased likelihood of weight gain at 9 months postpartum.

Table 8.1: Logistic regression of factors associated with maternal weight gain at nine months postpartum

		Weight Gain				
		n	**Odds Ratio**	**(95.0% C.I.)**		***P***
Antenatal Obesity	Obese	40	1.0[a]			
	Non-Obese	246	0.458	0.21	0.96	0.04
Physical Activity Level	Linear Variable	286	0.753	0.17	3.35	*NS*
Breastfeeding	No	100	1.0[a]			
	Yes	186	1.041	0.61	1.77	*NS*
Diet Quality	≤62.30	144	1.0[a]			
	>62.31	142	1.568	0.95	2.58	*NS*
Nulliparous	No	151	1.0[a]			
	Yes	135	0.712	0.43	1.19	*NS*
Relative Income Poverty	Yes	38	0.656	0.26	1.69	*NS*
	No	248	1.0[a]			
Relative Deprivation	Yes	56	0.781	0.38	1.59	*NS*
	No	230	1.0[a]			

Consistent Poverty	Yes	15	3.294	0.66	16.36	*NS*
	No	271	1.0[a]			
Age	< 30 years	71	1.0[a]			
	> 30 years	215	1.174	0.65	2.114	*NS*
Current Smoker	Yes	40	1.0[a]			
	No	246	0.419	0.19	0.92	0.03
Caesarean Section	Yes	59	1.0[a]			
	No	227	1.44	0.79	2.62	*NS*

Data for *n*=286 for which all variables were available, 1.0[a] denotes reference category, C.I. confidence interval

8.4 Discussion

This study found that EI, percentage energy from macronutrients and PAL were not associated with postpartum weight and BMI changes at nine months postpartum. On multivariate analysis, early pregnancy obesity and current smoking remained associated with weight gain at nine months postpartum.

As discussed previously, disparities in PPWR between SES groups have been observed in a number of studies (Dugdale & Eaton-Evans, 1989; Parker & Abrams, 1993; Ohlin & Rossner 1994; Gunderson *et al.*, 2000; Kac *et al*., 2004; Gunderson, 2009; Shewsbury *et al.*, 2009). However it is difficult to make comparisons between these studies. To our knowledge this is the first study which uses explicit indices of poverty and deprivation to measure SES and its possible association with weight and body composition changes in the postpartum period. Our study found that on multivariate analysis, none of the indicators of low SES was associated with postpartum weight gain.

On univariate analysis, there were a higher proportion of current smokers in the weight loss group at 9 months postpartum. On multivariate analysis, smokers were more likely to gain weight postpartum however, after adjusting for important confounding variables such as SES and

obesity. The relationship with smoking status and postpartum weight changes is complicated. It is possible given the considerable socioeconomic gradient in smoking behaviour, that after adjustment for this important SES confounder that the "true" positive relationship between smoking and PPWR emerges. As smoking cessation has been associated with increased postpartum weight retention in other studies (Levine *et al.*, 2012b), further research is required to fully understand the relationship between smoking status and postpartum weight and body composition changes.

Several studies have shown sub-optimal dietary quality among women in the postpartum period (Mackey *et al.,* 1998; George *et al.,* 2005; Fowles & Walker, 2006; Durham *et al.*, 2011; Wiltheiss *et al.,* 2013). Among overweight and obese women (*n*=392), poorer dietary quality in the postpartum period was associated with increased BMI, lower breastfeeding rates and lower household income (Wiltheiss *et al.,* 2013). Dietary quality has also been previously shown to predict weight change from five to fifteen months postpartum; although this relationship did not persist after controlling for confounders such as household income, baseline maternal weight, parity, education, age, and smoking status (Wiltheiss *et al.,* 2013). Other previous American studies have shown no association between dietary quality and postpartum weight changes (Fowles & Walker, 2006; Boghossian *et al.,* 2013).

Our study showed no association between dietary quality and postpartum weight changes. It has been shown that in people who have lost weight, multiple physiological compensatory mechanisms occur to protect against weight loss and to promote weight regain. These adaptive changes include a reduction in total energy expenditure and hormonal alterations which elicit increased fat deposition, and these changes can persist for a year after the weight loss has occurred (Sumithran *et al*., 2011; Sumithran & Proietto, 2013). It is possible that such adaptive

responses may be occurring among the women who were obese in early pregnancy in this study. These women initially lost weight up to four months postpartum, but experienced weight gain between four and 9 months postpartum, ultimately being more likely to have a net weight gain between early pregnancy and nine months postpartum than their non-obese peers.

8.5 Conclusions

Nine months after childbirth, postpartum weight gain was associated with antenatal maternal obesity status, but was not associated with maternal PAL or dietary quality. The prepregnancy period may provide a window of opportunity to intervene with obese women who at greater risk of PPWR. In addition given that the postpartum period is often a difficult and transitional period for many women, prepregnancy interventions may be more effective.

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Chapter 9

Conclusions

This thesis began by highlighting the socioeconomic, anthropometric and other differences which exist between women who under-reported their EI and those who reported plausible EIs. The findings that women who under-reported EI were younger, more likely to be materially deprived, obese and to have a higher percentage body fat highlights a significant source of potential bias in obesity research among obstetric populations.

The fact that these under-reporting women had to be excluded from our nutrient intake analyses has important implications for the subsequent diet related studies undertaken in this project. If these participants were to remain in the analyses, this would have resulted in a systematic under estimation of EI and other nutrient intakes. While adjustment of energy and nutrient intakes to off-set such under estimations has been proposed as a possible methodological solution to this problem, there is evidence that the participants in this study have selectively mis-reported certain food groups, thereby rendering their dietary and nutrient intake data void. The exclusion of these women however, leaves a study population who are less obese, older and leaner than the full population under investigation. So while the integrity of the remaining intake data is enhanced, it must also be acknowledged that the remaining study population is now less representative of their broader peer group.

To qualify their findings, researchers need to be aware of EI mis-reporting and the defining characteristics of subjects who mis-report their dietary intake. For example, in our investigation into maternal dietary intakes and FPG levels in the first trimester of pregnancy,

under-reporting was shown to be more common among women with a higher BMI. This needs to be considered when conducting research into GDM as increased BMI is strongly associated with the development of this condition. In this context, under-reporting of EI among obese women, and their consequent exclusion from food and nutrient intake analyses may yield a study population with lower prevalence of GDM whose dietary patterns and nutrient intakes differ from those of their uncaptured, high-risk peers. The potential for systematic bias and the deduction of erroneous conclusions regarding the dietary and nutritional predictors of GDM is relevant in such circumstances.

It may be that women who are more likely to mis-report their EI require alternative dietary assessment methods which rely less on the strict quantitative estimation of all food consumed. The second study in this thesis compared dietary quality scores from a newly developed online DAT against nutrient intakes derived from the validated WFFQ. Technology increasingly influences the way in which we collect and communicate information. The relatively good agreement between these two dietary assessment methods suggests that in evaluating overall dietary quality among pregnant women, novel methods of collecting and assessing food based dietary data may be useful in overcoming the difficulties which can arise with more traditional, nutrient based models.

The dietary quality scores generated by the DAT provide a sound overall representation of nutrient intakes which are important to maternal and fetal health outcomes. In addition, its technological advantages such as the use of images to quantify portion sizes may help to reduce the number of women who inaccurately report their dietary intake. However, further studies are needed to assess the acceptability among study populations of web-based dietary assessment

methods, and of future potential dietary intervention models delivered over the same online interface.

As mentioned previously, the third study described in this thesis found that obesity in early pregnancy was the main predictor of elevated FPG levels during pregnancy. No association was found with food group and macronutrient intakes in the periconceptional period and FPG levels during pregnancy. These findings highlight the preconceptional period as the optimal time for weight management interventions in overweight and obese women, to reduce their risk of elevated FPG levels during pregnancy. Obese women in this study had higher energy and starch intakes than non-obese women, further suggesting that such dietary interventions in before pregnancy should focus on the restriction of EIs through a reduction of high starch foods such as potatoes, breads, cereal products, rice and grains.

The latter chapters of this thesis investigated trajectories in postpartum weight and body composition. To date, interventions to reduce PPWR have been generally unsuccessful. This work found that postpartum weight and body composition trajectories are non-linear and differ between obese and non-obese women. The use of BIA showed that weight gained by obese women between four and nine months postpartum was disproportionately FFM, with an overall loss of FM and % FM. Conversely, the apparently favourable weight loss observed in ideal and overweight women between four and nine months postpartum, was characterized by a loss in FFM and a gain in FM. These findings emphasise the critical value of collecting body composition data when examining body weight trajectories in the research setting. Our findings were captured through the longitudinal study design and strengthened by the measurement of maternal weights, as oppose to a reliance on maternal self-reporting.

On univariate analyses, obese women were less likely to EBF. In addition, EBF was associated with an increase in maternal weight and FM between early pregnancy and four month postpartum, before adjusting for confounding variables. It could be argued that in non-obese women, fat mass accretion may arise from physiological changes designed to enable the accumulation of a metabolic energy "store" to fuel lactation. However, we found that after adjusting for important confounding variables, EBF was not associated with weight and body composition changes at four months postpartum. Further studies are therefore needed to elucidate the relationship between breastfeeding and longer term postpartum weight and body composition changes.

In the current study, the absence of an association between breastfeeding and enhanced weight loss in the postpartum period suggests that women may be disappointed when their expectations of weight loss while breastfeeding are not realised. Our findings suggest that clinicians should be cautious when advising mothers about expected rates of weight loss while breastfeeding, and should instead focus on the more convincing reasons why women should breastfeed. Women of low SES, among whom poor health behaviours tend to cluster, may benefit particularly from a breastfeeding promotion strategy which more clearly articulates the advantages of breastfeeding.

The final study in this thesis found no association between postpartum diet quality, macronutrient intake and PAL, and postpartum weight or body composition changes between early pregnancy and four and nine months. Maternal obesity in the preconceptional period was the main predictor of postpartum weight changes. These findings suggest that the preconceptional period may offer a window of opportunity to intervene with women who are at increased risk of PPWR. The rationale for prioritising interventions in the preconceptional period

is further strengthened by the difficulties associated with engagement and retention of women in postpartum weight management interventions, a limitation that was also observed in this study. Additionally, intervention during the prepregnancy period would optimise maternal micronutrient stores and provision to the developing foetus; as well as enabling the early identification and treatment of metabolic complications such as diabetes mellitus and hypertension which can compromise pregnancy outcomes.

Appendix 1: Coombe Women and Infants University Hospital Ethics Approval Letter

Coombe Women & Infants University Hospital

Excellence in the Care of Women and Babies

Foirfeacht i gCuram Ban agus Naionan

MC/MJ

29 May 2012

Prof. Michael Turner
UCD Professor of Obstetrics & Gynaecology

Re.: Study No. 7 – 2012 – Gestational weight gain in pregnancy

Dear Prof. Turner

At the recent research ethics committee meeting held on the 16th May 2012, this study was discussed and approved subject to clarification from you on the requirement of patients to have a glucose tolerance test. There was some confusion in that the protocol gave the impression that all patients were to receive a glucose tolerance test rather than patients who met the criteria for the test as is the usual practice.

Yours sincerely

Dr Michael Carey
Chairman

Copy: Dr Amy' O'Higgins, Research Fellow CW&IUH

Appendix 2: Dublin Institute of Technology Ethics Approval Letter

Institiúid Teicneolaíochta Átha Cliath, Sráid Caoimhín, Baile Átha Cliath 8, Éire
Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland
www.dit.ie/graduateresearchschool

SCOIL TAIGHDE IARCHÉIME / GRADUATE RESEARCH SCHOOL
Professor Mary McNamara

23rd June 2014

Ms. Laura Mullaney

Re: Ethical Clearance Ref 13-24

Dear Laura

I am pleased to inform you that the following project:

'AN INVESTIGATION INTO THE DIETARY AND HEALTH BEHAVIOURS OF PREGNANT WOMEN IN IRELAND'

which you submitted to the Research Ethical Committee has been approved. The committee would like to wish you very best of luck with the rest of research project. If you have any further queries, please do not hesitate to contact Conor McCague on (01) 402 7920 or at conor.mccague@dit.ie.

Yours sincerely

Dublin Institute of Technology
Research Ethics Committee

Appendix 3: Fellowship in Reproductive Nutrition Project Protocol

Background
There is evidence that peri-gestational weight gain and obesity can have adverse effects on the health of the mother and her offspring (Dennedy *et al.*, 2010). There is also substantial evidence to suggest that pregnancy represents a "window of opportunity" during which young women may be more receptive to healthy diet and exercise messages (Magon & Sheshiah, 2011), and during which such messages may elicit clinically meaningful changes in diet and exercise behaviours (Wilkinson & McIntyre, 2012).

There is currently a paucity of high quality dietary, nutritional and health behavioural data describing the pregnancy and post-partum habits of women in Ireland, particularly in relation to bodyweight status at these times.

Project Design
This collaborative study between DIT and the UCD Centre for Human Reproduction aims to investigate the dietary and lifestyle parameters associated with overweight and obesity in pregnancy, as well as the determinants of post-gestational weight retention among mothers.

The Research Fellow will conduct a prospective, longitudinal study during pregnancy and post-delivery, which will use a variety of dietary assessment tools to assess the relationship between maternal diet and maternal weight trajectories. This will require the collection of anthropometric, body composition and biomarker data from expectant mothers (n=400) during pregnancy and at delivery. Maternal dietary, lifestyle, socio-economic and nutritional status data will also be captured at four and nine months *postpartum*.

These data will be analysed by univariate analyses (cross tabulation with Chi-square analysis, paired- and independent-samples t-tests, analysis of variance (ANOVA) and repeated measures) and multivariate analyses (binary and ordinal logistic regression analyses). Interpretation of these statistical data will reveal the dietary, lifestyle and socio-economic habits associated with weight retention *postpartum*.

Ethical Approval
Ethical approval for this study has been received from the Research Ethics Committee of Coombe Women's and Infants' University Hospital [Ref. Study No. 2008 01 -Maternal and Fetal Body Composition in Pregnancy]

Deliverables
As well as presenting the findings of this work at research meetings and conferences, the Research Fellow will produce at least one peer-reviewed paper in a high impact obstetrics and gynaecology journal.

The Research Fellow will also produce a thesis at the end of their two-year Fellowship describing their findings; submission of which, along with successful completion of a *viva voce* examination, will lead to the award of Master of Philosophy (M.Phil.) from DIT.

The study will be supervised by:
Dr. Daniel McCartney, Lecturer in Human Nutrition & Dietetics, School of Biological Sciences, Dublin Institute of Technology.

Prof. Michael Turner, UCD Professor of Obstetrics and Gynaecology and HSE Clinical Lead in Obstetrics and Gynaecology, UCD Centre for Human Reproduction, Coombe Women's and Infants' University Hospital, Cork Street, Dublin 8.

References
Dennedy MC, Avalos G, O'Reilly MW, O'Sullivan ES, Gaffney G, Dunne F (2010). ATLANTIC-DIP: raised BMI confers adverse fetal and maternal pregnancy outcome in a normoglycaemic cohort of Irish women. *Diabetes* **20**, 1952.

Magon N, Seshiah V (2011) Gestational diabetes mellitus: Non-insulin management. *Indian J Endocrinol Metab.* **15**, 284-93.
Wilkinson SA, McIntyre HD (2012) Evaluation of the 'healthy start to pregnancy' early antenatal health promotion workshop: a randomized controlled trial. *BMC Pregnancy Childbirth.* **12**,131.

Appendix 4: Consent Form

Body composition In Pregnancy

Consent Form

Maternal and Fetal Body Composition in Pregnancy

This study and this consent form have been explained to me. My midwife/doctor has answered all my questions to my satisfaction. I believe I understand what will happen if I agree to be part of this study. I have read, or had read to me, this consent form and the information leaflet. I have had opportunity to ask questions and all my questions have been answered to my satisfaction. I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.

PARTICIPANT'S NAME (CAPITALS):

PARTICIPANT'S SIGNATURE:

DATE:

(Date on which the participant was first furnished with this form)

I agree to participate in the research programme and to have my body composition and body mass index (BMI) measured, and to have my body composition measured during and after pregnancy.

Yes□ No □

I agree to give an additional blood sample at my booking visit to measure markers of maternal nutrition.

Yes □ No □

I agree to be contacted after I take my baby home and to be invited to participate in longterm follow-up studies in this research programme.

Yes □ No □

***Statement of investigators responsibility:** I have explained the nature, purpose, procedures, benefits, risks of, or alternatives to, this research study. I have offered to answer any questions and fully answer such questions. I believe that the participant understands my explanation and had freely given informed consent.

RESEARCHER'S SIGNATURE:

DATE: **CONTACT NUMBER:**

Appendix 5: Information Leaflet

Body composition In Pregnancy

Patient Information Leaflet

Maternal and Fetal Body Composition in Pregnancy

It is normal for women to gain weight during pregnancy. The amount gained varies widely and the optimum weight for each woman is also likely to vary. Although new guidelines for weight gain have been produced for American women, there is little information available on pregnancy weight gain in Irish women.

Under the supervision of Professor Michael Turner, the UCD Centre for Human Reproduction in the Coombe Women and Infants University Hospital is conducting a large study which will examine the relationships between weight gain in pregnancy and the clinical outcomes for the woman and her baby. We are asking you to participate.

If you are agreeable, you will be asked after an ultrasound examination at your first confirms that you have a healthy pregnancy. Your weight and height will be measured as usual. Your body composition will be analysed using the advanced Tanita machine which is similar to what you may have used in a gym in the past. This takes approximately two minutes and has been shown to be safe in pregnancy. We will also require a urine sample which will be stored for subsequent measurement of biomarkers of metabolic and inflammatory changes in pregnancy.

We will also give you an appointment to be reviewed by the obstetrician, Dr. Amy O'Higgins, who is conducting the study at 20-22, 28 and 38 weeks gestation. At each visit, she will conduct the standard antenatal check and ask you for another urine sample for storage and analysis. She will also weigh you again and measure your body composition. At the 38 weeks visit, she will undertake an ultrasound examination to assess the well-being of your baby and measure its growth. The records of your pregnancy and delivery will be recorded for analysis but the details will remain confidential within the hospital.

If you participate in the study, there will be an appointment system so that your waiting time for your study visits will be shorter than usual. Otherwise your care during pregnancy and labour will be with your own team.

If you decide not to participate in the study, the decision will not affect your care in any way. You may also, if you wish, withdraw from the study at any time during pregnancy.

All participants are expected to sign a written consent form which will be discussed with one of the medical team. It is planned to publish the results of this research nationally and internationally. It is hoped that our findings will help shape public policy about the optimum diet, physical activity and weight gain for women generally, and Irish women in particular.

We thank you for your cooperation.

Professor Michael Turner

Dr Amy O'Higgins

Appendix 6: Publications

Journal of Public Health Advance Access published October 29, 2014

Journal of Public Health | pp. 1–9 | doi:10.1093/pubmed/fdu086

An estimation of periconceptional under-reporting of dietary energy intake

Laura Mullaney[1], Amy C. O'Higgins[2], Shona Cawley[1], Anne Doolan[3], Daniel McCartney[1], Michael J. Turner[2]

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[2]UCD Centre for Human Reproduction, Coombe Women and Infants University Hospital, Dublin 8, Republic of Ireland
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ABSTRACT

Background The purpose of this cross-sectional study was to examine periconceptional misreporting of energy intake (EI) using the Willet food frequency questionnaire (WFFQ).

Methods Women were recruited in the first trimester. Women completed a semi-quantitative WFFQ. Maternal body composition was measured using eight-electrode bioelectrical impedance analysis. Under-reporters were those whose ratio of EI to their calculated basal metabolic rate fell below the calculated plausible threshold for their physical activity category.

Results The mean age was 30.1 ± 5.3 years ($n = 524$). The mean body mass index (BMI) was 25.4 ± 5.6 kg/m^2, and 16.6% were obese (BMI ≥ 30.0 kg/m^2). Under-reported EI was observed in 122 women (23.3%) with no over-reporters in the sample. Under-reporters were younger ($P < 0.001$), less likely to have a normal BMI ($P = 0.002$) and more likely to be obese ($P < 0.001$) than plausible reporters. Under-reporters had higher percentage of body-fat and lower percentage of body fat-free mass ($P < 0.001$), were more likely to be at risk of relative deprivation ($P = 0.001$) and reported a higher percentage of EI from carbohydrate ($P = 0.02$) than plausible reporters.

Conclusions Observed differences between under-reporters and plausible reporters suggest that the exclusion of these under-reporters represents an important potential source of bias in obesity research among women in the periconceptional period.

Keywords energy intake, periconceptional, under-reporters, Willet food frequency questionnaire

Introduction

Dietary misreporting is an accepted shortcoming in nutritional surveys.[1] The use of external reference measures, such as whole-body calorimetry, and biomarkers, such as urinary nitrogen excretion and doubly labelled water (DLW), have confirmed that misreporting is common in self-reported dietary assessments, with a strong tendency towards under-reporting.[2,3] It has consequently been recommended that all dietary intake studies include an external independent measure of validity.[4] The DLW method, for example, can measure energy expenditure with good accuracy.[5] However, it is costly and unsuitable for large samples.[6] As a result, a method based on the ratio of energy intake (EI) to basal metabolic rate (BMR) (EI/BMR) has been introduced[7] and refined[8] to detect misreporting in weight-stable individuals.

Reporting of EI may be influenced by factors including age, sex, body fat, body mass index (BMI), education level, social desirability and income level.[9–12] Obesity affects one in six women booking for antenatal care in our hospital and is an important modifiable obstetric risk factor.[13] Maternal obesity increases the risk of pregnancy-related complications, such as gestational diabetes mellitus, which is also associated

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Michael J. Turner, FRCOG, Professor of Obstetrics and Gynaecology

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with the increased risk of type 2 diabetes mellitus in later life.[14,15] Maternal obesity is associated with an increase in obstetric interventions such as caesarean section[16] and is associated with an increased risk of congenital malformations such as neural tube defects.[17]

Metabolic ill-health in pregnancy has been mainly attributed to high maternal bodyweight,[18] as well as excessive refined sugar intake.[19] Findings of lower micronutrient status in obese pregnant women have prompted speculation that deficits in vitamin D[20] and iron[21] status in obese women may exacerbate their observed metabolic and immunological abnormalities in pregnancy.

As income decreases, consumption of low-cost, energy-dense, nutrient-dilute foods increases.[22] Lower income levels in women have also been associated with more frequent under-reporting of EI.[9] Correction of micronutrient deficiencies in obese and low-income group women might improve their maternal metabolic and inflammatory status, potentially enhancing the long-term health of their offspring.

However, the increased incidence of under-reporting in overweight, obese and low-SES women may obfuscate their actual nutritional risk. For example, many studies exclude mis-reporters from their final analyses or rely on predictive equations to estimate correct EI.[12] Thus, mis-reporters may be either omitted entirely from such nutrient intake analyses introducing systematic bias or may have their nutrient intakes estimated from derived quantitative data, which assume the absence of qualitative bias in these respondents' dietary reporting. Maternal diet and nutritional status can be modified before conception, and given the potential importance of maternal diet in foetal programming and lifelong health, all women in pregnancy or planning pregnancy, who are at risk of micronutrient deficiencies or excessive macronutrient intakes, should be identified and interventions evaluated.[23] The purpose of this cross-sectional study was to analyse the characteristics of women who misreported dietary EI in the periconceptional period according to the validated Willet food frequency questionnaire (WFFQ).[24]

Methods

This cross-sectional study was carried out in the Coombe Women and Infants University Hospital, which 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 between February and August 2013. The main inclusion criterion was women booking for antenatal care after an ultrasound examination confirmed a singleton ongoing pregnancy in the first trimester. The main exclusion criterion was multiple pregnancies so to reduce the number of confounding variables.

Height was measured to the nearest centimetre using a Seca wall-mounted digital metre stick with women standing in their bare feet. Weight and body composition were measured digitally to the nearest 0.01 kg (Tanita MC 180, Tokyo, Japan) and BMI calculated. Socioeconomic, health behavioural and physical activity data were also collected at the same time using an unsupervised questionnaire. The clinical and health behavioural data included any medical conditions or medications which applied to the individual, or if the individual was taking supplements. Supplement data were not included in the final nutrient estimation.

Food frequency questionnaire

To collect 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. The WFFQ is adapted from the European Prospective Investigation into Cancer and Nutrition (EPIC) study and validated for use in a population of Irish adults.[25–27] The WFFQ has also been validated in an Irish obstetric population.[24]

The adapted WFFQ comprises 170 food and beverage items. Frequency of consumption of a standard portion of each food or beverage item consumed was divided into nine categories, ranging from 'never or less than once per month' to 'six or more times per day'. This instrument captures food and nutrient data reflective of the periconceptional period, as the WFFQ 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 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.[28]

Other lifestyle information

Questions collecting socioeconomic data were derived from the Survey on Income and Living Conditions.[29] Material indices of disadvantage including 'at risk of poverty' status, relative deprivation and consistent poverty were also calculated. 'At risk of poverty' status was calculated by comparing equalized household income against the 60% median income threshold. Relative deprivation was assessed by determining whether the respondents had experienced the enforced absence (due to financial constraint) of two or more basic necessities from a list of eleven. Consistent poverty was identified if a respondent reported being 'at risk of poverty' in

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addition to experiencing enforced absence of two or more of the eleven basic markers of deprivation.[29]

Self-assessed habitual physical activity levels (PALs) were also collected using a self-administered, unsupervised questionnaire. Individual PAL was 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)].[30]

Assessment of energy under- and over-reporting

BMR was calculated using standard equations based on gender, weight and age.[31] EI was calculated using WFFQ data and WISP v 4.0 software (Tinuviel Software). Lowest plausible thresholds for PAL were calculated according to respondents' individual self-reported PAL.[8] 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.[7] In all categories, those with an EI/BMR of >2.5 were classified as dietary over-reporters.[3]

Statistical analysis

Data analysis was carried out using SPSS statistics version 20.0 (IBM Corporation, Armonk, New York). Respondent data for weight, height, age, gestational age, BMI, % fat mass and % fat-free mass were all normally distributed. Independent samples *t*-tests were used to compare the mean values for these variables between the plausible reporter and mis-reporter groups. As fat mass and fat-free mass levels were non-normally distributed, differences in their median levels between the plausible reporter and mis-reporter groups were assessed using Mann–Whitney *U* tests. Cross-tabulation with Chi-square analyses were used to test differences between the proportions of plausible reporters and mis-reporters in different socioeconomic and health behavioural groups, e.g. ethnicity, smoking status, reporting the Yates continuity correction for all dichotomous 2×2 tests.

Nutrient data were non-normally distributed; thus, Mann–Whitney *U* tests were used to test differences in median absolute nutrient intakes between plausible reporters and mis-reporters. Nutrient intakes per MJ of EI were calculated according to previously described protocols.[32] Mann–Whitney *U* tests were used to test differences in median energy-adjusted macronutrient and micronutrient intakes between these two groups.

Results

Of the 588 women studied, 524 women were included in the final analysis, for the following reasons: fifty-two women (8.8%) did not complete the PAL self-assessment and 12 women (2.0%) did not complete the WFFQ due to time constraints (response rate 89%). For the total population ($n = 524$), the mean age was 30.1 $\pm$ 5.3 years, the mean gestational age was 12.6 $\pm$ 2.6 weeks, the mean BMI was 25.4 $\pm$ 5.6 kg/m^2, with 16.6% obese, and the mean PAL was 1.75 $\pm$ 0.2 METs. Forty-five per cent of the sample was primigravidas.

The mean ratio of EI\BMR was 2.1 $\pm$ 0.9 in the underweight BMI category, 1.7 $\pm$ 0.7 in the ideal weight BMI category, 1.6 $\pm$ 0.7 in the overweight BMI category and 1.3 $\pm$ 0.9 in the obese BMI category ($P < 0.001$). Under-reported EI were observed in 122 women (23.3%). There were no over-reporters in the sample. Differences in anthropometric and socioeconomic parameters between the under-reporters and plausible reporters are outlined in Table 1. Under-reporters were less likely to have a normal BMI ($P = 0.002$) and more likely to be obese ($P < 0.001$) than plausible reporters. Under-reporters also had higher body fat percentages and lower body fat-free mass percentages than plausible reporters (both $P < 0.001$). Under-reporters were more likely to be at risk of relative deprivation ($P = 0.001$). Consistent poverty levels were the same in the plausible and under-reporter groups.

Under-reporters reported lower absolute intakes of all macro and micronutrients as per the WFFQ (Table 2). Under-reporters reported a higher percentage of energy from carbohydrate ($P = 0.02$) and higher intakes of riboflavin ($P < 0.001$), thiamine ($P = 0.03$), niacin ($P = 0.001$), vitamin B_6 ($P = 0.002$), folate ($P = 0.006$) and dietary fibre ($P < 0.004$) per MJ of energy consumed according to their WFFQ data. Under-reporters reported lower intakes of calcium ($P = 0.01$), magnesium ($P = 0.03$) and retinol ($P = 0.002$) per MJ of energy consumed as per their WFFQ (Tables 3 and 4).

Discussion

Main finding of this study

This cross-sectional study, using the WFFQ to assess periconceptional diet, found that under-reporting was more likely to occur in obese women. Under-reporting was also positively associated with increasing fat mass and increasing percentage of body fat. The under-reporters were younger than the plausible reporters ($P < 0.001$) and had a higher prevalence of relative deprivation ($P = 0.001$). Therefore, excluding under-reporters introduces a potential bias in assessing the links between food and nutrient intake and obesity among pregnant women. When macronutrients were expressed as percentages of total energy, under-reporters reported a higher percentage of energy from carbohydrate than plausible

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Table 1 Characteristics of study subjects

	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 at first visit (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[b]	14 (3.5)	1 (0.8)	–
Ideal weight	225 (55.8)	45 (36.9)	0.002
Overweight	120 (29.8)	33 (27)	NS
Obese	44 (10.9)	43 (35.2)	<0.001
Fat mass (kg)[c]	19 (10)	24 (15.6)	<0.001
Fat mass (%)[a]	29.7 ± 6.6	33.2 ± 7.6	<0.001
Fat-free mass (kg)[c]	46 (6.3)	49 (9.3)	<0.001
Fat-free mass (%)[a]	70.2 ± 6.7	66.8 ± 7.6	<0.001
Parity[c]	1 (1)	0 (1)	–
Cultural background[b]			
Irish	304 (75.6)	100 (82.0)	NS
Other European	69 (17.2)	17 (13.9)	NS
Asian	6 (1.5)	2 (1.6)	–
African	4 (1.0)	0 (0)	–
Other	19 (4.7)	3 (2.5)	–
Have you ceased full-time education?[b]			
Yes	286 (71.1)	88 (72.1)	NS
No	116 (28.9)	34 (27.9)	
Smoking status[b]			
Current smoker	51 (12.7)	14 (11.5)	NS
Former smoker	181 (45.0)	48 (39.3)	
Never smoked	170 (42.3)	60 (49.2)	
Alcohol consumption[b]			
Yes	230 (57.2)	66 (54.1)	NS
No	172 (42.8)	56 (45.9)	
Relative income poverty[b,d]			
At risk	139 (34.6)	30 (24.6)	NS
Not at risk	263 (65.4)	87 (71.3)	
Relative deprivation[b,e]			
At risk	31 (7.7)	23 (18.9)	0.001
Not at risk	355 (88.3)	99 (81.1)	
Consistent poverty[b,f]			
At risk	31 (7.7)	9 (7.4)	NS
Not at risk	355 (88.3)	108 (88.5)	

[a]Mean ± SD.
[b]Number (% of group).
[c]Median (IQR).
[d]Missing data, $n = 5$.
[e]Missing data, $n = 16$.
[f]Missing data, $n = 21$.

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Table 2 Comparison between plausible reporters and under-reporters in absolute macro- and micro-nutrient intakes

	Plausible reporters[a] *(n = 402)*	*Under-reporters* [a] *(n = 122)*	*P*
Protein (g)	94.0 (51)	56.0 (19)	<0.001
Carbohydrate (g)	259 (129)	155 (61)	<0.001
Fat (g)	84.5 (41)	47.0 (21)	<0.001
Saturates (g)	29.0 (15)	16.5 (8)	<0.001
Monounsaturated fat (g)	27.0 (14)	15.0 (8)	<0.001
Polyunsaturated fat (g)	19.0 (10)	10.0 (5)	<0.001
Fibre (g) (AOAC)	30.0 (15)	18.0 (9)	≤0.001
Non-milk extrinsic sugar (g)	35.0 (32)	20.0 (18)	<0.001
Alcohol (g)	1.00 (5)	0.00 (1)	<0.001
Sodium (mg)	2837 (1465)	1655 (982)	<0.001
Potassium (mg)	4292 (6736)	2427 (1108)	<0.001
Calcium (mg)	794 (534)	425 (230)	<0.001
Magnesium (mg)	387 (588)	207 (101)	<0.001
Phosphorus (mg)	1553 (952)	889 (346)	<0.001
Iron (mg)	17.0 (12)	9.00 (5)	<0.001
Copper (mg)	2.00 (1)	1.00 (0)	<0.001
Zinc (mg)	11.0 (5)	6.00 (2)	<0.001
Chloride (mg)	4131 (2028)	2412 (1434)	<0.001
Iodine (mg)	91.0 (48)	53.0 (28)	NS
Retinol (μg)	297 (244)	160 (108)	0.002
Carotene (μg)	6437 (4976)	4016 (4040)	NS
Vitamin D (μg)	3.00 (2)	1.00 (1)	<0.001
Vitamin E (mg)	11.0 (6)	7.00 (3)	<0.001
Vitamin C (mg)	220 (149)	132 (109)	<0.001
Thiamine (mg)	2.00 (1)	1.00 (1)	<0.001
Riboflavin (mg)	2.00 (1)	1.0 0 (0)	<0.001
Niacin (mg)	26.0 (11)	16.0 (7)	<0.001
Vitamin B_6 (mg)	3.00 (1)	2.00 (1)	<0.001
Vitamin B_{12} (mg)	4.00 (3)	2.00 (1)	≤0.001
Folate (μg)	337 (170)	213 (95)	0.006

[a]Median (IQR); AOAC: Association of Organic and Analytic Chemists method used by WISP V 4 to measure fibre content of food.

reporters ($P = 0.02$), possibly reflecting selective biases in their under-reporting behaviour.

Our study has a large sample size. Another strength of our study is that individually reported PAL were used to assess lowest plausible thresholds for PAL.[8] This allowed for the identification of women who were deemed likely to be mis-reporters at an individual level, i.e. if EI/BMR was less than the individual's lowest plausible threshold for PAL, they were considered under-reporters. Many studies use a single PAL value to estimate the group's PAL, which may be considered inaccurate as estimated habitual PALs among free-living individuals vary greatly.[3] It has been suggested that to optimize the accuracy of data collected, a measure of physical activity should be collected, which allows individuals to be categorized into different activity levels for the purpose of stratified EI/BMR threshold calculation.[33] Our study used bioelectric impedance to measure maternal weight and body composition. The accurate assessment of bodyweight is critical as women, in particular obese women, have been shown to underestimate their weight.[13]

Limitations of this study

A limitation of the study is that only one dietary assessment method was used to assess energy and nutrient intakes and that this was a self-reported questionnaire. Studies have shown that accuracy of the food frequency questionnaire (FFQ) can be lower than other methods, with the FFQ containing a substantial amount of measurement error because it makes several assumptions about food portion size and may

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Table 3 Comparison between plausible reporters and under-reporters in percentage of EIs from macronutrients

	Plausible reporters[a] *(n = 402)*	*Under-reporters*[a] *(n = 122)*	*P*
Protein (%/MJ/day)	17.3 (5)	17.3 (4)	NS
Carbohydrate (%/MJ/day)	48.1 (10)	49.9 (11)	0.02
Fat (%/MJ/day)	36.2 (7)	35.2 (10)	NS
Saturates (%/MJ/day)	12.0 (3)	11.7 (4)	NS
Monounsaturated fat (%/MJ/day)	11.6 (3)	11.1 (4)	NS
Polyunsaturated fat (%/MJ/day)	7.70 (3)	7.40 (3)	NS
Fibre (g/MJ/day) (AOAC)	3.20 (1)	3.70 (1)	0.004
Non-milk extrinsic sugar (%/MJ/day)	6.70 (5)	6.60 (5)	NS

[a]Median (IQR); AOAC: Association of Organic and Analytic Chemists method used by WISP V 4 to measure fibre content of food.

result in an underestimation of dietary intake due to an inadequate list of food items.[9,34] Nonetheless, the FFQ can be reliably used to rank individuals according to food or nutrient intake and, thus, represents an appropriate tool to analyse the characteristics of mis-reporters.

Our study did not record nausea in the first trimester. Dietary intake should increase during pregnancy.[35] However, common fluctuations in appetite, nausea and vomiting may affect this anticipated increase.[36] Thus, a specific period of pregnancy may not be representative of the whole gestation. It has been shown that a single FFQ administration around the time of delivery was able to capture dietary intake throughout the whole pregnancy among Portuguese pregnant women.[37] These researchers found that the performance of their FFQ was not modified by the presence of nausea and/or vomiting, daily number of meals or weekly weight gain. Similarly, an FFQ given once during pregnancy, between 12 and 34 weeks of gestation, in Irish multigravidas was shown to be representative of dietary intake throughout the whole pregnancy.[24,38] The WFFQ used in this study is representative of the periconceptional period. Further studies are needed to assess the extent and characteristics of women who under-report EI throughout the whole gestation.

What is already known on this topic?

Studies using DLW and urinary nitrogen have confirmed a higher prevalence of under-reporting among obese subjects, as well as differential dietary reporting patterns with respect to different foods.[39–41] Other researchers have also reported that non-pregnant subjects who have higher BMI are more likely to under-report.[12] In a Brazilian study, using DLW as an external validator of energy, there was a positive association between increasing BMI and under-reporting in 65 women. Similarly, in our study, under-reporters were more likely to be overweight or obese.

Lower income levels have been associated with more frequent under-reporting.[9] As income decreases, an increase in energy-dense, nutrient-dilute foods can occur, possibly as a means to maintain EI at a lower cost. If income decreases further, households may decrease EI below daily requirements, resulting in overt deprivation.[22] The current study found that women who under-reported EI were more likely to be at risk of relative deprivation. These women may be consuming an EI below requirements as a means to reduce costs, as opposed to actually under-reporting EI.

In a Canadian study, 43% of participants were classified as under-reporters when evaluated by the Goldberg technique. Female under-reporters were older ($P = 0.01$), heavier ($P = 0.04$), had a higher BMI ($P = 0.02$) and were more likely to report intakes of foods containing a higher percentage of carbohydrate ($P = 0.02$) or a lower percentage of fat ($P = 0.002$), than plausible reporters.[42] Other studies have also observed that older women were more likely to under-report EI than younger women.[43] One study in postmenopausal women identified no effect of age on energy reporting levels.[44] Another study found that younger, postmenopausal women under-reported EI more frequently than older women.[45] In our study, under-reporters were more likely to be younger ($P < 0.001$). There are few studies investigating the effect of age on energy under-reporting in the periconceptional period, and the interpretation of such data is further complicated by the socioeconomic gradient in primiparous age.[46,47]

The EPIC-Postdam study also found that EI/BMR ratios decreased with increasing BMI ($P < 0.001$).[41] In our study, the mean EI/BMR also decreased as BMI increased ($P < 0.001$). EI was measured in the EPIC-Postdam study using a semi-quantitative FFQ, and BMR was calculated using standard equations including weight and age.[48] The EPIC-Postdam study found that a higher proportion of under-reporters reported a higher proportion of energy from protein and carbohydrate, and a lower proportion of energy from fat.[41] Our study also found that under-reporters reported a higher proportion of energy from carbohydrate.

In 436 Australian middle-aged women, the relationship between body fat using dual X-ray absorptiometry and the dietary characteristics of energy under-reporters was

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Table 4 Comparison between plausible reporters and under-reporters in percentage of EIs from micronutrients

	Plausible reporters[a] *(n = 402)*	*Under-reporters*[a] *(n = 122)*	*P*
Sodium (mg/MJ/day)	308 (84)	313 (114)	NS
Potassium (mg/MJ/day)	653 (508)	451 (165)	NS
Calcium (mg/MJ/day)	86.2 (34)	78.1 (31)	0.01
Magnesium (mg/MJ/day)	41.6 (44)	37.9 (16)	0.03
Phosphorus (mg/MJ/day)	166 (49)	164 (31)	NS
Iron (mg/MJ/day)	1.70 (0.9)	1.70 (0.7)	NS
Copper (mg/MJ/day)	0.20 (0.1)	0.20 (0.1)	NS
Zinc (mg/MJ/day)	1.20 (0.3)	1.20 (0.3)	NS
Chloride (mg/MJ/day)	453 (124)	454 (162)	NS
Iodine (mg/MJ/day)	9.70 (4)	9.90 (4)	NS
Retinol (μg/MJ/d)	33.1 (22)	29.6 (18)	0.002
Carotene (μg/MJ/d)	709 (591)	752 (789)	NS
Vitamin D (μg/MJ/d)	0.30 (0.2)	0.30 (0.2)	NS
Vitamin E (mg/MJ/day)	1.30 (0.4)	1.20 (0.4)	NS
Vitamin C (mg/MJ/day)	22.8 (17)	25.2 (23)	NS
Thiamine (mg/MJ/day)	0.22 (0.1)	0.23 (0.1)	0.03
Riboflavin (mg/MJ/day)	0.17 (0.1)	0.19 (0.1)	<0.001
Niacin (mg/MJ/day)	2.90 (0.9)	3.10 (1)	0.001
Vitamin B_6 (mg/MJ/day)	0.30 (0.1)	0.33 (0.1)	0.002
Vitamin B_{12} (mg/MJ/day)	0.50 (0.2)	0.50 (0.3)	NS
Folate (μg/MJ/d)	37.1 (14)	42.0 (15)	0.006

[a]Median (IQR).

investigated.[49] Women categorized as under-reporters had increased weight ($P < 0.01$), BMI ($P < 0.01$), total fat mass ($P < 0.05$) and fat-free mass ($P < 0.05$) than plausible reporters. However, percentage of body fat did not differ between the two groups. While higher percentage of body fat was seen in women with a lower EI/BMR ratio in the EPIC-Postdam study ($P < 0.001$), the calculation of percentage of body fat in this study was based on derivation using skin-fold measurements.[41,50] In our study, under-reporters had a higher BMI, higher fat mass and body fat percentages and lower fat-free mass and body fat-free mass percentages than plausible reporters, suggesting that both BMI and adiposity are associated with under-reporting.

The characteristics of under-reporters have been well documented in general populations; there are fewer studies investigating the characteristics of under-reporters in the periconceptional period. Periconceptional nutrition is known to be crucial for an optimal onset and development of pregnancy.[51] In 260 Irish multigravidas women, between 10 and 18 weeks of gestation, a high proportion (44%) were classified as under-reporters.[10,38] In 490 Indonesian women, the mean EI/BMR was 1.33, classifying 29.7% as under-reporters in the first trimester of pregnancy.[11] The authors believed that this percentage represented a group with inadequate dietary intake as opposed to under-reporting, as many women reported nausea during the first trimester.

What this study adds

The observed dietary reporting bias in this study, as well as the biases introduced by the exclusion of dietary misreporters or the adjustment of their reported dietary intakes based on exclusively quantitative correction equations, may generate misleading associations between dietary and nutrient intakes and obstetric outcome. The increased incidence of under-reporting in overweight and obese women in particular may result in erroneous conclusions regarding the nutritional status and risk profile of these women. The assessment of body composition allowed us investigate the association between body fat levels in early pregnancy and the likelihood of under-reporting, which as far as we are aware has not been investigated in any previous studies in pregnancy. Women with at risk of relative deprivation may be at particular risk of nutritional deficiencies. Maternal diet and nutritional status can be modified before conception, and given the potential importance of maternal diet in foetal programming and

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lifelong health, the associations between nutritional intake and status and gestational outcome need to be clearly and accurately articulated. On the basis of these findings, all women who are planning pregnancy or in pregnancy who may be at risk of nutritional deficiencies or excesses need to be accurately identified so that effective interventions can be implemented. Particular emphasis on specialist dietary assessment in overweight and obese women in pregnancy may also be needed to ensure the collection of more robust nutritional intake data from these women. There may also be a need to refine advice given to women who are pregnant or planning a pregnancy.

Acknowledgements

This work was partially funded by an unlimited educational grant from Danone which we acknowledge with gratitude. We also acknowledge with gratitude the participation of the pregnant women who took part in this study.

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Irish Journal of Medical Science (1971 -)

ISSN 0021-1265

Ir J Med Sci
DOI 10.1007/s11845-016-1430-x

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Ir J Med Sci
DOI 10.1007/s11845-016-1430-x

ORIGINAL ARTICLE

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

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Received: 27 August 2015 / Accepted: 21 February 2016
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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

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

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Published online: 11 March 2016

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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 ($\sim$2 h duration), with the WFFQ given to participants $\sim$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 socio-

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economic 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

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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 ($P = 0.01$)

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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

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($P < 0.001$), 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)

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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)		

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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.

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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)		

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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

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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

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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.

Acknowledgments We acknowledge with gratitude the participation and cooperation of the pregnant women who participated in this study. This project was gratefully supported by an unrestricted educational grant provided by Danone Nutricia Early Life Nutrition.

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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DOI: 10.1111/1747-0080.12278

Nutrition & Dietetics

ORIGINAL RESEARCH

Relationship between fasting plasma glucose levels and maternal food group and macronutrient intakes in pregnancy

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Abstract

Aim: Increased maternal body mass index (BMI) has been consistently associated with elevated blood glucose levels during pregnancy. Studies to date investigating the relationship between maternal blood glucose levels and dietary intake have shown mixed results. We investigated the association between maternal fasting plasma glucose (FPG) levels and food group and macronutrient intakes in the first trimester of pregnancy, after adjustment for maternal bodyweight.

Methods: Women were recruited after sonographic confirmation of an ongoing singleton pregnancy in the first trimester. Dietary information was collected using the validated Willett Food Frequency Questionnaire. Maternal height and weight were measured and BMI calculated. Body composition was measured using advanced bioelectrical impedance analysis. FPG levels were obtained for women who were selectively screened with a 75 g oral glucose tolerance test.

Results: No associations were observed between maternal FPG levels and food group or macronutrient intakes but higher energy and starch intakes were found in obese subjects ($P = 0.009$ and $P = 0.03$ respectively). On univariate analysis, higher FPG levels were associated positively with higher maternal bodyweight, BMI, body fat, fat free mass and visceral fat (all $P < 0.001$). However, on multivariate regression analysis, higher FPG levels remained associated only with maternal BMI > 29.9 kg/m^2 (OR 7.4, $P = 0.01$).

Conclusions: Our findings indicate that maternal BMI is the key determinant of maternal glycaemia. Interventions which focus on overall energy restriction and especially the limitation of dietary starch to optimise prepregnancy maternal bodyweight are likely to be useful in improving glycaemic control in higher risk pregnancies.

Key words: fasting plasma glucose, food group, gestational diabetes, obesity, pregnancy.

Introduction

Gestational diabetes mellitus (GDM) is associated with adverse outcomes not only for the woman, but also for her offspring.[1–3] GDM has been associated with increased caesarean section rates and pre-eclampsia, while women who develop GDM are also at increased risk of developing type 2 diabetes mellitus (T2DM) later in life.[4,5] Offspring of mothers with GDM are at risk of macrosomia, as well as obesity and T2DM later in life.[4,5] In women with GDM, higher levels of blood glucose pass through the placenta. This results in foetal hyperinsulinaemia and hyperglycaemia leading to an increase in foetal fat and protein stores, and subsequently macrosomia.[6]

While the definition of GDM as glucose intolerance with onset or first recognition during pregnancy is largely accepted, the exact level of glucose intolerance which defines GDM remains contentious.[1–4,7,8] The Hyperglycaemia and Adverse Pregnancy Outcome study found a linear association between maternal plasma glucose (PG) levels and adverse perinatal outcomes across the whole distribution of PG levels in pregnancy.[9] Thus, there is no clear PG threshold above which women and their offspring are at high clinical risk and below which they are at low risk. Criteria for the diagnosis of GDM have been developed, however, in an attempt to identify thresholds which best predict adverse maternal and neonatal outcomes. Unfortunately,

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Accepted February 2016

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clear evidence demonstrating improved clinical outcomes through the use of one criterion over another has remained elusive. This has led to the use of several different criteria for the diagnosis of GDM which are arbitrary and often based on expert opinion.[7] Diagnosis of GDM can be further complicated by poorly controlled pre-analytical handling of the fasting glucose sample.[8]

Diet and physical activity level (PAL) have been proposed as modifiable risk factors for the development of GDM.[10–16] However, diet and lifestyle interventions to enhance blood glucose control in pregnancy have yielded inconsistent results.[17] Conversely, it is established that the risk of developing GDM is increased in women with higher prepregnancy body mass index (BMI), and that this risk increases progressively across the BMI categories of overweight and obesity.[18–20] Total body fat mass has also been linked to insulin resistance.[21–23] However, there is a lack of studies examining the association between maternal fat mass and glycaemic control during pregnancy.

Effective interventions to prevent and treat GDM are important to reduce the short- and long-term adverse health consequences for women and their offspring. The aim of this study was to investigate the association between maternal FPG levels and energy intake (EI), PAL, food group intake and macronutrient intake in the first trimester of pregnancy after adjustment for bodyweight and other potential confounders.

Methods

The Coombe Women and Infants University Hospital 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 were recruited at their convenience between February and August 2013 as part of a longitudinal study investigating maternal weight trajectories.[24,25] The women's clinical and socio-demographic details were computerised routinely at the first antenatal visit. The main inclusion criteria were women booking for antenatal care after an ultrasound confirmation of a singleton ongoing pregnancy in the first trimester. Exclusion criteria included multiple pregnancies, women with pre-existing diabetes or women who subsequently delivered in another hospital.

To collect habitual food and nutrient intakes, women were asked to complete the previously validated semi-quantitative Willett Food Frequency Questionnaire (WFFQ).[26–28] Socioeconomic, health behavioural and physical activity data were also collected using an online questionnaire. 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 and BMI calculated. Body composition was measured using an eight-lead multi-frequency bioelectrical impedance analyser (BIA) (Tanita MC 180, Tokyo, Japan).[29,30]

Of a total study population of 524 women, oral glucose tolerance tests (OGTT) were performed between weeks 24 and 28 of gestation on a cohort 180 women identified to have risk factors for GDM according to national screening guidelines.[24,31] Written informed consent was obtained from all study participants. The study was approved by the Coombe Women and Infants University Hospital Research Ethics Committee.

The FFQ used was a self-administered WFFQ adapted from the European Prospective Investigation into Cancer and Nutrition study and validated for use in Irish adults.[26,27,32] This WFFQ has also been recently validated in an Irish obstetric population.[28] Frequency of consumption of a 'standard portion' of each food or beverage item consumed was divided into 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 Food Standards Agency's Average Portion Sizes reference text.[33] This dietary assessment protocol captured food and nutrient data reflective of the periconceptual period, as the WFFQ focuses on consumption patterns over the previous year. The WFFQ food intake data were entered into WISP version 4.0 (Tinuviel Software, Llanfechell, Anglesey, UK) to convert these reported food intakes into 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.[34]

The clinical and health behavioural data collected included any applicable medical conditions and medications, as well as the woman's smoking status. Questions collecting socioeconomic data were derived from the EU Survey on Income and Living Conditions 2012.[35,36] Material indices of disadvantage included relative income poverty, as well as relative deprivation, while consistent poverty status was also calculated using these two parameters. Relative income poverty status was calculated by comparing equivalised household income against the 60% median income threshold. Relative deprivation was assessed by determining whether women had experienced the enforced absence (due to financial constraint) of two or more basic necessities from a list of 11 over the previous year. Consistent poverty was identified if a woman's equivalised household income fell below the relative income poverty threshold, in addition to experiencing the enforced absence of two or more of the 11 basic markers of deprivation over the preceding 12 months.

Self-assessed habitual PALs were also collected using a self-administered, unsupervised questionnaire. Individual PAL was estimated for each woman from 1.45 metabolic equivalents (MET) (seated work with no option of moving around and no strenuous leisure time activity), up to 2.20 MET (strenuous work or highly active leisure time (e.g. competitive athletes in daily training).[37]

Women who under- and over-reported EI were excluded from the final food and nutrient intake datasets as previously described[24] so as to enhance the integrity of our analyses.[38] Data analyses were carried out using SPSS version 20.0 (IBM Corporation, Armonk, NY, USA). Descriptive analyses were initially carried out to characterise the cohort with respect to their age, parity, ethnicity, stage of gestation,

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socioeconomic status, smoking status and PAL. One-way ANOVA tests were used to compare mean values for continuous variables (age, gestational age, PAL) between the FPG tertiles. Cross-tabulation with chi-square analyses were used to test differences in categorical socioeconomic and health behavioural variables across the FPG tertiles. Data for weight, BMI, body fat mass, percentage body fat and fat free mass were non-normally distributed. Kruskal–Wallis tests were used to assess differences in these parameters between the FPG tertiles. Kruskal–Wallis tests were also used to test differences in median energy-adjusted food group and macronutrient intakes among women in each FPG tertile. Binary logistic regression was used to assess factors associated with FPG levels >4.5 mmol/L. This regression model incorporated variables such as antenatal obesity, family history of diabetes, early pregnancy weight, body fat %, fat free mass, visceral fat level, age, parity, smoking status, Irish nativity, glycaemic index of the diet and EI, sugar, carbohydrate, protein, fat and dietary fibre intake. Mann–Whitney *U*-test was used to assess differences in energy-adjusted macronutrient intakes between obese and non-obese women.

Results

OGTTs were undertaken by 180 women. GDM was diagnosed in 16 women (8.9%) according to the International Association of Diabetes and Pregnancy Study Group recommendations.[39] Mean FPG levels were 4.5 mmol/L (range 3.6–8.9 mmol/L). The social and demographic characteristics of this study population both overall, and according to FPG level, are shown in Table 1. Women completed the WFFQ at 12.6 ± 2.8 weeks gestation. FPG levels increased with increasing weight, BMI, body fat mass, percentage body fat, fat free mass, and visceral fat (all $P < 0.001$) (Table 2).

EI under-reporting was observed in 57 women (31.7%). There were no EI over-reporters in the sample. EI under-reporters in this sample had a higher weight (87.1 ± 19.3 *vs* 73.9 ± 15.2 kg ($P = 0.001$)), BMI (32.0 ± 7.1 *vs* 26.9 ± 5.5 kg/m^2 ($P = 0.001$)), body fat % (37.1 ± 7.4 *vs* 32.4 ± 7.4% ($P = 0.001$)), and fat free mass (53.6 ± 7.4 *vs* 49.0 ± 5.9 kg ($P = 0.001$)) compared with plausible reporters of EI. No differences were seen in energy-adjusted food group and macronutrient intakes across FPG tertiles (Table 3).

On logistic regression only antenatal obesity (BMI > 29.9 kg/m^2; OR 7.4, $P = 0.01$) was associated with a FPG level >4.5 mmol/L. Obese plausible reporters (n = 35) had a higher EI (3254.9 *vs* 2281.5 kcal/day ($P = 0.009$)), higher starch intake (28.2 *vs* 24.2% total energy (TE) ($P = 0.03$)), higher maltose intake (0.65 *vs* 0.45% TE ($P = 0.04$)) and lower fructose intake (3.37 *vs* 3.88% TE ($P = 0.03$)) compared with non-obese women. There was no difference in self-reported PAL between obese and non-obese women (1.76 ± 0.2 *vs* 1.75 ± 0.2 ($P = 0.598$)).

One- and two-hour post glucose load PG levels also showed no association with maternal food and macronutrient intakes. The one-hour PG levels also increased as maternal weight, BMI and body composition increased. Interestingly the two-hour PG levels were not as significant as the FPG or one-hour PG levels. Only BMI increased as the two-hour PG levels increased ($P = 0.03$).

Discussion

This study found that maternal FPG levels at 24–28 weeks gestation were not associated with food group and macronutrient intakes in the periconceptional period. Obesity in early pregnancy was associated with higher FPG levels after adjusting for important confounding variables. This suggests that weight management interventions should be targeted at women of child-bearing age in the prepregnancy period, especially those who are obese. These weight management programmes should incorporate limitations on overall dietary EI particularly that derived from starchy foods, as high intakes of both were associated with maternal obesity.

Our study has a number of strengths. Maternal weight was measured, not self-reported. While the accurate assessment of bodyweight is critical, women, particularly those who are obese, have been shown to commonly underestimate their weight when self-reporting, which may lead to BMI mis-categorisation.[40,41] BIA was used to measure maternal weight and body composition.[29,30] The maternal weight was taken in the first trimester, which has been shown to be the optimal time for weight measurement in pregnancy, as maternal weight and body composition only begin to change after 18 weeks of gestation.[30] The availability and use of the women's body composition data is another strength of this study. Given the lack of clear consensus around the exact level of glucose intolerance which defines GDM, FPG levels were investigated in this study.[1–4,7,8]

A possible limitation of this study is the difficulty associated with accurate assessment of dietary intake. The WFFQ is a semi-quantitative FFQ and, therefore, does not facilitate portion size estimation for individuals. Nonetheless, the WFFQ has been validated as a dietary data collection instrument in several Irish population studies, including a recent study on pregnant women in Dublin.[26–28,32] Another potential weakness is that convenience recruitment may introduce an unforeseen self-selection bias that was not addressed in the multivariate analysis.

Women who under-reported their EI were excluded from the final food and nutrient intake datasets to enhance the integrity of the population's nutrient intake data.[38] Under-reporting of EI is a phenomenon associated with dietary surveys and must be taken into account when interpreting the results of such surveys.[24] Specifically, under-reporting of EI is increased amongst women in higher BMI categories and, therefore, needs to be considered when conducting research into GDM as increased BMI is associated with the development of GDM. Disproportionate exclusion

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Table 1 Social and demographic characteristics of the study population analysed by fasting plasma glucose (FPG) levels in early pregnancy (n = 180)

	Total (n = 180)	*Lower FPG (<4.3 mmol/L) (n = 63)*	*Moderate FPG (4.3–4.59 mmol/L) (n = 63)*	*Higher FPG (≥4.6 mmol/L) (n = 54)*	P
Age[(a)] (years)	30.6 (5.5)	30.4 (5.4)	30.2 (5.8)	31.2 (5.1)	0.58
Nulliparous % (n)	41.1 (74)	38.1 (24)	39.7 (25)	46.3 (25)	0.64
Relative income poverty[(b)] % (n)	22.6 (39)	19.1 (12)	20.6 (13)	25.9 (14)	0.55
Relative deprivation % (n)	32.2 (58)	33.3 (21)	31.8 (20)	31.5 (17)	0.97
Consistent poverty[(b)] % (n)	11.1 (19)	11.5 (7)	8.2 (5)	14.0 (7)	0.62
Under-reporters % (n)	31.7 (57)	25.4 (16)	34.9 (22)	35.2 (19)	0.41
Gestational age[(a)] (weeks)	12.6 (2.8)	12.5 (2.6)	12.6 (3.3)	12.6 (2.5)	0.96
Irish-born % (n)	74.4 (134)	69.8 (44)	74.6 (47)	79.6 (43)	0.48
Current smoker % (n)	11.1 (20)	11.1 (7)	11.1 (7)	11.1 (6)	1.00
Physical activity level[(a)] (MET)	1.75 (0.3)	1.70 (0.2)	1.70 (0.2)	1.80 (0.2)	0.06

(a) Mean (SD).
(b) Data available on n = 172.
FPG, fasting plasma glucose; MET, metabolic equivalents.

Table 2 Univariate comparison of maternal anthropometric characteristics in early pregnancy analysed by fasting plasma glucose (FPG) levels (n = 180)

	Lower FPG (<4.3 mmol/L) (n = 63)	*Moderate FPG (4.3–4.59 mmol/L) (n = 63)*	*Higher FPG (≥4.6 mmol/L) (n = 54)*	P
Weight (kg)	68.0 (15.0)	80.0 (22.0)	82.4 (23.3)	<0.001
BMI (kg/m^2)	24.0 (5.0)	28.0 (10)	30.0 (8.3)	<0.001
% Body fat (kg)	32.0 (9.0)	36.0 (11.0)	36.6 (9.0)	<0.001
Fat mass (kg)	21.0 (9.0)	29.0 (16.0)	30.5 (16.6)	<0.001
Fat free mass (kg)	46.0 (7.0)	51.0 (7.0)	53.0 (11.3)	<0.001
Visceral fat level	4.0 (2.0)	5.8 (3.2)	6.0 (4.0)	<0.001

All values reported are median (interquartile range).

of obese women on the basis of dietary under-reporting may therefore result in bias and erroneous conclusions regarding the nutritional intakes and GDM risk profile of obese women, and this is an important limitation of the current study. However, as the inclusion of under-reported food group and nutrient intakes from these women would have significantly distorted the inferential associations between population food and nutrient intake estimates and GDM risk in the current cohort, their exclusion was necessary to preserve the veracity of findings from the remaining dataset.[24]

It is established that the risk of developing GDM is increased in women with higher prepregnancy BMI.[18–20] Visceral fat and total body fat mass have been linked to insulin resistance among general adult populations.[21–23] However, there is a lack of studies investigating body fat mass in pregnancy and how it affects the risk of developing GDM. A cross-sectional study (n = 79) found that women with GDM had higher body fat mass levels compared with women with normal blood glucose levels.[42] Univariate analysis in our study suggested that increased adiposity in early pregnancy was associated with higher blood glucose levels. However, after controlling for important confounding factors, only antenatal obesity as measured by BMI remained associated with higher blood glucose levels.

Recent meta-analysis found no difference in the likelihood of developing GDM between women receiving diet and exercise interventions, and those allocated to control

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Table 3 Comparison of energy-adjusted food group macronutrient intakes in plausible reporters analysed by FPG tertiles (n = 123)

Food group (g/MJ energy)	*Low FPG (<4.3 mmol/L) (n = 47)*	*Moderate FPG (4.3–4.59 mmol/L) (n = 41)*	*High FPG (≥4.6 mmol/L) (n = 35)*	P
Breads	4.7 (7.1)	4.5 (5.2)	4.1 (7.1)	0.16
Breakfast cereals	4.1 (8.2)	4.1 (5.5)	3.9 (4.9)	0.50
Rice/pasta	9.0 (8.8)	10.2 (9.8)	11.4 (9.9)	0.32
Eggs	1.9 (1.7)	1.9 (1.5)	2.2 (1.9)	0.58
Potatoes	10.1 (7.1)	10.6 (6.4)	9.7 (7.8)	0.93
Fats/oils	0.6 (1.0)	0.6 (0.7)	0.5 (0.5)	0.32
Alcoholic drinks	1.9 (9.4)	0.8 (6.2)	1.2 (4.3)	0.74
Sugar groups	12.2 (11.0)	15.5 (13.4)	12.3 (11.5)	0.31
Fruit and vegetables	62.2 (36.2)	54.8 (46.3)	51.1 (35.9)	0.94
Milk/cream/cheese	4.0 (5.5)	3.1 (3.6)	4.4 (4.7)	0.08
Fish	2.89 (4.6)	5.01 (6.93)	2.09 (3.97)	0.21
Meat	13.3 (6.6)	13.4 (6.4)	14.6 (9.3)	0.39
Other drinks	61.3 (64.4)	60.0 (59.5)	54.2 (67.1)	0.96
Other foods	11.6 (9.9)	12.8 (12.5)	10.5 (13.7)	0.90
Energy (MJ/day)	10.0 (5.8)	9.8 (4.7)	9.5 (3.3)	0.38
Carbohydrate (% TE)	45.2 (8.3)	48.6 (8.9)	47.1 (9.4)	0.45
Sugars (% TE)	18.9 (6.2)	21.2 (7.6)	19.0 (7.1)	0.45
Starch (% TE)	25.2 (10.2)	26.9 (9.2)	27.0 (7.8)	0.67
NMES (% TE)	5.6 (2.5)	6.5 (4.9)	6.7 (4.1)	0.62
Fructose (% TE)	3.8 (2.4)	3.7 (2.9)	3.6 (2.0)	0.94
Sucrose (% TE)	5.9 (3.4)	6.5 (2.8)	6.1 (3.4)	0.76
Lactose (% TE)	0.7 (0.7)	0.5 (0.5)	0.6 (0.5)	0.93
Maltose (% TE)	0.5 (0.7)	0.5 (0.6)	0.5 (0.6)	0.95
Oligosaccharides (% TE)	0.02 (0.1)	0.06 (0.1)	0.06 (0.2)	0.29
Fat (% TE)	36.4 (7.8)	34.7 (6.2)	35.6 (10.3)	0.91
Saturated fat (% TE)	13.4 (4.2)	13.1 (2.8)	13.3 (4.2)	0.34
Monounsaturated fat (% TE)	11.3 (2.3)	10.9 (2.7)	10.8 (3.1)	0.96
Polyunsaturated fat (% TE)	6.5 (2.8)	7.2 (3.1)	6.8 (2.4)	0.25
Dietary fibre (per MJ energy)	5.0 (1.8)	4.8 (2.9)	4.6 (2.4)	0.35
Protein (% TE)	18.0 (5.8)	18.2 (4.2)	18.4 (4.7)	0.92
Alcohol (g/day) (% TE)	0.4 (2.0)	0.3 (1.2)	0.4 (1.6)	0.82

All values reported are median (interquartile range).
FPG, fasting plasma glucose; NMES, non-milk extrinsic sugars; TE, total energy.

groups.[17,43] There was a trend towards a beneficial effect among women receiving primarily diet-based interventions, however, with a potentially significant reduction in GDM risk observed when these interventions were limited to obese and overweight women.[43]

Our study showed no association between energy adjusted food group or macronutrient intakes and FPG levels. However, while PAL levels were similar across all BMI categories, overall dietary EI and starch consumption were both higher among obese subjects. While causation cannot be confirmed, these findings suggest that excessive dietary EI, especially that derived from starchy carbohydrate, may contribute to the development of obesity, the main driver of GDM. This suggests that both excessive EI and high starchy food intake are important targets for dietary interventions in this area.

Previous studies investigating dietary intakes in early pregnancy and the risk of developing GDM have yielded inconsistent findings. In relation to macronutrients, some studies have shown that the type and quantity of carbohydrate may influence maternal blood glucose concentrations.[13] In non-obstetric populations, high fructose intake has been linked with adverse metabolic effects.[44] However, there is a lack of studies investigating fructose consumption and the development of GDM. While glycaemic index and energy-adjusted carbohydrate or fructose intakes were not associated with blood glucose levels in this study, high starch intakes were associated with obesity, the main

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predictor of elevated maternal glucose. While further studies are needed to investigate the possible detrimental effects of excessive fructose intake on maternal blood glucose levels in pregnancy, research exploring the effect of high starchy carbohydrate intake is also warranted.

Our findings indicate that weight management in the prepregnancy period may have a more beneficial effect on FPG than altering diet in early pregnancy. Obesity was the main driver of higher FPG levels. Obese women had higher energy and starch intakes than non-obese women. Weight loss prior to pregnancy in obese women, particularly through a reduction in overall energy and starch intakes, may be more effective in improving maternal glycaemic control than attempts to adjust diet in early pregnancy.

Funding source

This project was supported by the UCD Centre for Human Reproduction and was partially funded by an unlimited educational grant from Danone Nutricia Early Life Nutrition for the first author. Danone Nutricia Early Life Nutrition had no role in the study design, data analysis, data interpretation or writing of this article.

Conflict of interest

The authors have no conflict of interests to declare.

Authorship

All authors contributed to this work. LM, AB, ACOH, DMcC and MJT formulated the research question and developed the experimental design. LM, ACOH, SC collected the data. LM and AB analysed the data. All authors contributed to drafting and revisions of the manuscript and approved the final version prior to submission.

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Short Communication

Maternal weight trajectories between early pregnancy and four and nine months postpartum

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ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form
11 November 2015
Accepted 15 February 2016
Available online xxx

Introduction

Over a generation there has been a dramatic increase in adult obesity levels in well-resourced countries. Maternal weight retention after pregnancy is variable.[1] However, optimising weight management following childbirth may potentially reduce the long-term risks of obesity-related disorders such as diabetes, heart disease and cancer among women of childbearing age; as well as reducing their risk of obesity-related obstetric complications in future pregnancies.

The National Institute for Health and Care Excellence (NICE) Guidelines identified the postpartum period as a vulnerable life stage for weight gain.[2,3] It has been suggested that more knowledge about weight management during the postpartum period is required.[4] The Institute of Medicine (IoM) has also stated that there are gaps in the surveillance of postpartum weight retention (PPWR), and that findings should be reported by Body Mass Index (BMI) category.[5] NICE identified the need for a population-based approach in relation to weight management before, during and after pregnancy in order to reach all women of childbearing age as many pregnancies are unplanned. NICE have also highlighted that information describing the most effective time for women to start managing their weight after childbirth, and the optimal rate of weight loss during this postpartum period is lacking.[3]

The aim of this prospective longitudinal study was to address these knowledge deficits by comparing trajectories in maternal weight and BMI between early pregnancy and four months postpartum and nine months postpartum, and to analyse these trajectories by BMI category.

The Coombe Women and Infants University Hospital (CWIUH) is one of the largest maternity hospitals in the EU and cares for women from all socio-economic groups and from across the urban-rural divide. Women were recruited to our study at their convenience between February and August 2013 after an ultrasound examination confirmed an ongoing singleton pregnancy. The woman's clinical and sociodemographic details were computerized routinely at the first antenatal visit and updated immediately after delivery.

Height was measured to the nearest centimetre using a Seca wall-mounted digital height measure with the woman standing in her bare feet. Weight was measured in a standardized way before 18 weeks gestation. We have previously reported in a cross-sectional study that there is no significant change in mean maternal weight before this stage of gestation.[6,7] BMI was calculated and categorized according to the World Health Organization BMI classification.[8] Written informed consent was obtained. Women received no dietary or lifestyle interventions as part of the research either during or after pregnancy.

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http://dx.doi.org/10.1016/j.puhe.2016.02.017
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Please cite this article in press as: Mullaney L, et al., Maternal weight trajectories between early pregnancy and four and nine months postpartum, Public Health (2016), http://dx.doi.org/10.1016/j.puhe.2016.02.017

Women were invited back to the hospital at approximately four and nine months postpartum. The woman's weight and BMI were re-measured and socio-economic and infant feeding data were collected using standardized questionnaires. The study was approved by the hospital's Research Ethics Committee on the 16th May 2012.

The number of women initially enrolled in the first trimester was 1035. Of the 1035 women, 98% (n = 1018) delivered a live-born baby in the hospital. Women returned for their four month postpartum appointment (n = 494) at 18.0 ± 2.2 weeks postpartum and their nine month postpartum appointment (n = 328) at 39.8 ± 3.6 weeks postpartum. Of the 328 women who attended all appointments, mean weight at the antenatal visit was 69.3 ± 14.3 kg, mean Body Mass Index (BMI) was 25.3 ± 5.0 kg/m^2 and 14.4% were obese.

Longitudinal changes in weight and BMI

Wilcoxin signed rank tests, conducted with a Bonferroni correction, were used to assess longitudinal changes in maternal weight and BMI which occurred from early pregnancy to four and nine months postpartum (n = 328). Increases in weight (r = 0.46; z = −8.5 ($P \leq 0.001$)) and BMI (r = 0.47; z = −8.43 ($P \leq 0.001$)) occurred between early pregnancy and four months postpartum. Conversely, decreases in weight (r = 0.43; z = −7.9 ($P \leq 0.001$)) and BMI (r = 0.40; z = −7.4 ($P \leq 0.001$)) were observed between four months and nine months postpartum.

At four months postpartum the mean change in weight from the first antenatal visit was +1.6 ± 4.2 kg, the mean change in BMI was +0.6 ± 1.5 kg/m^2, and 19.2% were obese. Of the 494 women who returned at this visit, 330 (66.8%) had gained weight between their booking visit and their four month postpartum follow-up. At nine months postpartum, the mean change in weight from early pregnancy was +0.2 ± 4.7 kg, the mean change in BMI was −0.06 ± 1.8 kg/m^2, and 16.8% were obese. Of the 328 women who returned, 166 (33.6%) had gained weight between their booking visit and their nine month postpartum follow-up.

Of women who had an ideal BMI in early pregnancy (n = 271), 16.6% and 11.1% were overweight at four and nine months postpartum respectively. Of women who were overweight in early pregnancy (n = 138), 20.3% and 14.3% had become obese at four and nine months postpartum respectively. Ninety percent of women who were obese in early pregnancy remained obese at four and nine months postpartum.

Women who had gained weight between early pregnancy and four months postpartum had a lower early pregnancy BMI, were less likely to be obese in early pregnancy (both $P < 0.001$) and were less likely to be at risk of consistent poverty ($P = 0.02$). Women who gained weight between four and nine months postpartum were more likely to be obese in early pregnancy ($P < 0.001$) (Table 1).

Women who had ideal weight and those who were overweight in early pregnancy had mean gains in weight and BMI between early pregnancy and four months postpartum. It is notable that women who were obese in early pregnancy (n = 70), however, experienced mean losses of weight and BMI from early pregnancy to four months postpartum (−1.6 kg and −0.7 kg/m^2 respectively). Women who had ideal weight in early pregnancy, and those who were overweight in early pregnancy had mean losses in weight and BMI between four and nine months postpartum. Women who were obese in early pregnancy experienced mean increases in weight and BMI (0.3 kg and 0.1 kg/m^2 respectively) between four and nine months postpartum, ultimately being heavier on average at this final time point than they had been in early pregnancy.

The study fills a knowledge gap by assessing weight trajectories according to participants' sociodemographic and WHO BMI categorization at the first antenatal visit.[5,8] Its longitudinal design means that exact weight gains and losses could be tracked according to these characteristics from early pregnancy.

A previous Irish longitudinal study found that two thirds of first time mothers had gained weight when they reattended for antenatal care on their next pregnancy and as a result, one in five women moved into a higher BMI category, and one in 20 women became obese, according to their WHO BMI categorization.[9] In an American study (n = 550) where the IoM

Table 1 – Postpartum characteristics of women who gained weight compared with those who lost weight between early pregnancy, four and nine months postpartum.

Characteristic	Four months postpartum			Between four and nine months postpartum		
	Gained weight (n = 330)	Lost weight (n = 164)	P-value	Gained weight (n = 95)	Lost weight (n = 233)	P-value
Age (years)[a]	31.2 ± 4.8	31.1 ± 5.3	NS	32.0 ± 5.5	32.1 ± 4.6	NS
Antenatal BMI (kg/m^2)[a]	24.6 ± 4.2	26.7 ± 6.3	<0.001	26.9 ± 6.3	24.7 ± 4.3	<0.001
Antenatal obesity (%)	9.1	24.4	<0.001	26.3	9.9	<0.001
Nulliparous (%)	44.5	40.2	NS	53.7	43.3	NS
Relative risk of poverty (%)[c]	14.0	15.4	NS	14.9	12.6	NS
Relative deprivation (%)[c]	17.8	24.4	NS	20.5	19.5	NS
Consistent poverty (%)[c]	3.8	9.0	0.02	4.6	5.5	NS
Caesarean section (%)	22.4	17.7	NS	25.3	18.9	NS
Birthweight (kg)[a]	3.5 ± 0.5	3.6 ± 0.6	NS	3.6 ± 0.5	3.5 ± 0.5	NS
Breastfeeding (%)[b]	66.7	62.2	NS	63.6	66.3	NS

[a] Mean ± standard deviation.
[b] Data available on n = 471.
[c] Data available on n = 470.

Please cite this article in press as: Mullaney L, et al., Maternal weight trajectories between early pregnancy and four and nine months postpartum, Public Health (2016), http://dx.doi.org/10.1016/j.puhe.2016.02.017

guidelines were used to categorize BMI, 14.2% of women who started pregnancy with an ideal weight (BMI 19.8–26.0 kg/m^2) became overweight by 12 months postpartum.[10] Among women who were overweight (BMI 26.0–29.0 kg/m^2), 40% became obese by 12 months postpartum. However, this study relied on maternal self-reporting of pre-pregnancy weight.

In our study, 90% of women who were obese in early pregnancy remained obese at nine months postpartum. Of ideal weight or overweight women, over one in three women moved up one BMI category at four months postpartum and one in five women moved up one BMI category at nine months postpartum. Interventions are, therefore, required to help prevent women post-pregnancy moving into a higher BMI category for all women with a BMI >18.5 kg/m^2.

There is also a lack of data concerning the most effective time for women to initiate weight management after childbirth.[3] Obese women in this study increased their weight between four and nine months postpartum. Women with a normal BMI had weight and BMI gains up to four months postpartum. This information is important for the design of research studies and public health interventions intended to address the clinical challenges of postpartum weight retention and maternal obesity. In light of our findings, the health behavioural traits which characterize women at high risk of postpartum weight gain and weight retention need to be elucidated as targets for intervention.

Overall, the weight and BMI of the participants increased between early pregnancy and four months postpartum, and decreased between four and nine months postpartum. However, when analysed by BMI category, obese women lost weight until four months postpartum and experienced a 'rebound' in weight gain between four and nine months postpartum.

Maternal obesity has emerged as one of the most important challenges in contemporary obstetrics because it is associated with an increase in both adverse fetal and maternal outcomes. Our findings that maternal weight changes in the first nine months postpartum are not linear, that they differ between obese and non-obese women and that a significant number of women become obese within nine months of delivery should each help to inform the design of future interventions aimed at preventing postpartum weight retention.

Author statements

Acknowledgements

We acknowledge the commitment of the pregnant women who took part in this study.

Ethical approval

This study was approved by the hospital's Research Ethics Committee on the 16th May 2012.

Funding

This project was supported by the UCD Centre for Human Reproduction and was partially funded by an unlimited educational grant from Danone Nutricia Early Life Nutrition for the first author. Danone Nutricia Early Life Nutrition had no role in the study design, data analysis, data interpretation or writing of this article.

Competing interests

The authors declare no conflict of interests.

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Please cite this article in press as: Mullaney L, et al., Maternal weight trajectories between early pregnancy and four and nine months postpartum, Public Health (2016), http://dx.doi.org/10.1016/j.puhe.2016.02.017

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Breast-feeding and postpartum maternal weight trajectories

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Submitted 24 April 2015: Final revision received 21 August 2015: Accepted 15 September 2015

Abstract

Objective: We examined whether breast-feeding, and in particular exclusive breast-feeding, was associated with maternal weight and body composition changes at 4 months postpartum independently of other maternal variables.

Design: Prospective longitudinal study. Women were recruited in the first trimester after an ultrasound examination confirmed an ongoing singleton pregnancy. Weight and body composition were measured using advanced bio-electrical impedance analysis at the first antenatal visit and 4 months postpartum. Detailed questionnaires were completed on breast-feeding, socio-economic status, diet and exercise in addition to routine clinical and sociodemographic details.

Setting: Large Irish university maternity hospital.

Subjects: Women who delivered a baby weighing ≥500 g between November 2012 and March 2014.

Results: At the postpartum visit, the mean weight was 70·9 (SD 14·2) kg (*n* 470) and the mean BMI was 25·9 (SD 5·0) kg/m^2. 'Any breast-feeding' was reported by 65·1 % of women (*n* 306). Irish nativity (OR = 0·085, $P < 0·001$), current smoking (OR = 0·385, $P = 0·01$), relative income poverty (OR = 0·421, $P = 0·04$) and deprivation (OR = 0·458, $P = 0·02$) were negatively associated with exclusive breast-feeding. At 4 months postpartum there was no difference in maternal weight change between women who exclusively breast-fed and those who formula-fed (+2·0 *v.* +1·1 kg, $P = 0·13$). Women who exclusively breast-fed had a greater increase in percentage body fat at 4 months postpartum compared with women who formula-fed (+1·0 *v.* −0·03 %, $P = 0·02$), even though their dietary quality was better. Exclusive breast-feeding was not associated with postpartum maternal weight or body fat percentage change after adjusting for other maternal variables.

Conclusions: There are many reasons why breast-feeding should be strongly promoted but we found no evidence to support postpartum weight management as an advantage of breast-feeding.

Keywords
Breast-feeding
Postpartum weight
Diet quality
Body composition

The benefits of breast-feeding for mother and child are well established[1,2]. Variables associated with breast-feeding rates include socio-economic status, education, smoking, maternal age and pre-pregnancy weight[3–6]. The postpartum period has been associated with an increase in food intake and a decrease in physical activity level (PAL)[7–9]. Breast-feeding also has been shown to be positively associated with improved dietary quality in overweight and obese women[10,11]. However, no differences in PAL have been observed between women who never initiated breast-feeding and those who practise exclusive breast-feeding (EBF)[12].

The influence of breast-feeding on postpartum weight changes is not clear. Some studies suggest that breast-feeding aids postpartum weight loss while others challenge that belief[13]. EBF has been associated with greater weight loss; however, this relationship is not consistent between studies[13]. Longitudinal studies that investigate breast-feeding and postpartum weight changes usually rely on self-reporting of maternal pre-pregnancy weight, which has limitations[13,14]. Self-reporting of weight in obese women may be particularly subject to error[15]. There is a lack of longitudinal studies in which both maternal pre-pregnancy and postpartum weights are measured and weight changes analysed by infant feeding practices. Further studies are also needed to ascertain whether some breast-feeding women lose weight postpartum more readily than others.

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Conflicting results have also been found with regard to breast-feeding and its effect on maternal body composition. The majority of studies report little or no association between breast-feeding and body composition. However, many of these studies rely on small sample sizes[13]. There is a paucity of research investigating the association between breast-feeding and other maternal variables that can be examined independently of dietary quality and physical activity.

The purpose of the present paper was to examine whether breast-feeding, and in particular EBF, was associated with maternal weight and body composition changes after delivery independently of other variables such as diet, physical activity, smoking, socio-economic disadvantage and demographic differences.

Methods

The Coombe Women and Infants University Hospital is one of the largest maternity hospitals in the European Union and cares for women from all socio-economic groups and from across the urban–rural divide. Women were recruited at their convenience after an ultrasound examination confirmed an ongoing singleton pregnancy.

Clinical and sociodemographic details were computerised routinely at the first visit and after delivery. In addition, socio-economic, health behavioural and PAL data were collected at the first visit using standardised questionnaires. Height was measured to the nearest centimetre using a Seca wall-mounted digital height measure with the woman standing in her bare feet. Weight and body composition were measured using advanced, eight-electrode bio-electrical impedance analysis (Tanita MC 180, Tokyo, Japan) and BMI was calculated. Women received no lifestyle interventions as part of the research during or after pregnancy other than the standard antenatal care.

Women were invited back to the hospital for review at 4 months postpartum. Socio-economic, health behavioural and PAL data were again gathered at this visit, and the woman's weight, body composition and BMI re-measured. The women's dietary quality information was also gathered. The study was approved by the Hospital's Research Ethics Committee on 16 May 2012. Written informed consent was obtained from each participant.

Inclusion/exclusion criteria

The main inclusion criteria were attendance for antenatal care following ultrasound examination and confirmation of an ongoing singleton pregnancy in the first trimester. To reduce the number of confounding variables, the main exclusion criteria were multiple pregnancy, women <18 years of age and women with a gestational age >18 weeks at the first booking visit. Women who delivered elsewhere were also excluded.

Health behavioural information and socio-economic status

The health behavioural information gathered included any medical conditions, medications, smoking status and PAL. Additional questions collecting socio-economic data were derived from the Survey on Income and Living Conditions 2012[16]. Material indices of socio-economic status included relative income poverty and relative deprivation status, while consistent poverty status was also calculated[17]. Relative income poverty was calculated by comparing equivalised household income against the 60 % median income threshold. Relative deprivation was assessed by determining whether respondents had experienced the enforced absence (due to financial constraint) of two or more basic necessities from a list of eleven over the previous year. Consistent poverty was identified if a respondent's equivalised household income fell below the relative income poverty threshold, in addition to experiencing the enforced absence of two or more of the eleven basic markers of deprivation over the previous year[17].

Self-assessed habitual PAL was also collected using a self-administered, unsupervised questionnaire. Individual PAL was estimated for each participant from 1·45 MET (seated work with no option of moving around and no strenuous leisure-time activity) up to 2·20 MET (strenuous work or highly active leisure-time activity, e.g. competitive athletes in daily training)[18], where MET is metabolic equivalents of task.

Dietary quality data

Dietary quality data were collected using a self-administered, unsupervised questionnaire. This included information about the respondent's meal pattern (number of meals per day) and her habitual intakes of fruit and vegetables, breakfast cereals and oily fish. Participants' starchy food, meat and poultry, dairy food and sugary food and drink intakes were also recorded. Intakes of fat-rich foods including chips and savoury snacks were determined next, with participants finally asked to estimate their habitual alcohol intake and their daily intakes of water and other sugar-free fluids.

Each of the dietary domains was ranked, based on its respective nutritional importance in pregnancy. For example, breakfast cereals were highlighted as a priority food group due to their high content of critical nutrients for pregnancy including folate, Fe and vitamin D[19–21]. Dietary domain scores were derived for each domain based on the participant's consumption of foods within that domain, and these scores were amalgamated to yield one composite score reflecting the overall quality of the participant's diet (range of 0 to 100).

Infant feeding practices

When they returned for their 4-month postpartum visit women were asked by questionnaire whether they had breast-fed after delivery. Breast-feeding women were

also asked at this postpartum visit whether they had exclusively breast-fed (EBF; only breast milk, no formula) or engaged in partial breast-feeding (breast milk and formula combined). Women were asked how long they had breast-fed for, with options ranging from '0 to 3 days', '4 to 6 days', '1 week' with weekly options up to '12 weeks', '3 months' with monthly options to '5 months' to finally whether they were 'still breast-feeding'.

To capture both the intensity and duration of breast-feeding we used a scale that reflects the energy costs of full and partial breast-feeding[22,23]. Women were assigned 1 point/week for EBF and 0·5 point/week for partial breast-feeding. The breast-feeding scale was used as a continuous scale.

Statistical analysis

Data analysis was carried out using the statistical software package IBM SPSS Statistics version 20·0. Baseline anthropometric characteristics of the women who returned for follow-up were compared with those of the total original sample using independent-samples *t* tests, to ensure that the final prospective cohort was representative of the broader study population. Age and anthropometric characteristics of the exclusive breast-feeders were compared with those of women who formula-fed using independent-samples *t* tests. Cross-tabulation with χ^2 analyses were used to test differences between the proportions of exclusive breast-feeders and women who formula-fed in different socio-economic and health behavioural groups.

Binary logistic regression was performed to assess the unconfounded association between a number of factors and participants' self-reported EBF and formula-feeding practices. The final model comprised seven independent variables (nativity, obesity, relative income poverty, relative deprivation, consistent poverty, nulliparity and current smoking status). Factors were included in the multivariate model based on a statistically significant association with infant feeding method upon univariate analyses ($P<0·05$).

Differences in maternal body weight and body composition changes between baseline and 4 months postpartum between women who EBF and women who formula-fed were analysed by the Mann–Whitney *U* test as these data were non-normally distributed. Differences in PAL and dietary quality at 4 months postpartum were analysed according to infant feeding practices using the Kruskal–Wallis test.

Binary logistic regression was performed to assess the association between a number of factors and maternal weight and body fat percentage gain or loss postpartum. The model contained eight independent variables (early pregnancy obesity status, nulliparity, stage of gestation at booking visit, birth weight, dietary quality score, breast-feeding scale, PAL and EBF).

Results

The total sample recruited initially in the first trimester was 1035 women and 98 % (*n* 1018) delivered a live-born baby in the Hospital between November 2012 and March 2014. At 4 months postpartum, 470 women agreed to return for repeat measurements for research purposes and completed the breast-feeding questionnaire. Women who returned for follow-up (*n* 470) did not differ from the full baseline sample (*n* 1035) in weight, BMI or stage of gestation at booking visit. Women who did not return were younger (28·9 *v.* 30·9 years, $P=0·001$) and more likely to be current smokers (20·2 *v.* 9·7 %, $P=0·001$) than women who returned.

The mean stage of gestation at booking (*n* 470) was 12·4 (SD 1·7) weeks and mean postpartum follow-up was at 18·0 (SD 2·2) weeks. The mean age at recruitment was 30·8 (SD 5·0) years. The mean antenatal weight was 69·2 (SD 14·2) kg and mean antenatal BMI was 25·3 (SD 5·1) kg/m^2, with 14·9 % of participants (*n* 70) obese. Forty-three per cent (*n* 213) of the women were nulliparous. The women's mean dietary quality score was 68·3 (SD 26·0). Women who EBF had a mean breast-feeding scale score of 11·8 (SD 5·2) and women who partially breast-fed a breast-feeding scale score of 4·1 (SD 3·1).

The mean postpartum weight was 70·9 (SD 14·2) kg and the mean BMI was 25·9 (SD 5·0) kg/m^2. The characteristics of the study population analysed by postpartum infant feeding method are shown in Table 1. Women who EBF reported breast-feeding for 86·0 (SD 46·6) d (range 1·5–168 d), whereas women who partially breast-fed reported breast-feeding for 56·8 (SD 43·5) d (range 1·5–168 d; $P<0·001$). When binary logistic regression was performed to assess the association between a number of maternal factors and the likelihood that women would EBF or not breast-feed, relative income poverty ($P=0·04$), deprivation ($P=0·02$), Irish nativity ($P<0·001$) and current tobacco use ($P=0·01$) remained negatively associated with EBF (Table 2).

There was no difference in maternal weight change from baseline to 4 months postpartum between women who EBF and those who did not breast-feed (Table 3). Women who EBF, however, had an increased fat mass ($P=0·03$) and percentage body fat ($P=0·02$) between early pregnancy and 4 months postpartum compared with non-breast-feeders. We found no relationship between infant feeding and postpartum changes in fat distribution (Table 4). Women who EBF had a better dietary quality score than women who did not breast-feed or those who partially breast-fed ($P<0·001$). There was no relationship between PAL and infant feeding practices (Table 5).

After controlling for breast-feeding, breast-feeding scale, nulliparity, stage of gestation at booking and PAL, only

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Table 1 Characteristics of the study population at 4 months postpartum analysed by postpartum infant feeding method (*n* 470), Dublin, Republic of Ireland

	Formula-feeding (*n* 164)		Partial breast-feeding (*n* 114)		Exclusive breast-feeding (*n* 192)		
	Mean	SD	Mean	SD	Mean	SD	*P* value*
Age (years)	30·5	5·6	32·9	4·6	31·7	4·4	NS
Weight (kg)	72·2	15·5	70·9	14·6	70·1	12·6	NS
BMI (kg/m^2)	26·4	5·6	25·9	5·1	25·4	4·4	<0·05
	%		%		%		
Obese	25·0		17·5		15·1		0·01
Nulliparous	34·8		53·5		43·8		0·03
Irish nativity	94·5		63·2		60·4		0·002
Currently smoking	22·6		10·5		9·9		<0·001
Caesarean section	17·7		24·6		20·3		NS
Risk of poverty†	23·8		6·2		11·5		0·002
Relative deprivation	29·3		18·4		13·0		0·002
Consistent poverty	10·4		3·5		2·6		0·002
	Mean	SD	Mean	SD	Mean	SD	
Any breast-feeding duration (d)	0	–	56·8	43·5	86·0	46·6	<0·001

**P* value testing for significant difference between formula-feeding and exclusive breast-feeding (except for 'Any breast-feeding duration' variable, where *P* value tests for significant difference between partial breast-feeding and exclusive breast-feeding) using independent-samples *t* tests and χ^2 analyses.
†Data available on *n* 469.

Table 2 Binary logistic regression of postpartum factors associated with exclusive breast-feeding compared with formula-feeding (*n* 356), Dublin, Republic of Ireland

	n	OR	95 % CI	*P* value
Nativity				
Non-Irish	85	1·0	Ref.	
Irish-born	271	0·085	0·04, 0·2	<0·001
Obesity				
Obese	70	1·0	Ref.	
Non-obese	286	1·523	0·9, 2·9	NS
Relative income poverty				
Yes	61	0·421	0·2, 1·0	0·04
No	295	1·0	Ref.	
Relative deprivation				
Yes	73	0·458	0·2, 0·9	0·02
No	283	1·0	Ref.	
Consistent poverty				
Yes	22	1·715	0·4, 7·6	NS
No	334	1·0	Ref.	
Nulliparous				
No	214	1·0	Ref.	
Yes	142	1·225	0·8, 2·0	NS
Smoking currently				
Former/never	299	1·0	Ref.	
Current	57	0·385	0·2, 0·8	0·01

Ref., reference category.

Table 3 Differences in maternal weight and body composition changes between early pregnancy and 4 months postpartum according to infant feeding practices (*n* 470), Dublin, Republic of Ireland

	Formula-feeding (*n* 164)		Partial breast-feeding (*n* 114)		Exclusive breast-feeding (*n* 192)		
	Mean	Range	Mean	Range	Mean	Range	*P* value*
Weight (kg)	+1·1	−18·8 to 17·8	+1·7	−7·6 to 10·2	+2·0	−8·2 to 17·9	NS
Fat mass (kg)	+0·4	−14·8 to 13·3	+0·8	−9·1 to 9·2	+1·2	−6·3 to 10·8	0·03
Fat mass (%)	−0·03	−9·8 to 9·1	+0·4	−8·5 to 8·7	+1·0	−11·0 to 12·4	0·02
Fat-free mass (kg)	+0·7	−7·2 to 7·0	+0·9	−4·5 to 6·0	+0·7	−4·9 to 11·3	NS
Total body water (kg)	+0·5	−5·0 to 5·0	+0·6	−3·2 to 4·2	+0·6	−3·5 to 8·0	NS
Bone mass (kg)	+0·04	−0·3 to 0·3	+0·04	−0·2 to 0·3	+0·04	−0·3 to 0·6	NS
Visceral fat level	+0·2	−4·0 to 3·0	+0·3	−2·0 to 2·0	+0·3	−2·0 to 3·0	NS

**P* value testing for significant difference between formula-feeding and exclusive breast-feeding using Mann–Whitney *U* test.

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Table 4 Difference in maternal segmental body composition changes between early pregnancy and 4 months postpartum according to infant feeding practices (*n* 467), Dublin, Republic of Ireland

	Formula-feeding (*n* 167)		Partial breast-feeding (*n* 114)		Exclusive breast-feeding (*n* 186)		
	Mean	Range	Mean	Range	Mean	Range	*P* value*
Right arm fat (kg)	+0·001	−1·0 to 0·8	+0·02	−0·5 to 0·7	+0·05	−0·5 to 0·8	NS
Right arm fat (%)	−1·02	−12·8 to 9·9	−1·1	−12·6 to 8·3	−0·2	−14·0 to 17·3	NS
Left arm fat (kg)	−0·01	−1·2 to 1·0	+0·01	−0·4 to 0·7	+0·04	−0·7 to 1·0	NS
Left arm fat (%)	−1·3	−12·5 to 10·4	−1·2	−12·6 to 10·6	−0·5	−16·1 to 11·6	NS
Right leg fat (kg)	+0·2	−3·6 to 4·1	+0·4	−3·5 to 3·5	+0·3	−2·3 to 5·0	NS
Right leg fat (%)	+1·3	−18·8 to 33·0	+2·5	−23·2 to 31·4	+1·9	−20·1 to 37·9	NS
Left leg fat (kg)	+0·2	−5·7 to 3·0	+0·3	−2·8 to 3·1	+0·4	−2·3 to 3·8	NS
Left leg fat (%)	+1·0	−31·6 to 26·5	+1·7	−18·7 to 25·1	+2·0	−17·4 to 29·0	NS
Trunk fat (kg)	−0·01	−5·4 to 7·4	+0·005	−4·8 to 5·2	+0·3	−5·4 to 5·7	NS
Trunk fat (%)	−0·6	−10·9 to 13·9	−0·8	−14·4 to 8·7	+0·1	−17·0 to 14·7	NS

**P* value testing for significant difference between formula-feeding and exclusive breast-feeding using Mann–Whitney *U* test.

Table 5 Dietary quality scores and physical activity levels according to infant feeding practices (*n* 450), Dublin, Republic of Ireland

	Formula-feeding (*n* 157)		Partial breast-feeding (*n* 109)		Exclusive breast-feeding (*n* 184)		
	Mean	SD	Mean	SD	Mean	SD	*P* value*
Dietary quality score	60·5	25·4	68·1	26·9	75·4	24·0	<0·001
Physical activity (MET)	1·79	0·2	1·78	0·13	1·76	0·20	NS

MET, metabolic equivalents of task.
**P* value tested using Kruskal–Wallis test.

Table 6 Logistic regression of factors associated with maternal weight and body fat percentage gain at 4 months postpartum (*n* 337 for whom all variables were available), Dublin, Republic of Ireland

		Weight gain			Body fat percentage gain		
	n	OR	95 % CI	*P* value	OR	95 % CI	*P* value
Antenatal obesity							
Obese	52	1·0	Ref.		1·0	Ref.	
Non-obese	285	3·778	2·0, 7·2	<0·001	2·729	1·4, 5·3	0·003
Physical activity level							
Linear variable	337	3·679	0·8, 17·4	NS	1·747	0·4, 7·4	NS
Exclusive breast-feeding							
No	156	1·0	Ref.		1·0	Ref.	
Yes	181	0·901	0·4, 2·2	NS	0·752	0·3, 1·7	NS
Breast-feeding scale							
Linear variable	337	1·015	1·0, 1·1	NS	1·047	1·0, 1·1	NS
Booking gestation							
Linear variable	337	0·955	0·8, 1·1	NS	0·939	0·8, 1·1	NS
Dietary quality							
Linear variable	337	1·011	1·0, 1·1	0·03	1·011	1·0, 1·1	0·02
Birth weight							
Linear variable	337	0·944	0·6, 1·5	NS	1·085	0·7, 1·7	NS
Nulliparous							
No	203		Ref.		1·0	Ref.	
Yes	134	1·311	0·8, 2·2	NS	1·059	0·7, 1·7	NS

Ref., reference category.

early pregnancy BMI < 30·0 kg/m^2 and diet quality score remained associated with weight and body fat percentage gain at 4 months postpartum (Table 6).

Discussion

We found in a longitudinal observational study that on univariate analysis obese women were less likely to breast-feed, but that EBF was associated with an increase on average in maternal weight and an increase in maternal adiposity. Women who breast-fed were more likely to put on weight and to become fatter even though their diet quality was superior and their PAL was similar to women who formula-fed. They were also less likely to smoke, less likely to be socially deprived and less likely to have been born in Ireland. EBF was not associated with postpartum maternal weight or body fat percentage changes after

adjusting for maternal obesity, breast-feeding duration, PAL, booking gestation, dietary quality, infant birth weight and nulliparity. Therefore, we found no evidence to support promoting breast-feeding on the basis of improving maternal weight postpartum. As part of a public health strategy to promote breast-feeding there are more convincing reasons why a woman should breast-feed exclusively[1,2].

Our study has strengths. The study population is well characterised. The clinical and sociodemographic details were computerised as usual at the first antenatal visit and after delivery, but additional data were collected prospectively using detailed questionnaires that gathered information on breast-feeding, dietary quality, physical activity and social disadvantage.

A further strength of our study was the clinical measurement (rather than self-reporting) of early pregnancy weight. The baseline weight measurement and BMI calculations were obtained before 18 weeks' gestation, which is optimal[24]. There are few studies investigating measured differences in weight and BMI between early pregnancy and the postpartum period, with many studies relying on self-reported pre-pregnancy weight which is unreliable and leads to BMI misclassification[14]. Self-reporting of weight in obese women may be particularly subject to error[15]. To our knowledge, the present study is one of the largest to measure maternal body composition directly using advanced bio-electrical impedance analysis, which means that trajectories in fat and fat-free mass can be tracked over time and analysed by infant feeding practices.

Another strength of the study is that its prospective design minimises recall bias which is a potential problem with post-pregnancy research[25]. The study also highlights the advantage of longitudinal studies. Based on a cross-sectional analysis postpartum maternal obesity was associated with formula-feeding; however, on longitudinal analysis maternal weight gain was associated with breast-feeding. Our longitudinal study design overcomes this critical inability of cross-sectional studies to measure changes in anthropometric status between the antenatal and postpartum time points.

A potential weakness of the study is that recall bias may have occurred at 4 months postpartum when women reported their breast-feeding duration. Women were asked how long they had breast-fed. While the inability of this question to differentiate between EBF and partial breast-feeding introduces a degree of imprecision, this limitation is mitigated by the use of a scale that captures the intensity and duration of breast-feeding (and hence estimates the overall bio-energetic cost of breast-feeding during the postpartum period) for both EBF and partial breast-feeding mothers. Another potential weakness of the study is that convenience recruitment may introduce an unforeseen bias that was not addressed in the multivariable analysis. However, consecutive recruitment is practically challenging in a longitudinal study whose timeframe spans early pregnancy until four months following a woman's discharge home with her newborn baby. We are also uncertain whether our observations are applicable in the developing world.

The benefits of breast-feeding for mother and child are well established[1,2]. Many factors have been associated with breast-feeding rates including nationality, socio-economic status, education, smoking status, maternal age and pre-pregnancy weight[3–6]. In the present study, multivariate analysis showed that women who smoked, who were Irish and who were living in relative income poverty and deprivation were less likely to EBF.

It has been suggested that common lifestyle risk factors cluster among adults[26]. In this context, our study suggests a clustering of poorer health behaviours among women who choose to formula-feed. This suggestion is further strengthened by our finding that women who EBF had better dietary quality scores than women who partially breast-fed or formula-fed. Insight into the prevalence of clustering is important, because it can potentially help in locating high-risk groups where multi-component health promotion initiatives may yield extra benefit[26]. Our study findings have public health implications as they show that additional emphasis on breast-feeding promotion may be needed in women of low socio-economic status who have other adverse health behaviours such as smoking.

There is insufficient evidence to assert a benefit for breast-feeding in postpartum weight loss[13], yet this remains a commonly held belief[2,4,27]. Many studies in this area rely on self-reporting of maternal weight, which has limitations[14]. Consequently, it has been suggested that more robust studies are needed to reliably assess the impact of breast-feeding on postpartum weight management[13]. In our study, there was no difference in weight change from early pregnancy to 4 months postpartum between women who EBF and those who formula-fed. The perception that breast-feeding aids postpartum weight loss may, therefore, not be true for all women. Overweight and obese women with persistently high, unrealistic expectations of breast-feeding and weight loss have been shown to give up on breast-feeding earlier[4]. For this reason, evidence-based breast-feeding promotion strategies may need to focus on health benefits to the mother and child other than weight loss.

In our study, women who EBF had a greater increase in postpartum fat mass and percentage body fat compared with women who formula-fed. Conflicting results have also been found in relation to breast-feeding and its effect on maternal body composition, with the majority of studies reporting little or no association between breast-feeding and body composition. However, many of these studies rely on small sample sizes[13]. When dual-energy X-ray absorptiometry was used to measure body composition in a US study (n 168), non-breast-feeding women lost whole-body, arm and leg fat at a faster rate than the breast-feeding

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women (who intended to breast-fed for >6 months and to provide no more than one formula feeding per day) between 2 weeks and 6 months postpartum[28].

It has been reported that body fat deposition during lactation occurs at central sites, for example, on the trunk and thighs[29]. Although no difference in body fat distribution between lactating and non-lactating women was observed in our study, it may be that lactating women have an overall physiological increase in body fat to support the extra energy costs of lactation. Further longitudinal studies are needed to clarify whether postpartum changes in fat distribution are influenced by breast-feeding.

Conclusions

The present study found that exclusive breast-feeding was not associated with postpartum maternal weight or body fat percentage changes after adjusting for important confounders. Breast-feeding promotion strategies may need to focus on women of low socio-economic status. These women, who may be subject to a clustering of poor lifestyle behaviours, such as smoking and poorer dietary quality, may benefit from the established advantages to mother and child of breast-feeding. The perception that breast-feeding aids postpartum weight loss, however, is not true for all women. Clinicians should be cautious when advising mothers about expected rates of weight and fat loss during lactation. Breast-feeding promotion strategies should instead focus on health benefits to mother and child other than maternal weight loss.

Acknowledgements

Acknowledgements: The authors acknowledge with gratitude the participation of the pregnant women who took part in this study. *Financial support:* This project was supported by the UCD Centre for Human Reproduction and was partially funded by an unlimited educational grant from Danone Nutricia Early Life Nutrition for the first author. Danone Nutricia Early Life Nutrition had no role in the study design, data analysis, data interpretation or writing of this article. *Conflict of interest:* The authors declare no conflict of interests. *Authorship:* All authors contributed to this work. L.M., A.C.O.H., D.Mc.C. and M.T.J. formulated the research question and developed the experimental design. L.M., A.C.O.H., S.C. and R.K. collected the data. L.M. analysed the data. All authors contributed to drafting and revisions of the manuscript and approved the final version prior to submission. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/patients were approved by the Research Ethics Committee of the Coombe Women and Infants University Hospital. Written informed consent was obtained from all subjects/patients.

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Appendix 7: Calculation of PAL Thresholds for Determination of EI Under-Reporters

Threshold 1:

$$PAL \times \exp [SD_{Min} \times ((S/100)/\sqrt{n})]$$

$$1.45 \times \exp [-2 \times ((S/100) \sqrt{1}]$$

$$S=\sqrt{[(CV^2_{wEI}/d) + CV^2_{WB} + CV^2_{tP}]}$$

$$S=\sqrt{[(23)^2/21) + 8.8^2 + 15^2]}$$

$$S=\sqrt{[25.2 + 77.44 + 225]}$$

$$S=18.1$$

$$1.45 \times \exp [-2 \times ((18.1/100) \sqrt{1}]$$

Threshold = 1.0005

Threshold 2:

$$PAL \times \exp [SD_{Min} \times ((S/100)/\sqrt{n})]$$

$$1.6 \times \exp [-2 \times ((S/100) \sqrt{1}]$$

$$1.6 \times \exp [-2 \times ((18.1/100) \sqrt{1}]$$

Threshold = 1.104

Threshold 3:

$$PAL \times \exp [SD_{Min} \times ((S/100)/\sqrt{n})]$$

$$1.75 \times \exp [-2 \times ((S/100) \sqrt{1}]$$

$$1.75 \times \exp [-2 \times ((18.1/100) \sqrt{1}]$$

Threshold = 1.2075

Threshold 4:

$$PAL \times \exp\left[SD_{Min} \times ((S/100)/\downarrow n)\right]$$

$$1.9 \times \exp\left[-2 \times ((S/100)\downarrow 1\right]$$

$$1.9 \times \exp\left[-2 \times ((18.1/100)\downarrow 1\right]$$

Threshold = 1.235

Threshold 5:

$$PAL \times \exp\left[SD_{Min} \times ((S/100)/\downarrow n)\right]$$

$$2.05 \times \exp\left[-2 \times ((S/100)\downarrow 1\right]$$

$$2.05 \times \exp\left[-2 \times ((18.1/100)\downarrow 1\right]$$

Threshold = 1.4145

Threshold 6:

$$PAL \times \exp\left[SD_{Min} \times ((S/100)/\downarrow n)\right]$$

$$2.2 \times \exp\left[-2 \times ((S/100)\downarrow 1\right]$$

$$2.2 \times \exp\left[-2 \times ((18.1/100)\downarrow 1\right]$$

Threshold = 1.518

Appendix 8: Statistical Analysis for Chapter 8

Table: Weight, BMI and body composition changes from early pregnancy to nine months postpartum according to PAL, dietary quality and SES at nine months postpartum (*n*=287)

	Weight Gain (*n*=140)	**Weight Loss (*n*=147)**	***P***
Age (years) [a]	32.1 ± 4.8	32.7 ± 4.9	*NS*
Physical Activity Level	1.78 ± 0.2	1.78 ± 0.2	*NS*
Dietary Quality Score	59.8 ± 9.5	62.8 ± 9.6	*NS*
Relative Income Poverty (number (%))[b]	17 (12.2)	21 (14.3)	*NS*
Deprivation (number (%))	25 (17.9)	32 (21.6)	*NS*
Consistent Poverty (number (%))[b]	4 (2.9)	11 (7.5)	*NS*
Current Smoker (number (%))	14 (10.0)	26 (17.6)	0.04*
	BMI Gain (*n*=137)	**BMI Loss (*n*=150)**	
Age (years)[a]	32.1 ± 4.7	32.8 ± 5.0	*NS*
Physical Activity Level	1.78 ± 0.2	1.78 ± 0.2	*NS*
Dietary Quality Score	60.0 ± 9.8	62.2 ± 9.3	*NS*
Relative Income Poverty (number (%))[b]	19 (12.8)	19 (14.0)	*NS*
Deprivation (number (%))	27 (18.0)	30 (21.9)	*NS*
Consistent Poverty (number (%))[b]	6 (4.0)	9 (6.6)	*NS*
Current Smoker (number (%))	16 (10.7)	24 (17.5)	*NS*
	Body Fat % Gain (*n*=111)	**Body Fat % Loss (*n*=176)**	
Age (years)[a]	32.2 ± 4.9	32.3 ± 4.8	*NS*
Physical Activity Level	1.78 ± 0.2	1.78 ± 0.2	*NS*
Dietary Quality Score	60.3 ± 10.0	61.5 ± 9.4	*NS*
Relative Income Poverty (number (%))[b]	17 (15.5)	21 (11.9)	*NS*
Deprivation (number (%))	21 (18.8)	36 (20.5)	*NS*
Consistent Poverty (number (%))[b]	6 (5.5)	9 (5.1)	*NS*
Current Smoker (number (%))	14 (12.6)	26 (14.8)	*NS*
	Fat Mass Gain (*n*=126)	**Fat Mass Loss (*n*=161)**	
Age (years)[a]	32.2 ± 5.0	32.6 ± 4.8	*NS*
Physical Activity Level	1.79 ± 0.2	1.78 ± 0.2	*NS*
Dietary Quality Score	60.3 ± 12.9	61.7 ± 9.2	*NS*
Relative Income Poverty (number (%))[b]	19 (15.3)	19 (11.7)	*NS*
Deprivation (number (%))	24 (19.2)	33 (20.4)	*NS*
Consistent Poverty (number (%))[b]	6 (4.8)	9 (5.6)	*NS*
Current Smoker (number (%))	15 (12.0)	25 (15.4)	*NS*
	FFM Gain (*n*=167)	**FFM Loss (*n*=120)**	
Age (years)[a]	32.1 ± 4.9	32.9 ± 4.7	*NS*
Physical Activity Level	1.78 ± 0.2	1.78 ± 0.2	*NS*
Dietary Quality Score	59.8 ± 9.5	62.8 ± 9.6	0.008*
Relative Income Poverty (number (%))[b]	18 (10.8)	20 (16.7)	*NS*
Deprivation (number (%))	29 (17.4)	28 (23.1)	*NS*
Consistent Poverty (number (%))[b]	5 (3.0)	10 (8.3)	0.04*
Current Smoker (number (%))	23 (13.8)	17 (14.2)	*NS*

[a] data on *n*=328, [b]data on *n*=286, **NS* after Bonferroni correction

Table: Weight, BMI and body composition changes from early pregnancy to nine months postpartum according to energy and macronutrient intakes at nine months postpartum (*n*=110)

	Weight Gain (*n*=49)[1]	**Weight Loss (*n*=61) [1]**	***P***
Energy Intake (kcal)	2155.0 (759)	2057.5 (627)	*NS*
% Energy Fat	37.3 (6.5)	35.7 (7.6)	*NS*
% Energy Protein	19.1 (7.7)	18.2 (6.7)	*NS*
% Energy Carbohydrate	47.0 (8.1)	46.9 (8.4)	*NS*
	BMI Gain (*n*=54)[1]	**BMI Loss (*n*=56)[1]**	
Energy Intake (kcal)	2153.5 (741)	2023.0 (640)	*NS*
% Energy Fat	37.5 (7.4)	35.3 (8.0)	0.03[*]
% Energy Protein	18.3 (7.5)	18.3 (6.4)	*NS*
% Energy Carbohydrate	46.8 (7.9)	47.1 (7.7)	*NS*
	Body Fat % Gain (*n*=54)[1]	**Body Fat % Loss (*n*=56)[1]**	
Energy Intake (kcal)	2153.5 (727)	2096.0 (684)	*NS*
% Energy Fat	37.3 (6.4)	36.0 (7.4)	*NS*
% Energy Protein	17.9 (6.1)	18.7 (6.6)	*NS*
% Energy Carbohydrate	47.5 (7.8)	46.6 (8.1)	*NS*
	Fat Mass Gain (*n*=54)[1]	**Fat Mass Loss (*n*=56)[1]**	
Energy Intake (kcal)	2153.5 (706)	2096.0 (684)	*NS*
% Energy Fat	37.0 (6.1)	35.8 (7.8)	0.03[*]
% Energy Protein	18.3 (8.1)	18.3 (6.0)	*NS*
% Energy Carbohydrate	47.1 (7.9)	46.9 (8.0)	*NS*
	FFM Gain (*n*=54)[1]	**FFM Loss (*n*=56)[1]**	
Energy Intake (kcal)	2152.0 (863)	1997.0 (599)	*NS*
% Energy Fat	36.7 (7.9)	35.7 (7.8)	*NS*
% Energy Protein	18.1 (7.0)	18.9 (7.2)	*NS*
% Energy Carbohydrate	47.0 (8.2)	46.5 (8.1)	*NS*

[1]Median (IQR) Data presented in plausible EI reporters, [*]*NS* after Bonferroni correction

Table: Weight, BMI and body composition changes from early pregnancy to nine months postpartum according to postpartum socioeconomic and sociodemographic characteristics in non-obese women

	Early Pregnancy Non-Obese (*n*=280)		
	Weight Gain	**Weight Loss**	***P***
Relative Income Poverty[a]	16 (12.8)	19 (15.7)	*NS*
Deprivation[b]	21 (16.7)	24 (19.8)	*NS*
Consistent Poverty[a]	3 (2.4)	10 (8.3)	0.04[*]
Current Smoking[b]	14 (11.1)	26 (21.5)	*NS*
≥ 30 years[c]	102 (70.8)	104 (76.5)	*NS*
Primigravidous[c]	75 (52.1)	62 (45.6)	*NS*
	BMI Gain	**BMI Loss**	***P***
Relative Income of Poverty[a]	18 (13.4)	17 (15.3)	*NS*
Deprivation[b]	23 (17.0)	22 (19.8)	*NS*
Consistent Poverty[a]	5 (3.7)	8 (7.2)	*NS*
Current Smoking[b]	16 (11.9)	24 (21.6)	*NS*
≥ 30 years[c]	110 (71.2)	95 (76.6)	*NS*
Primigravidous[c]	77 (49.7)	59 (47.6)	*NS*
	Fat % Gain	**Fat % Loss**	***P***
Relative Income Poverty[a]	6 (15.7)	19 (13.2)	*NS*
Deprivation[b]	18 (17.5)	27 (18.8)	*NS*
Consistent Poverty[a]	5 (4.9)	8 (5.6)	*NS*
Current Smoking[b]	14 (13.6)	26 (18.1)	*NS*
≥ 30 years[c]	78 (66.1)	130 (77.8)	0.02[*]
Primigravidous[c]	58 (49.2)	79 (47.3)	*NS*
	Fat Mass Gain	**Fat Mass Loss**	***P***
Relative Income Poverty[a]	18 (16.1)	17 (12.7)	*NS*
Deprivation[b]	20 (17.7)	25 (18.7)	*NS*
Consistent Poverty[a]	5 (4.5)	8 (6.0)	*NS*
Current Smoking[b]	15 (13.3)	25 (18.7)	*NS*
≥ 30 years[c]	86 (68.3)	120 (77.9)	*NS*
Primigravidous[c]	65 (51.6)	72 (46.8)	*NS*
	FFM Gain	**FFM Loss**	***P***
Relative Income Poverty[a]	18 (12.4)	17 (16.8)	*NS*
Deprivation[b]	24 (16.4)	21 (20.8)	*NS*
Consistent Poverty[a]	5 (3.4)	8 (7.9)	*NS*
Current Smoking[b]	23 (15.8)	17 (16.8)	*NS*
≥ 30 years[c]	122 (71.68)	86 (74.8)	*NS*
Primigravidous[c]	86 (50.6)	51 (44.3)	*NS*

All values are number (percentage) [a] data on n=286, [b]data on n=288, [c] data on n=328, [*]*NS* after Bonferroni correction

Table: Weight, BMI and body composition changes from early pregnancy to nine months postpartum according to postpartum socioeconomic and sociodemographic characteristics in obese women

	Early Pregnancy Obese (*n*=48)		
	Weight Gain	**Weight Loss**	***P***
Relative Income Poverty[a]	1 (7.1)	2 (7.7)	*NS*
Deprivation[b]	4 (28.6)	8 (29.6)	*NS*
Consistent Poverty[a]	1 (7.1)	1 (3.8)	*NS*
Current Smoking[b]	0 (0)	0 (0)	*NS*
≥ 30 years[c]	12 (66.7)	26 (86.7)	*NS*
Primigravidous[c]	7 (38.9)	8 (26.7)	*NS*
	BMI Gain	**BMI Loss**	***P***
Relative Income of Poverty[a]	1 (6.7)	2 (8.0)	*NS*
Deprivation[b]	4 (26.7)	8 (30.8)	*NS*
Consistent Poverty[a]	1 (6.7)	1 (4.0)	*NS*
Current Smoking[b]	0 (0)	0 (0)	*NS*
≥ 30 years[c]	12 (63.2)	26 (89.7)	0.03[*]
Primigravidous[c]	8 (42.1)	7 (24.1)	*NS*
	Fat % Gain	**Fat % Loss**	***P***
Relative Income Poverty[a]	1 (12.5)	2 (6.2)	*NS*
Deprivation[b]	3 (33.3)	9 (28.1)	*NS*
Consistent Poverty[a]	1 (12.5)	1 (3.1)	*NS*
Current Smoking[b]	0 (0)	0 (0)	*NS*
≥ 30 years[c]	8 (66.7)	30 (83.3)	*NS*
Primigravidous[c]	6 (50.0)	9 (25.0)	*NS*
	Fat Mass Gain	**Fat Mass Loss**	***P***
Relative Income Poverty[a]	1 (8.3)	2 (7.1)	*NS*
Deprivation[b]	4 (30.8)	8 (28.6)	*NS*
Consistent Poverty[a]	1 (8.3)	1 (3.6)	*NS*
Current Smoking[b]	0 (0)	0 (0)	*NS*
≥ 30 years[c]	12 (66.7)	26 (86.7)	*NS*
Primigravidous[c]	6 (33.3)	9 (30.0)	*NS*
	FFM Gain	**FFM Loss**	***P***
Relative Income Poverty[a]	0 (0)	3 (15.8)	*NS*
Deprivation[b]	5 (23.8)	7 (35.0)	*NS*
Consistent Poverty[a]	0 (0)	2 (10.5)	*NS*
Current Smoking[b]	0 (0)	0 (0)	*NS*
≥ 30 years[c]	18 (72.0)	20 (87.0)	*NS*
Primigravidous[c]	10 (40.0)	5 (21.7)	*NS*

All values are number (percentage) [a] data on n=286, [b]data on n=288, [c] data on n=328, [*]*NS* after Bonferroni correction

Appendix 9: Questionnaires

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SLÁN-06 - FOOD FREQUENCY QUESTIONNAIRE

Cluster Number: ☐ ☐ ☐ Respondent Number: ☐ ☐

YOUR DIET OVER THE PAST YEAR

For each food there is an amount shown, either what we think is a "medium serving" or a common household unit such as a slice or teaspoon. Please put a tick in the box to indicate how often, **on average**, you have eaten the specified amount of each food, to the nearest whole number **during the past year i.e. from when you receive this questionnaire to the same month the previous year**.

Please estimate your average food use as best you can. Please answer every question, do not leave ANY lines blank.

EXAMPLES:

The following are examples on how to estimate how often and how much bread and potatoes you ate over the past year. Please estimate your food intake for all foodstuffs in the same way.

Potatoes: If you ate a medium serving of potatoes 3 times per week over the past year put a tick in the box "2-4 per week". If you think you usually ate more or less than a medium serving please try to estimate which box suits best.

	AVERAGE USE LAST YEAR								
Potatoes, Rice and Pasta (medium serving)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Boiled, instant or jacket potatoes				√					

For white bread a medium serving is one medium sized slice. Therefore if you usually ate 1 medium slice 4 or 5 times per day, you should put a tick in the column headed "4-5 per day". If you ate 2 medium slices 4 or 5 times per day, then you should put a tick in the column "6+ per day".

	AVERAGE USE LAST YEAR								
BREAD AND SAVOURY BISCUITS (One slice or one biscuit)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
White bread and rolls (including ciabatta and pannini bread)								√	

Please check that you put a tick (√) on every line

When you have completed the Questionnaire, please return it to the interviewer or return it to the ESRI in the reply-paid envelope.

	AVERAGE USE LAST YEAR								
A. MEAT, FISH AND POULTRY (Medium serving – the size of a deck of cards)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Beef roast									
2. Beef: steak									
3. Beef: mince									
4. Beef: stew									
5. Beef burger (1 burger)									
6. Pork: roast									
7. Pork: chops									
8. Pork: slices/escalopes									
9. Lamb: roast									
10. Lamb: chops									
11. Lamb: stew									
12. Chicken portion or other poultry e.g. turkey: roast									
13. Breaded chicken, chicken nuggets, chicken burger									
14. Bacon									
15. Ham									
16. Corned beef, Spam, Luncheon meats									
17. Sausages, Frankfurters (1 sausage)									
18. Savoury pies (e.g. meat pie, pork pie, steak & kidney pie, sausage rolls)									
19. Liver, heart, kidney									
20. Liver paté									
21. Fish fried in batter, as in fish and chips									
22. Fish fried in breadcrumbs									
23. Oven baked/grilled fish (in breadcrumbs or batter)									
24. Fish fingers/fish cakes									
25. Other white fish, fresh or frozen (e.g. cod, haddock, plaice, sole, halibut, coli)									
26. Oily fish, fresh or canned (e.g. mackerel, kippers, tuna, salmon, sardines, herring)									
27. Shellfish (e.g. crab, prawns, mussels)									

	AVERAGE USE LAST YEAR								
B. BREAD AND SAVOURY BISCUITS (One slice or one biscuit)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. White bread and rolls (including ciabatta and pannini bread)									
2. Brown bread and rolls									
3. Wholemeal bread and rolls									
4. Cream crackers, cheese biscuits									
5. Crisp bread, e.g. Ryvita									
6. Pancakes, muffins, oatcakes									

	AVERAGE USE LAST YEAR								
C. CEREALS (One medium sized bowl)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Porridge, Readybrek									
2. All Bran, Weetabix, Shredded Wheat									
3. Branflakes, Bran Buds									
4. Cornflakes, Rice Krispies									
5. Muesli (e.g. Country Store, Alpen, sugar coated)									
6. Sugar Coated Cereals (e.g. Frosties, Crunchy Nut Cornflakes, Crunchy Sugar Coated Muesli)									

	AVERAGE USE LAST YEAR								
D. POTATOES, RICE AND PASTA (Medium serving – about a cupful)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Boiled, instant or jacket potatoes									
2. Mashed potatoes									
3. Chips									
4. Roast potatoes									
5. Potato Salad									
6. White Rice									
7. Brown Rice									
8. White/yellow or green pastas (e.g. spaghetti, macaroni, noodles)									
9. Wholemeal pasta									
10. Lasagne (meat based)									
11. Lasagne (vegetarian)									
12. Moussaka									
13. Pizza									
14. Macaroni Cheese									

	AVERAGE USE LAST YEAR								
E. DAIRY PRODUCTS AND FATS	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Cream (tablespoon)									
2. Full-fat yoghurt or Greek-style Yoghurt (125g carton)									
3. Dairy desserts (125g carton)									
4. Cheddar cheese (medium serving)									
5. Low-fat cheddar cheese (medium serving)									
6. Eggs as boiled, fried, scrambled, poached (one)									
7. Quiche (medium serving)									
8. Light salad cream or light mayonnaise (tablespoon)									
9. Salad cream, mayonnaise (tablespoon)									
10. French dressing (tablespoon)									
11. Other salad dressing (tablespoon)									
12. The following on bread or vegetables									
13. Butter (teaspoon)									
14. Lite Butter e.g. Dawn Lite, Connacht Gold (teaspoon)									
15. Sunflower margarine e.g. Flora (teaspoon)									
16. Low-fat margarine (e.g. low-low)									
17. Cholesterol Lowering Spreads e.g. Flora Pro Active, Dairy Gold Heart (teaspoon)									
18. Cream & Vegetable Oil spread e.g. Golden Pasture, Kerrymaid, Dairy Gold – teaspoon									
19. Olive oil spread e.g. Golden Olive (teaspoon)									

	AVERAGE USE LAST YEAR								
F. FRUIT (1 Fruit or medium serving)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Apples									
2. Pears									
3. Oranges, satsumas, mandarins									
4. Grapefruit									
5. Bananas									
6. Grapes									
7. Melon									
8. Peaches, plums									
9. Apricots									
10. Strawberries, raspberries, kiwi fruit									
11. Tinned fruit									
12. Dried fruit e.g. raisins									
13. Frozen fruit									

	AVERAGE USE LAST YEAR								
G. VEGETABLES Fresh, frozen or tinned (Medium Serving – 2 tablespoons)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Carrots									
2. Spinach									
3. Broccoli, spring greens, kale									
4. Brussel sprouts									
5. Cabbage									
6. Peas									
7. Green beans, broad beans, runner beans									
8. Courgettes									
9. Cauliflower									
10. Parsnips, turnips									
11. Leeks									
12. Onions									
13. Garlic									
14. Mushrooms									
15. Sweet peppers									
16. Beansprouts									
17. Green salad, lettuce									
18. Cucumber, celery									
19. Tomatoes									
20. Sweetcorn									
21. Beetroot									
22. Coleslaw									
23. Baked beans									
24. Dried lentils, beans, peas									
25. Tofu, soya meat, TVP, vegeburger									

	AVERAGE USE LAST YEAR								
H. SWEETS AND SNACKS (Medium serving)	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Chocolate coated sweet biscuits e.g. digestive (one)									
2. Plain sweet biscuits e.g. Marietta, digestives, rich tea (one)									
3. Cakes e.g. fruit, sponge									
4. Buns, pastries e.g. croissants, doughnuts									
5. Fruit pies, tarts, crumbles									
6. Sponge puddings									
7. Milk puddings e.g. rice, custard, trifle									
8. Ice cream, choc ices, Frozen desserts									
9. Chocolates, singles or squares									
10. Sweets, toffees, mints									
11. Sugar added to tea coffee, cereal (teaspoon)									
12. Sugar substitute e.g. canderel added to tea coffee, cereal (teaspoon)									
13. Crisps or other packet snacks									
14. Peanuts or other nuts									

	AVERAGE USE LAST YEAR								
I. SOUPS, SAUCES AND SPREADS	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Vegetable soups: homemade/fresh (1 bowl)									
2. Vegetable soups: tinned/packet (1 bowl)									
3. Meat or cream soups: homemade/fresh (1 Bowl)									
4. Meat or cream soups: tinned/packet (1 bowl)									
5. Sauces e.g. white sauce, cheese sauce, gravy (tablespoon)									
6. Tomato based sauces e.g. pasta sauces									
7. Curry-type sauces									
8. Pickles, chutney (tablespoon)									
9. Marmite, Bovril (tablespoon)									
10. Jam, marmalade, honey, syrup (teaspoon)									
11. Peanut butter (teaspoon)									

	AVERAGE USE LAST YEAR								
J. DRINKS	Never or less than once per month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
1. Tea (cup)									
2. Coffee instant (cup)									
3. Coffee ground (cup)									
4. Coffee, decaffeinated (cup)									
5. Coffee whitener e.g. coffee-mate (teaspoon)									
6. Cocoa, Hot Chocolate (cup)									
7. Horlicks, Ovaltine (cup)									
8. Wine (glass)									
9. Beer, Larger or Cider (half pint)									
10. Alcopops e.g. Bacardi Breezer 11. (bottle)									
12. Port, Sherry, Vermouth, liqueurs (glass)									
13. Spirits e.g. Gin, Whiskey (single measure)									
14. Low calorie or diet soft fizzy (glass)									
15. Fizzy Soft drinks e.g. Cocoa Cola (glass)									
16. Pure fruit drinks e.g. orange juice (small glass)									
17. Fruit squash (small glass)									

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.