The relationship between gestational weight gain, maternal upper-body subcutaneous fat changes and infant birth size: a pilot observational study amongst women with obesity.

Abstract

Background: It is widely acknowledged that maternal obesity and excessive gestational weight gain (GWG) are associated with increased risk of fetal macrosomia and recent studies have suggested a role for the timing and composition of GWG.

Aims: To examine the effect of the rate of change in GWG and maternal upper-body subcutaneous fat on neonatal anthropometric outcomes in a pilot observational study amongst women with obesity.

Study design: Expectant women with a body mass index (BMI) > 30 kg/m^2 at first antenatal appointment were recruited at 12 weeks gestation. Maternal height, weight and skinfold thickness (SFT) measurements were collected at baseline and repeated at 28 and 36 weeks gestation. Following delivery, World Health Organisation (WHO)-UK infant birthweight z-scores were calculated, and infant anthropometric measurements were obtained.

Results: The sum of upper body SFT measurements increased in mid-pregnancy (0.08 ± 0.71 mm/week) and decreased in late pregnancy (-0.04 ± 1.17 mm/week). After adjustment for maternal age, BMI and parity, mid- but not late- pregnancy GWG was positively associated with infant birthweight z-score ($p<0.05$), while mid- but not late-pregnancy changes in the sum of SFT were inversely associated with infant birthweight z-score ($p<0.01$).

Conclusions: The present study suggests that mid- rather than late-pregnancy changes in weight and upper-body subcutaneous fat are associated with infant birthweight. Further research is required in larger, more diverse populations to explore whether pregnancy interventions aiming to improve maternal and offspring health can be personalised beyond BMI and GWG.

Key words: Pregnancy, maternal obesity, body composition, skinfold thickness, birthweight.

Abbreviations: BMI - body mass index; GWG – gestational weight gain; UK - United Kingdom; UME – upper arm muscle area estimate; UFE – upper arm fat area estimate; FM – fat mass; FFM – fat free mass.

Introduction

Obesity has become a worldwide epidemic, and in the United Kingdom (UK), it is estimated that half of women of childbearing age are living with overweight or obesity [1] with the prevalence of maternal obesity increasing, as defined by trimester one body mass index (BMI) [2]. It is well documented that maternal obesity has significant health implications for both mother and baby, increasing the risk of complications during pregnancy and labour [3]. Offspring of mothers with obesity are also more likely to be born large for gestational age or macrosomic [3–5] which predisposes infants to adiposity and obesity during infancy and childhood [6,7]. Excessive gestational weight gain (GWG) carries similar risks to maternal obesity for both maternal and neonatal outcomes [8,9], and postpartum weight retention increases the risk that women will enter their next pregnancy with obesity [10].

Due to the lack of evidence-based guidelines, the National Institute for Health and Care Excellence does not currently make recommendations for GWG amongst the UK population [11]. In the United States (US), the Institute of Medicine (IOM) has published recommendations for GWG, which were updated in 2009 to include BMI-specific guidelines [12]. Although the IOM recommendations were designed for the US population, the recommendations are largely based on evidence derived from the US and Europe, thus, the IOM recommendations have been adopted in many other countries worldwide and are widely reported in the literature [13,14]. As well as total GWG, the IOM recommend "normal" weekly rates of GWG for the second and third trimesters.

Recent studies conducted amongst women have tended to observe stronger positive associations between GWG in the second trimester [15,16] or early GWG (before the end of the second trimester) and infant birth size outcomes [17–19]. Studies examining the relationship between maternal body composition assessed via bioelectrical impedance analysis and infant birthweight have tended to observe a positive association between maternal fat-free mass (FFM), but not maternal fat mass (FM) [19–21]. With the exception of one study [17], these studies were conducted amongst women across all BMI ranges and tend to report estimates of FM or FFM at single time-points rather than changes during pregnancy, which makes it difficult to establish trimester-specific recommendations, particularly for women with obesity. A 2020 National Academy of Medicine discussion paper focusing on GWG amongst women with obesity highlights that many studies report total GWG over pregnancy, rather than patterns of GWG and correlations between GWG and fetal growth [22]. A recent study conducted amongst 72 women with obesity observed that individual differences in total GWG were predominantly explained by changes in FM, as assessed by air displacement plethysmography, with gains in FM significantly lower amongst women with Class III obesity, than amongst those with Class I and II [23]. In addition, when examined by trimester, FM was found to increase in the second trimester, and decrease in the third, whilst GWG in the third trimester was attributed to FFM accumulation and fetal growth. However, this study did not examine the relationship between these patterns of GWG, FM and FFM accrual and infant birth size and there appears to be a lack of observational studies conducted amongst women with obesity that examine these associations. The time periods examined also vary considerably between studies, with some looking at early versus late pregnancy, and others looking at trimesters, which makes comparison difficult. Studies examining rates of GWG at frequent assessments are therefore useful in order to increase our understanding of the importance of GWG during different stages of pregnancy, facilitate comparison of GWG amongst pregnancies or varying durations, and to enable the development of transferable recommendations.

The aim of the present study was therefore to identify whether there is a relationship between trimester-specific rates of GWG or upper-body skinfold thickness (SFT) measurements and infant birthweight and anthropometrics at birth. SFT measurements were chosen to assess subcutaneous fat stores, which traditionally accumulate up to the end of the second trimester and are subsequently mobilised in the third trimester to support maternal metabolism and rapid fetal growth. In addition, callipers are a simple, quick, portable and cost-effective tool that could be used in addition to weighing scales by health professionals caring for pregnant women, enabling personalised care beyond BMI [24]. SFT measurements could also be used as an additional outcome measure to assess the success of future pregnancy interventions aiming to reduce GWG and infant macrosomia if a relationship is observed between changes in maternal upper body subcutaneous fat and infant outcomes. As women with obesity are at increased risk of delivering a LGA or macrosomic baby, but at lower risk of multiple pregnancy complications than women with Class III obesity [3], the study focuses on women with Class I and Class II obesity (pre-pregnancy BMI ≥ 30 kg/m^2 and <40 kg/m^2). To our knowledge, this is the first study to report the association between GWG, changes to maternal upper-body SFT and infant birth size amongst women with obesity in the UK. It is therefore difficult to form a hypothesis in terms of how changes in maternal upper-body SFT will affect infant birth size, however, based on previous work examining changes in maternal weight, FM and FFM in women of all weights, we hypothesise that mid-pregnancy GWG will be more strongly associated with infant birthweight than late-pregnancy GWG, and that we will observe reductions in upper body subcutaneous fat in late pregnancy.

Methodology

Recruitment of women

Women aged between 18 and 40 years of age, with a BMI ≥ 30 and <40 kg/m^2 at booking and pregnant with a singleton pregnancy were eligible to take part in the study. Women meeting inclusion criteria were identified from their antenatal booking notes and approached by the researcher at their 12 week dating scan. Ethical approval was obtained from the NHS Health Research Authority National Research Ethics Service and local Research and Development approval was obtained from University Hospitals Plymouth NHS Trust.

Following recruitment, verbal and written informed consent were obtained from women, and the first study visit occurred between 12 and 14 weeks gestation. Further visits occurred at the end of the second trimester at approximately week 28 of gestation (visit 2), and at the end of the third trimester at approximately week 36 of gestation (visit 3). A single researcher performed all measurements at all study visits in order to reduce inter-observer error.

Maternal anthropometric measurements

In order to examine GWG throughout pregnancy, maternal weight was measured at each visit using the same digital scales for each woman throughout the duration of the study. GWG was recorded as a simple difference between weight at each study visit to give a crude value for GWG in each trimester and a 'total' GWG for the study duration.

Weekly rates of GWG were calculated for each woman, based on the difference in weight between study visits, divided by the number of weeks (and days) between visits. Reporting GWG in this way accounts for gestation, and facilitates comparison against the IOM guidelines (Table 1). Rates of GWG were calculated for the second trimester (between visits 1 and 2, defined as mid-pregnancy GWG), the third trimester (between visits 2 and 3, defined as late pregnancy GWG) and over the study duration (between visits 1 and 3, defined as total pregnancy). Women were further classified as achieving 'insufficient', 'adequate' or 'excessive' GWG according to their rate of GWG between each of these time points according to IOM guidelines (Table 1) [12].

Table 1 IOM recommendations for total and rate of weight gain during pregnancy, by pre-pregnancy BMI

	Total Weight gain	**Rate of weight gain, 2nd and 3rd trimester**
Pre-pregnancy BMI	**Range in kg**	**Mean (range) in kg / week**
Underweight (<18.5 kg/m^2)	12.5 – 18.0	0.51 (0.44-0.58)
Normal weight (18.5 – 24.9 kg/m^2)	11.5 – 16.0	0.42 (0.35–0.50)
Overweight (25.0 – 29.9 kg/m^2)	7.0 – 11.5	0.28 (0.23-0.33)
Obese (≥30 kg/m^2)	5.0 – 9.0	0.22 (0.17-0.27)

Maternal upper-body SFT of the biceps, triceps and subscapular were assessed at each anthropometric visit according to the methods described by Kannieappan et al. [25] and the International Society for the Advancement of Kinanthropometry (ISAK) [26] using Harpenden callipers (British Indicators, Sussex, England) by a single researcher in order to minimise inter-observer error. A full set of all three SFT measurements was completed in order to reduce the effects of skinfold compressibility prior to repeating a second measurement at each site. If the difference was greater than 7.5%, a third measurement was taken according to ISAK recommendations. SFT for each site was reported in mm as the mean of two measurements, or the median of three measurements [26]. In addition, SFT measurements were reported as the sum of all three measurements rather than entered into an equation as recommended by numerous authors to assess changes in body composition over time and to reduce systematic error associated with equations, which are particularly difficult to validate in a pregnant population [27,28]. Rate of change to the sum of these three SFT measurements over the study duration, as well as in mid-pregnancy and late-pregnancy were calculated (in mm/week) to adjust for length of gestation for each woman.

Infant outcomes

Information about the infants was collected from hospital notes, or through measurements made by the researcher. This included gestational age at delivery, method of delivery, the incidence of any complications, infant gender, birthweight and head circumference. Birthweight and head circumference were used to calculate the z-scores from UK-WHO reference values for term infants [29,30] using the LMS method [31] (LMS Growth Programme v2.77, Medical Research Council, UK) which adjusted for infant gender. Crown-heel length was measured by the researcher using a mobile measuring mat (Seca 210, Hamburg, Germany). This measurement was taken as soon after delivery as possible and recorded to the nearest 5 mm. Length z-scores were also calculated from UK-WHO reference values for term infants [29,30] using LMS software and were adjusted for infant gender and age at assessment.

Infant anthropometric measurements were taken as close to birth as possible, in most instances within 72 hours of delivery. Where this was not possible, for example, for infants who spent longer than this on the neonatal intensive care, or transitional care units, measurements were used after adjusting them for age. A model that calculated an infant upper arm fat area estimate (UFE) and upper arm muscle area estimate (UME) was used. The equations are based on mid-upper arm circumference and triceps skinfold, and has been previously validated against magnetic resonance imaging in children [32]:

$$\mathbf{TUA = C^2 / (4\pi)}$$

$$\mathbf{UFE = C \times (TS/2)}$$

$$\mathbf{UME = TUA - UFE}$$

TUA = total upper arm area; UFE = upper arm fat area estimate; UME = upper arm muscle area estimate; C = mid upper arm circumference, TS = triceps skinfold (mm).

Statistical analysis

All data was entered into and analysed using SPSS (Statistics Package for the Social Sciences) for Windows version 21 (IBM, Chicago USA). The level of significance was set to a probability $p < 0.05$ for all statistical tests performed, and unless otherwise stated, data were presented as means ± standard deviation (SD).

Continuous outcome measures were inspected for normality and if this assumption was met, parametric tests were performed. Pearson's correlation coefficients (r) were run to assess the relationships between maternal changes in upper body subcutaneous fat and GWG. Multiple regression was used to evaluate the extent to which maternal rates of GWG and SFT changes over pregnancy influence infant birthweight z-scores, UFE and UME after adjustment for maternal age, booking BMI and parity, and in the case of UFE and UME, also adjusted for infant sex and gestational age. For all models there was independence of residuals, as assessed by a Durbin-Watson statistic of approximately 2.0, homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values and there was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. As the current study is the first, to the author's knowledge, to examine the effect of the rate of change in upper body SFT measurements on birthweight and infant body composition, there was no data on which to base an *a priori* power calculation. However, posthoc power calculations show that the large effect sizes observed for the multiple regression analyses reached 99% power, and thus, statistical analysis was adequately powered.

Results

A total of 75 women gave their consent to participate in the study, which was 31% of women approached. All women in the study identified their ethnicity as White Caucasian.

Data was collected for 75 women at visit one (12-14 weeks gestation), 65 women at visit two (28 weeks gestation), and 59 women at visit three (36 weeks gestation), with a total of 16 women lost to follow up between the first and last study visit. Womens' ages ranged from 19 years to 40 years, with a mean age of 29.8 ± 4.8 years and mean BMI was 33.0 ± 1.9 kg/m^2. There were no significant differences in maternal descriptive characteristics nor birth outcomes obtained from notes between women completing the study and those who were lost to follow up, data not shown. Anthropometric measurements collected at each study visit are shown in Table 2.

Table 2 Maternal anthropometric measurements

	Visit 1 (n=75)	**Visit 2 (n=65)**	**Visit 3 (n=59)**
Weight (kg)	89.7 ± 8.7	95.1 ± 9.2	97.0 ± 9.9
Trimester-specific rate of GWG (kg/week)	-	0.3 ± 0.2	0.3 ± 0.4
Total pregnancy rate of GWG (kg/week)	-	-	0.3 ± 0.3
Proportion of women gaining in excess of IOM guidelines, n (%)	-	38 (59)	31 (54)
Arm circumference (cm)	35.2 ± 2.7	34.8 ± 2.8	34.3 ± 3.0
Triceps SFT (mm)	29.6 ± 5.2	30.4 ± 5.9	28.5 ± 5.7
Biceps SFT (mm)	18.9 {17.6-20.3}†	19.1 ± 6.0	18.0 ± 6.4
Subscapular SFT (mm)	34.2 ± 7.5	35.4 ± 9.0	34.5 ± 8.5
Sum of SFT (mm)	83.7 ± 13.6	85.0 ± 15.0	81.0 ± 17.1
Trimester-specific rate of change in SFT (mm/week)	-	0.1 ± 0.7	-0.1 ± 1.2
Total pregnancy rate of change in SFT (mm/week)	-	-	-0.1 ± 0.7

Data are mean ± SD unless otherwise stated.
†Mean calculated by back-transformation {CI}

Gestational weight gain (GWG), Institute of Medicine (IOM), Skinfold thickness (SFT).

Table 2 shows that mean rate of GWG in mid-pregnancy, late pregnancy, and in total over pregnancy was 0.33 ± 0.23, 0.29 ± 0.40 and 0.32 ± 0.26 kg/week, respectively. The proportion of women gaining in excess of IOM guidelines was 59 and 54% in mid- and late-pregnancy, respectively. In addition, Table 3 shows GWG class of obesity, and the proportion of women gaining weight in excess of the IOM guidelines. Mid-pregnancy GWG and rate of GWG were significantly higher amongst women in Class I (5.5 ± 0.5 kg and 0.4 ± 0.1 kg/week) than amongst women in Class II (2.8 ± 1.2 kg; p = 0.026 and 0.2 ± 0.1 kg/week; p=0.024), whereas GWG in late-pregnancy and over total pregnancy were not significantly different between women in the two classes of obesity (P>0.05).

Table 3 Gestational weight gain by obesity class.

	Class I Obesity (n=46)	Class II Obesity (n=11)
Mid-pregnancy GWG (kg)	5.5 ± 0.5	2.8 ± 1.2
Mid-pregnancy rate of GWG (kg/week)	0.4 ± 0.1	0.2 ± 0.1
Proportion of women gaining in excess of IOM guidelines in mid-pregnancy, n (%)	31.0 (67.4)	4.0 (36.4)
Late-pregnancy GWG (kg)	2.4 ± 0.5	2.1 ± 1.0
Late-pregnancy rate of GWG (kg/week)	0.3 ± 0.1	0.3 ± 0.1
Proportion of women gaining in excess of IOM guidelines in late-pregnancy, n (%)	26.0 (56.5)	5.0 (45.5)
Total GWG (kg)	8.1 ± 1.0	4.9 ± 1.9
Total pregnancy rate of GWG (kg/week)	0.3 ± 0.1	0.2 ± 0.1
Proportion of women gaining in excess of IOM guidelines over total pregnancy, n (%)	28.0 (60.1)	5.0 (45.5)

Data are mean ± SD unless otherwise stated.
Gestational weight gain (GWG), Institute of Medicine (IOM), Skinfold thickness (SFT).

The rate of GWG was significantly and positively associated with the rate of SFT changes in mid-pregnancy (r=0.467), late-pregnancy (r=0.478) and over total pregnancy (r=0.609; all p<0.01). Changes in SFT were highly variable over pregnancy for the study population with an overall trend for a reduction in upper body subcutaneous fat between early and late pregnancy, although this did not reach statistical significance (p=0.071).

Information concerning the delivery of infants, was available for 74 infants, of which three were pre-term (<37 weeks gestation) and excluded from analysis. Infant anthropometric measurements acquired from hospital notes and from the researcher's home visit are shown in Table 4.

Table 4 Infant outcomes (n=71)

	n	Mean	SD
Gestation length (days)†	71	275.0	13.0
Infant gender male, n (%)	71	41 (58)	-
Vaginal delivery, n (%)	71	45 (63)	-
Birthweight, g	71	3497.0	461.0
Birthweight, z-score	71	0.1	0.9
Head circumference, cm†	55	35.0	2.0
Head circumference, z-score	55	0.4	1.3
Crown-heel length, cm	56	50.8	2.1
Crown-heel length, z-score	56	0.1	1.0
Infant arm circumference, cm†	56	10.0	1.5
Triceps skinfold thickness, mm	56	6.7	1.8
UME, cm^2	56	445.5	105.1
UFE, cm^2	56	334.4	108.2

†Median (IQR)
Standard deviation (SD), upper arm area muscle estimate (UME), upper arm area fat estimate (UFE).

A multiple regression was used to evaluate the extent to which maternal rates of GWG and changes in SFT in mid- and late-pregnancy influence infant birthweight z-scores, UME and UFE after adjustment for maternal age, booking BMI and parity. The models examining UFE and UME were additionally adjusted for infant sex and gestational age, which were already accounted for in the birthweight z-scores. The models statistically significantly predicted birthweight z-score (p=0.016) and UFE (p = 0.017), but not infant UME, which didn't quite reach statistical significance (p =0.055). As shown in Table 5, mid- but not late-pregnancy GWG was significantly and positively associated with infant birthweight z-score, while mid- but not late-pregnancy change in the sum of SFT was significantly and inversely associated with infant birthweight z-score. Mid-pregnancy GWG was also positively associated with infant UFE, however, for late pregnancy this relationship was reversed.

Table 5 Multiple regression coefficients.

	Birthweight z-score (n=56)			UFE (n=53)		
	β	95% CI	p	β	95% CI	p
Mid-pregnancy GWG, kg/week	**0.47**	**0.39 – 3.32**	**0.014**	**0.49**	**53.03 – 384.3**	**0.011**
Mid-pregnancy change in the sum of SFT, mm/week	**-0.50**	**-1.11 - -0.28**	**0.001**	-0.28	-92.36– 3.39	0.068
Late-pregnancy GWG, kg/week	0.16	-0.39 – 1.12	0.329	**-0.37**	**-187.68 - -13.06**	**0.025**
Late-pregnancy change in the sum of SFT, mm/week	-0.24	-0.45 – 0.05	0.107	0.19	-10.87– 47.71	0.212

Multiple regression adjusted for maternal body mass index, parity, age, infant sex* and gestational age*
*UFE model only.

Discussion

This study is the first to our knowledge that has examined the impact of trimester-specific rates of GWG and changes in upper-body skinfold measurements on infant anthropometric measurements amongst women with obesity in the UK. Our findings suggest that mid- rather than late-pregnancy changes in weight and upper-body subcutaneous fat are associated with infant birthweight and upper body fat, suggesting that the second trimester may be an opportune window for pregnancy interventions aiming to improve pregnancy and infant outcomes for women with obesity.

Mid-pregnancy GWG was positively associated with birthweight z-score, while no association was observed for late-pregnancy GWG. These observations are consistent with others in the literature. For example, Farah et al. [19] observed a positive correlation between GWG before the third trimester and infant birthweight, with no association reported for GWG during the third trimester in a cohort of 184 non-diabetic women in Ireland. Hivert et al [15] observed a positive association between rate of GWG in all three trimesters and birthweight z-score amongst 979 mother-child pairs from the Project Viva cohort in the USA, with the largest effect size observed for second trimester GWG, while Widen et al [16] observed that high rate of GWG, as defined by tertiles, in the second trimester only was associated with higher infant birthweight and length amongst 156 women in another USA cohort.

In terms of changes in maternal adiposity, there was large variation in the accumulation of upper body fat amongst women in the cohort, and only mid-pregnancy changes in maternal upper-body skinfold measurements were associated with infant birthweight, in an inverse direction. This is in contrast to findings from Dodd et al [33] who estimated maternal FM from the same three sites measured in the present study amongst 1582 overweight women in South Australia, and did not observe any significant associations between total GWG, maternal percentage body fat, nor individual SFT measurements and infant birthweight. Hediger et al [34] observed an inverse relationship between change in triceps, but not subscapular SFT and infant birthweight, but this was in late pregnancy, in contrast to the findings in the current study, where late pregnancy changes in SFT did not contribute to the regression model. The study by Hediger et al. [34] was conducted in 608 women of all weights, and is more consistent with previous literature that suggests pregnant women accrue subcutaneous fat in early and mid-pregnancy, and tend to experience a decrease in SFT measurements in trimester three, when fat stores are mobilised to support rapid fetal growth [35,36]. However, studies conducted amongst women with obesity suggest that subcutaneous fat gains tend to be less than for women with a lower BMI [37,38]. A recent study conducted by Most et al. [23] found individual differences in GWG amongst 54 women with obesity to be largely explained by changes in maternal FM, with gains in FM signifcantly higher for women with Class I and II obesity (who gained FM) compared with women with Class III obesity (who lost FM). Straughen and colleagues [39] observed that subcutaneous fat declines measured by ultrasound in women with overweight or obesity were more rapid from early through to late pregnancy than amongst women with a healthy BMI. In a study conducted by Misra and Trudeau (2011), circulating leptin concentration at the start of pregnancy was 1.8 times higher for women with obesity compared with healthy weight women, but by the end of pregnancy it was just 1.2 times higher. These findings suggest that metabolic adaptions to pregnancy amongst women with obesity are different to those observed amongst healthy weight women and may explain our observation of an inverse relationship between mid-pregnancy subcutaneous fat changes and infant birth size, despite observing a positive relationship between mid-pregnancy GWG and infant birthweight. As already discussed women tend to experience a decrease in subcutaneous fat in the final trimester, but based on the observations from the present study, in combination with observations form the literature examining women with obesity discussed above, it is possible that fat stores are perhaps mobilised earlier, thus perhaps explaining, in part, the observations in the present study. In addition, the positive relationship between mid-pregnancy GWG and birthweight may be driven by changes to weight that exclude upper-body subcutaneous fat. For example increases in FFM, which would incorporate TBW, the foetus, placenta and amniotic fluid, or changes to maternal FM at other locations, such as visceral adipose tissue and breast tissue.

It is also important to acknowledge, that although it was a strength of the current study that one researcher took all SFT measurements to reduce inter-observer error, this would not be the case in clinical practice, if multiple health professionals were taking measurements, nor in larger research studies, with multiple researchers. Further studies using methods of assessment that are able to distinguish between the maternal and fetal unit are warranted, although achievement of this is likely to require the use of four-compartment models, which is not generally feasible in larger cohort studies. Widen and Gallagher [24] suggest further validation of portable methods such as BIA is required with revised equations for use in pregnancy to account for changes in TBW and FFM hydration during pregnancy, that can be effectively used in women from pre- to post-partum.

With regards to infant adiposity, higher mid-pregnancy GWG predicted infant UFE, while in late pregnancy, an inverse relationship was observed between GWG and UFE. The model did not significantly predict infant UME. These findings agree with others in the literature to an extent, with one study reporting that women gaining ‘excessive’ weight in early pregnancy gave birth to babies with significantly greater fat mass assessed via total body electrical conductivity, than those born to women gaining ‘excessive’ GWG in late pregnancy [18]. In keeping with the present study, the Norwegian STORK study used SFT measurements to assess infant subcutaneous fat and observed that mid-pregnancy rate of GWG (15-28 weeks gestation) was the strongest independent predictor of infant sum of SFT [40]. However, unlike the present study, no proxy for infant FFM was used, and late-pregnancy GWG was not reported.

Although findings from the current study and previous work suggest that infant birth size outcomes may be driven by changes in maternal weight and body composition, it is not clear whether advising women to adhere to IOM recommendations will positively influence infant birth size, particularly amongst women with obesity. This could explain why lifestyle interventions that successfully reduce GWG do not tend to observe significant reductions in infant birthweight [41,42].

A recent observational study, conducted in Ireland, suggests that when infant birthweight is subtracted from total GWG, the positive correlation between GWG and birthweight no longer exists [43]. The authors argue that modifying GWG and maternal adiposity in women with obesity during pregnancy is therefore unlikely to influence the growth of the baby, and that focus should move from restricting GWG to encouraging a varied, balanced diet. However, it is important to note that even if modifying GWG during pregnancy cannot alter infant birthweight, excess GWG is associated with increased risk of other adverse outcomes [8,44] such as postpartum weight retention, which increases the risk of women entering subsequent pregnancies with obesity, as well as their risk of associated chronic diseases [10].

The current study is not without its limitations, and the primary limitation of the study is the sample size of 75 women all of white ethnicity. This is due to the location of the study hospital, where 95.4% of the population identify themselves as belonging to this group [45]. Future studies investigating the relationship between maternal subcutaneous body fat changes and infant birth size need to be conducted in other areas of the UK amongst women with obesity to determine whether similar patterns are observed amongst more diverse populations. In addition, women were recruited at the end of their first trimester, at their 12 week dating scan, and therefore, we were unable to collect information concerning GWG and body composition changes from conception to week 12 gestation. Although some studies have indicated that minimal GWG occurs in the first trimester [12], physiological changes such as growth of the uterus and breast tissue and plasma volume expansion begin early in pregnancy. Studies examining maternal body composition changes early in pregnancy are scarce, due to the difficulties recruiting women early in their pregnancy before their pregnancy has been confirmed via dating scan, which occurs in the UK at 12 weeks gestation. Therefore, although the majority of published studies appear to report stronger associations between mid-late pregnancy GWG and FFM, observational studies examining changes in GWG and maternal body composition in cohorts of women from pre-conception through to delivery are required in larger, more ethnically diverse populations in order to confirm this, particularly amongst women with obesity, where relatively little is known about very early changes in maternal body composition.

Despite methodological differences between the studies described above and limitations of the present study, maternal changes in weight and body composition appear to play an important role in the predication of infant birthweight and adiposity, especially in mid-pregnancy. To our knowledge, this is the first study to have examined the relationship between the rate at which maternal upper body subcutaneous fat changes over pregnancy in women with obesity and highlights the need for a more personalised approach beyond BMI and total GWG to optimise outcomes for mother and baby, particularly in the second trimester. However, the findings from this pilot study amongst women with obesity, in combination with those in the literature amongst women of all weights, do not consistently support the use of SFT measurements in addition to the monitoring of GWG to assess risk of adverse birth size outcomes, but it is clear that more research is warranted examining the relationship between GWG and changes in maternal body composition amongst women with obesity. Future studies should examine the relationship between the composition of GWG and infant body composition using body composition assessment methods that can distinguish between the maternal and foetal unit, that are portable, and that can be used in a clinical setting throughout pregnancy at frequent intervals.

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Competing Interests:

The authors declare no competing interests.

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