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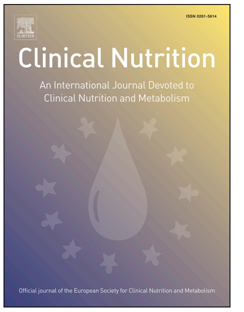

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Clinical Nutrition

Dietary quality influences body composition in overweight and obese pregnant women

Outi Pellonperä[1], Ella Koivuniemi[2], Tero Vahlberg[3], Kati Mokkala[2], Kristiina Tertti[1], Tapani Rönnemaa[4], Kirsi Laitinen[2]

[1]University of Turku and Turku University Hospital, Department of Obstetrics and Gynecology

[2]University of Turku, Institute of Biomedicine

[3]University of Turku, Department of Biostatistics

[4]University of Turku and Turku University Hospital, Department of Medicine

Correspondence: Outi Pellonperä, Department of Obstetrics and Gynecology, Turku University Hospital, Kiinamyllynkatu 4-8, PL 52, 20521 Turku, Finland. E-mail outi.pellonpera@utu.fi. Tel. +35823130384. Fax +358 2 3132340.

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The running title: Body composition of overweight pregnant women

Key words: body composition; gestational weight gain; nutrition; obesity; physical activity; pregnancy

Abbreviations:

BF%	body fat percentage
FFM	fat free mass
FM	fat mass
GWG	gestational weight gain
IDQ-index	index of diet quality
IOM	The Institute of Medicine
MET-index	metabolic equivalent index for leisure-time physical activity

ABSTRACT

Background & aims: Excessive adiposity and gestational weight gain (GWG) have been linked with maternal and offspring morbidity. We investigated the relation of maternal diet, physical activity and GWG on body composition in overweight and obese pregnant women.

Methods: Fat mass (FM) and fat free mass (FFM) of 110 overweight and obese pregnant women were measured by air displacement plethysmography in early and late pregnancy (mean 13 and 35 gestational weeks). At the same time points, the quality of overall diet was assessed by validated index of diet quality (IDQ) questionnaire (score $< 10/15$ denotes poor dietary quality and score $\geq 10/15$ denotes good dietary quality), nutrient intakes by 3-day food diaries, and physical activity by questionnaire. Weight gain between early and late pregnancy was compared to the gestational weight gain guidelines issued by Institute of Medicine.

Results: Of the women, 77% gained more weight than recommended; this was related to greater dietary fat consumption (80±21g/day vs. 67±11 g/day, $p=0.010$) and greater increase in FM (2.7±3.0 kg vs. -1.0±2.4 kg, $p<0.001$) compared to women with ideal GWG. Dietary protein intake (g) correlated positively with FFM at both time points (early pregnancy: $r=0.31$, $p<0.002$, late pregnancy: $r=0.39$, $p<0.001$). Women with higher dietary quality had more FFM, compared to women with lower dietary quality (early pregnancy FFM: 48.8±5.8kg vs. 45.8±4.7kg, $p=0.004$, late pregnancy FFM: 56.1±6.4kg vs. 53.4±5.6kg, $p=0.025$). No correlations were detected between total energy intake or physical activity and FM or FFM at early or late pregnancy.

Conclusions: Body composition changes from early to late pregnancy were related to the amount of weight gained and overall dietary quality during pregnancy. Higher dietary quality and protein intake were associated with greater FFM, while dietary fat intake was related to excess weight gain. Identification of these dietary determinants of body composition and weight offers new targets

for dietary counselling of pregnant women and thus potential for ensuing health benefits through reduced adiposity.

INTRODUCTION

Over the last decades, the obesity epidemic has spread and grown worldwide. Approximately every third woman of reproductive age in Europe and more than every other woman in the United States is overweight or obese (BMI >25kg m^{-2} and ≥30kg m^{-2} respectively)[1,2]. Maternal obesity is associated with a variety of health problems both to the mother and her child during pregnancy, delivery and in later life[3,4]. The mother is at risk of developing gestational diabetes, hypertension, pre-eclampsia or peripartal complications, and in later life, type 2 diabetes and cardiovascular disease[5]. The child is predisposed to suffering birth defects, prematurity, and macrosomia, and to the programming of obesity and a range of metabolic conditions, which may influence the health over the long term[1,5,6].

Body composition measurement by air displacement plethysmography (ADP) applies densitometric principles of lean soft-tissues and fat to estimate fat mass (FM) and fat free mass (FFM), from which body fat percentage (BF%) can be calculated. During the pregnancy the composition of the weight gain includes gains in maternal FM and FFM, which involve expansion of the body water compartments to support the pregnancy, and related tissues (placenta and amniotic fluid) and the fetus. There is marked inter-individual variation in FM and FFM gain, addressing the importance of measuring body composition[7-9]. Thus, body composition gives much more precise information about the adiposity of the body than widely used BMI and reflects also nutritional status [7,10]. It is well known that age, diet, physical activity and chronic illness may affect body composition in the non-pregnant state[11]. Although less studied, these same features are also likely to be related to body composition during pregnancy. The knowledge of the effects of lifestyle on gestational body composition enables the development of counseling procedures for pregnant women by health care professionals. This in turn would be expected to improve the health of both mother and child.

The degree of adiposity and gestational weight gain (GWG) have been linked to the pregnancy-associated maternal and offspring morbidity[12-14]. The Institute of Medicine (IOM) has issued guidelines for GWG; these recommend less weight gain for women with higher pre-pregnancy BMI to minimize the risks for pregnancy-related complications for both mother and child [15]. At the same time, it is recognized that more information is needed regarding the association of lifestyle factors with body composition in pregnant women, particularly in those in the upper BMI categories, as this would help targeting ways of health promoting optimal GWG to those women most in need of counselling.

The aim of this study was to investigate the changes in body composition over pregnancy and the extent to which diet and physical activity influence body composition in overweight and obese pregnant women. Secondly, we evaluated the differences in maternal body composition and lifestyle in relation to the GWG recommendations issued by IOM[15].

MATERIALS AND METHODS

This prospective study examined 110 pregnant women living in Southwest Finland. The data were collected from overweight and obese women participating in a mother-infant dietary intervention trial (ClinicalTrials.gov Identifier: NCT01922791). This study was conducted according to the guidelines laid down in the Declaration of Helsinki and approved by the Ethics Committee of the Hospital District of Southwest Finland. Written informed consent was obtained from all subjects.

Women at least 7 and maximum 17 gestational weeks and BMI ≥25kg m^{-2} were recruited in the study. Exclusion criteria included: pre-pregnancy BMI <25kg m^{-2}; more than 17 gestational weeks at recruitment; chronic diseases impacting metabolic and gastrointestinal health such as diabetes or inflammatory bowel diseases. We recruited generally healthy women. However, certain relatively common conditions that were not thought to interfere with body composition results were allowed. These were asthma and allergies, mild mental disorders, migraine and medically controlled hypothyroidism. In this analysis, we included in chronological order the first 135 women who were recruited. Study visits were conducted in early and in late pregnancy (mean 13.5 and 35.3 gestational weeks). Those women who were recruited but did not attend to the late pregnancy visit were excluded (n=25). The baseline characteristics did not differ between the included and 25 excluded women (data not shown).

Height was measured at the first visit with a wall stadiometer to the nearest 0.1cm. Pre-pregnancy weight was self-reported and was found to correlate highly with medical record values of measured weight at the first antenatal visit in local maternity clinics (Pearson correlation 0.99, $p<0.000001$). On both study visits, women had their body composition and weight measured. Women were classified into groups of excess, ideal and inadequate gestational weight gain according to the recommendations issued by the IOM[15]. The actual measured weight gain between early and late gestation visits was compared to recommended minimum and maximum weight gains taking into account the specific weeks of gestation and the recommended weight gain over the follow-up period. The IOM recommendation assumes a weight gain of 0.5-2kg in the first trimester for all women and during the 2nd and the 3rd trimesters of pregnancy, overweight women (pre-pregnancy BMI 25.0-29.9kg m-2) are advised to gain 0.23-0.33kg per week and obese women (pre-pregnancy BMI≥30.0kg m-2) 0.17-0.27kg per week. Enrollment of some women in the first trimester (i.e. ≤ 13+0 gestational weeks) was taken into account by multiplying the proportion of gestational weeks that was left from the first trimester with either 0.5 kg (recommended minimum) or 2.0 kg (recommended maximum) and by adding these first trimester weight gains respectively to recommended minimum or maximum weight gains during 2nd and 3rd trimesters of pregnancy.

Questionnaires concerning physical activity and dietary quality were filled in by 107-110 of women. Women were also asked to fill in questionnaires concerning their education, smoking habits and obstetric medical history.

Body composition measurements

Air displacement plethysmography and an electronic scale (the Bod Pod system, software version 5.4.0, COSMED, Inc., Concord, CA, USA) were used to measure body volume and weight according to the manufacturer's instructions. FM and FFM in kilograms were calculated from density using the formulas devised by van Raaij et al.[16], which take into account the length of gestation and the presence of marked general swelling when necessary. Thoracic gas volume was measured whenever possible (n=100/110 in early gestation and n=106/110 in late gestation) and used in the calculations of FM and FFM, otherwise predicted thoracic gas volume was used in body composition calculations. After overnight fasting and emptying the bladder, subjects entered the measurement chamber wearing a tight cap and tight underwear. They were advised not to exercise or to shower in the morning of measurements.

Dietary intake

Three-day food diaries (2 weekdays and 1 weekend day) were recorded during the week preceding the study visits. Subjects were given oral and written instructions on how to fill in the food diary and diaries were checked for completeness and accuracy with the help of an illustrated portion booklet. Mean daily intakes of energy (megajoules) and macronutrients (grams and E%) were calculated by using computerized software (AivoDiet 2.0.2.3;Aivo, Turku, Finland) utilizing the food composition database provided by the Finnish National Institute for Health and Welfare (www.fineli.fi).

The quality of overall diet was assessed by validated index of diet quality (IDQ) questionnaire on both study visits[17]. This questionnaire contains 18 questions regarding the frequency and amount of consumption of food products during the preceding week. The health promoting criteria included: use of wholegrain bread (≥4 slices/per day), saturated/unsaturated fatty acids (vegetable oil-based margarine on bread, fish at least twice a week, use of low-fat ≤1% dairy products, use of vegetable oil-based salad dressing), dairy products (at least 4 dl/ day), consumption of vegetables, fruits and berries(≥400 g/day), and use of sugar containing drinks and sweets (soft drinks max once/week, sweets max once/week, fruit and berry juices max 1 glass/day), and less than 2 skipped meals/week. The quality of the diet was defined as poor when index points were less than ten out of the maximum 15 points and good when points were ≥ 10/15[17].

Physical activity

Physical activity was assessed by a questionnaire[18]. Women were asked to report the intensity, frequency and duration of their habitual leisure-time physical activity during the preceding week. A metabolic equivalent index for leisure-time physical activity (MET-index) was calculated from the product of intensity x frequency x duration of activity (MET h/wk) on both study visits. The coefficients for the intensity of physical activity were estimated from the existing tables[19].

Statistical analysis

The normality of the data was checked visually from histograms. The data were summarized as frequencies and percentages for categorical variables and as means and standard deviations for normally distributed continuous variables. MET-indexes were generally non-normally distributed; consequently, medians and interquartile ranges are reported. Ninety five percent confidence intervals were calculated in cases where differences were reported.

In the comparisons, paired samples t-test was used to calculate change between early and late pregnancy in body composition variables or daily energy/macronutrient intakes. Wilcoxon signed ranks test was used to estimate if there were changes in physical activity (MET-index). To compare the differences in body composition between women with inadequate, ideal or excess weight gain, we used one-way ANOVA with Games-Howell post-hoc tests. When comparisons of energy intake, IDQ- or MET-indices were made between subgroups of different GWG and BMI categories, one-way ANOVA and independent samples t-test were used for normally distributed data and Mann Whitney and Kruskall-Wallis tests for non-normally distributed data (Supplementary table 2). When the subgroups were compared, adjustment for age and gestational weeks were not done, since these variables did not differ significantly between the groups.

Possible associations between lifestyle variables and body composition measures (outcome variables) were assessed using partial Pearson's correlation test adjusting for gestational weeks and continuous pre-pregnancy BMI. In adjustments, gestational weeks at the point of measurement of each variable were used and when change was evaluated, we also adjusted for weeks between early and late gestation measurements. Associations between MET-index and body composition (outcome variable) were assessed with Spearman's correlation test without adjustments, since no correlation between body composition variables and gestational weeks or pre-pregnancy BMI existed. Correlations of at least medium effect size ($r \geq 0.3$) were reported[20]. We also conducted linear models assessing the relationship between explanatory life style variables (physical activity, dietary quality and macronutrient intake) and change in either FM, FFM or BF% (outcome variables) (Supplementary table 2). We adjusted all models for intervention group, gestational weeks at enrollment, age, height, and for each early gestation body composition variable.

A p-value<0.05 was considered significant. Analyses were conducted with IBM SPSS statistics version 22.0 for Windows (IBM SPSS Inc. USA, Chicago, IL, USA).

RESULTS

All participants were white Caucasians. The clinical characteristics of the women are presented in table 1; 55% were overweight and 45% were obese. Women participating in the study were generally in good health, although 29 reported having asthma or allergies, 5 mild mental disorders, 5 migraine, 4 hypothyroidism controlled by medication and 2 psoriasis. No significant differences in body composition variables between women with or without asthma and allergies were found.

Table 1. Characteristics of the pregnant women.

Characteristics	n=110
Primipara	49 (44.5)
Age (years)	30.2 ±4.8
Pre-pregnancy BMI (kg m^{-2})	29.8 ±4.1
Overweight	61 (55.5)
Pre-pregnancy BMI (kg m^{-2})	27.0 ±1.7
Obese	49 (44.5)
Pre-pregnancy BMI (kg m^{-2})	33.3 ±3.3
Gestational age 1st visit (wk)	13.5 ±2.5
Gestational age 2nd visit (wk)	35.3 ±1.1
College or university education*	65 (60.7)
Smoking before pregnancy*	20 (18.7)
Smoking during pregnancy	7 (6.4)

Data are expressed as numbers (percentages) or mean ±SD

Overweight BMI 25-29.9 kg m^{-2}, Obese BMI ≥ 30.0 kg m^{-2}

*data available for n=107

Weight and body composition

The weight and body composition as well as their change over the follow-up period are presented in table 2. The mean weight gain was 9.1 kilograms (range 1.1-19.4kg) over a mean of 21.7 weeks. On average, 17% of the weight gain was FM and 83% FFM. Consequently, body fat percentage (BF%) decreased in the majority of the women (81%).

Table 2. Weight and body composition in 110 overweight and obese pregnant women measured with electronic scale and air displacement plethysmography.

	Early gestation	Late gestation		
	Mean ±SD	Mean ±SD	Mean change (95 % CI)	P-value[b]
All women n=110				
Weight (kg)	84.6 ±13.7	93.7 ±14.4	9.1 (8.4 ; 9.8)	<0.001
Fat mass (kg)	37.2 ±10.3	38.8 ±10.5	1.6 (0.9 ; 2.2)	<0.001
Fat free mass (kg)	47.4 ±5.4	54.9 ±6.2	7.5 (7.2 ; 7.9)	<0.001
Fat percentage	43.4 ±5.9	40.8 ±5.6	-2.5 (-3.0 ; -2.0)	<0.001
Overweight women n= 61				
Weight (kg)	76.6 ±8.3	86.6 ±10.1	9.9 (9.0 : 10.9)	<0.001
Fat mass (kg)	30.7 ±5.7	33.1 ±6.8	2.5 (1.6 ; 3.3)	<0.001
Fat free mass (kg)	46.1 ±5.3	53.4 ±5.9	7.5 (7.0 ; 7.9)	<0.001
Fat percentage	39.9 ±4.9	38.0 ±4.8	-1.8 (-2.5 ; -1.2)	<0.001
Obese women n=49				
Weight (kg)	94.6 ±12.5	102.7 ±14.1	8.1[a] (7.0 ; 9.2)	<0.001
Fat mass (kg)	45.4 ±8.9	45.8 ±10.0	0.4[a] (-0.6 ; 1.5)	0.402
Fat free mass (kg)	49.2 ±5.1	56.8 ±6.1	7.6[a] (7.0 : 8.3)	<0.001
Fat percentage	47.7 ±3.8	44.3 ±4.4	-3.4[a] (-4.1 ; -2.8)	<0.001

CI = confidence interval

Overweight BMI 25-29.9 kg m^{-2}, Obese BMI ≥ 30.0 kg m^{-2}

[a] Statistical significance of difference between overweight and obese women in the development of weight, fat mass, fat free mass and body fat percentage: p=0.011, p=0.002, p= 0.648 and p= 0.001, respectively.

[b] Paired Samples T-test

Impact of dietary intake and dietary quality on body composition

Although the total energy intake did not differ significantly between the early and late gestation, the intake of fat increased and that of carbohydrates as a proportion of energy intake (E%) decreased, (table 3). The dietary quality measured by IDQ did not change between the visits (9.8±2.2 vs. 9.8±2.1, p=0.81) and was found to be poor in 50% and 42% of the women in early and late pregnancy, respectively.

When the effects of diet on body composition were evaluated, it was found that women with poor dietary quality had significantly less FFM compared to those women consuming a good quality diet (in early pregnancy 45.8±4.7kg vs. 48.8±5.8kg, p=0.004 and in late pregnancy 53.4±5.6kg vs. 56.1±6.4kg, p=0.025). With respect to the macronutrients, protein intake (g) was found to correlate positively with FFM both in early and late gestation (r=0.31, p=0.002 and r=0.39, p<0.001 respectively). No other correlations were detected between body composition measures and intakes of other macronutrients, total energy intake or dietary quality (Supplementary table 1). Linear models examining the association of dietary quality and macronutrient intake (in grams) with change in body composition variables did not change these results (Supplementary table 2).

Table 3. Daily intakes of energy and macronutrients in early and late gestation.

	Early gestation	Late gestation		
	Mean ± SD	Mean ± SD	Mean change (95% CI)	P-value[a]
Energy, MJ	8.1 ± 2.0	8.3 ± 2.2	0.2 (-0.2, 0.6)	0.395
Carbohydrates, E%	46.7 ± 6.2	44.2 ± 7.1	-2.5 (-4.2, 0.8)	0.005
Carbohydrates, g	225.2 ± 71.4	217.8 ± 73.0	-7.3 (-23.1, 8.5)	0.362
Fat, E%	33.6 ± 6.3	36.3 ± 7.0	2.7 (1.1, 4.3)	0.001
Fat, g	73.9 ± 22.0	81.6 ± 25.9	7.7 (2.6, 12.9)	0.004
Protein, E%	17.4 ± 4.4	17.1 ± 3.6	-0.3 (-1.2, 0.6)	0.496
Protein, g	81.5 ± 21.8	82.0 ± 21.7	0.5 (-4.1, 5.1)	0.834

Data obtained from 3-day food diaries filled in by 99 women in both early and late gestation

CI = confidence interval, E% =Proportion of energy intake

[a] Paired Samples T-Test

The association of physical activity with body composition

Physical activity reduced significantly over the pregnancy: the median MET-index was 5.0 h/wk (2.0-12.0) in early gestation and 3.0 h/wk (0.2-11.0), $p<0.001$ at late gestation. No correlations were detected between physical activity or the change in physical activity and body composition measurements in either early or late gestation (data not shown). Linear model examining the relation of physical activity with change in body composition did not reveal significant associations (Supplementary table 2).

Differences in body composition and lifestyle between overweight and obese women

As shown in table 2, the obese women gained less weight than overweight women (p=0.011). This was attributable to a lower increase in their FM (p=0.002) whereas the gain of FFM did not differ between the groups (p=0.648). Consequently, obese women experienced a greater decrease in body fat percentage (p=0.001) over the follow-up period.

There were no significant differences in the total energy intake, dietary quality or physical activity between the overweight and obese subjects ($p> 0.125$ in all comparisons, Supplementary table 3). When intakes of macronutrients were compared, only the daily fat intake increased more between early and late gestation in obese than in overweight women (mean 14.5±27.3g vs. 3.9±25.3g, p=0.048).

There was no significant difference between overweight and obese women in the distribution into the inadequate, ideal or excess GWG class (p=0.207). The overweight women with excess weight gain acquired significantly more FM than obese women with excess weight gain (p=0.048), but there was no difference in the FFM gain (p=0.392). Consequently, in the women with excess weight gain, BF% decreased less in overweight women than in their obese counterparts (p=0.006).

Adherence to the weight gain recommendations

Most of the women, 77%, exceeded the recommended weight gain whilst 11% had an inadequate weight gain (table 4). Only women with excess GWG gained FM and the change in FM was significantly different between women with excess and ideal weight gain. Although women with excess GWG also gained more FFM, BF% decreased significantly less than in women with ideal GWG. The average daily fat intake, calculated as a mean fat intake in early and late gestation, was significantly higher in women with excess than ideal weight gain (80±21g vs. 67±11g, $p<0.010$), while no significant differences in the intakes of other macronutrients were found (data not shown).

Compared with women with the ideal weight gain, the women with inadequate weight gain lost significantly more FM, whilst no difference in the change of FFM was found (Table 4). When intakes of macronutrients were compared, only a lower intake in the average gestational carbohydrate intake as a percentage of energy intake (41.9±4.3 E% vs. 47.3±4.4 E% respectively, $p=0.018$) was detected in women with inadequate compared with ideal weight gain.

The energy intake, dietary quality or physical activity did not differ between the women with ideal, inadequate and excess weight gain ($p\geq0.092$ in all comparisons, Supplementary table 3).

Table 4. The change of weight and body composition in overweight and obese women with inadequate, ideal or excess GWG.

Adherence to GWG		Δweight	ΔFM		ΔFFM		ΔBF%	
recommendations	N (%)	Mean (kg) ±SD	Mean (kg) ±SD	P-value*	Mean (kg) ±SD	P-value*	Mean (%) ±SD	P-value[a]
All women n=110								
Inadequate	12 (10.9)	2.79 ±0.89	-3.44 ±1.92	0.042	6.23 ±2.03	0.996	-5.45 ±1.86	0.100
Ideal	13 (11.8)	4.95 ±1.27	-1.21 ±2.38		6.16 ±1.86		-3.70 ±2.19	
Excess	85 (77.3)	10.64 ±2.90	2.70 ±2.97	0.0001	7.94 ±1.92	0.015	-1.94 ±2.39	0.041
Overweight n=61								
Inadequate	5/61 (8.2)	2.73 ±1.11	-2.97 ±1.25	0.061	5.70 ±1.11	0.987	-5.40 ±1.07	0.175
Ideal	5/61 (8.2)	6.27 ±0.74	0.42 ±2.30		5.85 ±1.89		-2.72 ±2.61	
Excess	51/61 (83.6)	11.01 ±3.04	3.22 ±2.87	0.106	7.79 ±1.75	0.169	-1.37 ±2.40	0.551
Obese n=49								
Inadequate	7/49 (14.3)	2.83 ±0.79	-3.78 ±2.32	0.372	6.61 ±2.51	0.974	-5.49 ±2.36	0.549
Ideal	8/49 (16.3)	4.12 ±0.67	-2.23 ±1.91		6.35 ±1.95		-4.31 ±1.78	
Excess	34/49 (69.4)	10.08 ±2.64	1.92 ±2.99	0.0004	8.16 ±2.16	0.094	-2.80 ±2.13	0.135

[a] Inadequate and excess weight gains are compared to ideal weight gain (one-way ANOVA with Games-Howell post-hoc tests)

Women were divided into different GWG classes according to the recommendations issued by Institute of Medicine[15]

DISCUSSION

We demonstrated here that the good overall dietary quality and protein intake in grams were positively associated with FFM in early and late pregnancy. Most overweight and obese women exceeded gestational weekly weight gain recommendations, which led to an increase in body FM and was also reflected in BF%. The most important macronutrient determinant of excess GWG was fat intake. These results suggest that health counselling of overweight and obese pregnant women should focus on optimizing their weight gain by improving the overall quality of diet and favoring a proportional increment of protein intake instead of augmenting fat intake during gestation. The subsequent benefits may be seen in maternal body composition and further in improved maternal and child health.

Our results indicate, that among the overweight and obese pregnant women, the majority of weight gain is FFM and only women exceeding the recommendations of GWG gain overall FM, which is in line with a previous report with a similar setting[21]. Other studies also confirm the association of excess GWG with the FM accrual[22,23]. However, in our study, recommendations of GWG rate were exceeded even more frequently than previously reported for total GWG among overweight and obese women (77% vs. 41-45%) [21,24]. Some observational studies[25,26] have suggested that a higher energy intake is associated with higher GWG, but studies are inconsistent[27]. According to our results, the increment in adiposity was not explained by the energy intake or physical activity per se. Even after adjustments for possible confounding factors in the linear model, no significant associations between gain of FM and several life style variables were found. In previous reports[15,24,28] as well as in the present study, it has been revealed that both GWG and increase in FM are inversely proportional to pre-pregnancy BMI.

All things considered, energy intake and physical activity do not seem to account wholly for gestational FM accrual or differences in FM gain between women with excess and ideal GWG or overweight and obese women. Several mechanisms have been proposed to explain these phenomena. Firstly, despite the lack of correlation with maternal body composition, physical activity was strongly reduced during pregnancy, as reported also by others[29,30]. In the third trimester, the reduction in physical activity can account for nearly half of the estimated additional energy needs of pregnancy, at least in normal weight women[31]. Secondly, differences in macronutrient intakes or in the hormonal milieu could exert some influence[32]. In our study, women increased their fat intake, and those with excess GWG were found to have significantly higher average fat consumption than women experiencing an ideal GWG. Reports in the literature are inconsistent regarding the relation of fat intake and GWG[27], but some studies suggest that there is an association, at least among overweight women[25,33]. Thirdly, presumably heavier women need more energy to support their increased metabolic size. Additionally, it has been suggested that cumulative increases in basal metabolic rate are significantly correlated with pre-pregnancy FM, indicating that fatter women display the energy-profligate response. This indicates that the obese women waste energy in pregnancy by increasing their basal metabolic rate, resulting in less FM gain than non-obese women[34-36]. This could explain our finding with less FM accrual in obese compared to overweight women despite their similar lifestyles. Finally, it has been postulated that pregnancy alters homeostatic mechanisms, allowing for a more efficient storage of fat. The proposed mechanism is pregnancy-induced alterations in gut microbiota allowing for highly efficient energy extraction from the diet without major changes in energy intake or energy expenditure[37-39]. All in all, it is apparent that there are several complex mechanisms behind GWG and FM accrual and these mechanisms are probably dependent on pre-gestational fat stores or some other unknown factors.

Based on the gestational dietary reference intakes issued by the IOM[40], it is evident that fat intake increased above the recommendations during the study. At the same time, protein intake remained constant and at a sufficient, but not a particularly high, level. During pregnancy, the average protein requirement increases to provide additional amino acids for protein synthesis in maternal, fetal, and placental tissues. Protein intake correlated with FFM both in early and late gestation, which is logical since FFM consists mainly of water and protein[41,42]. Favoring protein intake over augmenting fat consumption could be beneficial in reducing body adiposity also during pregnancy, since FFM is the main determinant of basal metabolic rate, which in turn, is an essential component of total energy expenditure[43-45]. Protein intake has been suggested to decrease GWG as a result of higher energy expenditure because the thermogenesis of protein is larger than that of carbohydrate or fat[46,47]. Furthermore, a higher protein intake might also increase satiety and appears to be safe during pregnancy[48,49]. These adjustments to the diet are already possible within current nutritional recommendations[40], and thus may be implemented by counseling the pregnant women.

The strength of this study was that this was a prospective study in a well-controlled setting with a large sample size compared to most earlier studies involving air displacement plethysmography measurements during pregnancy[9,21,50]. As is the case with other techniques, body composition measurements with air displacement plethysmography do not distinguish fetal from maternal tissues. This can affect the results, since fetal growth is heterogenous particularly in late pregnancy and, also the amount of amniotic fluid and size of the placenta varies. Nevertheless, ADP has been found a valid method to measure adiposity in overweight and obese non-pregnant women[51], and it has also been suggested to be the preferred method for assessing maternal FM in late pregnancy[9].

There was minimal previous knowledge regarding the effects of lifestyle on gestational body composition of women in different BMI categories. Therefore, new information applicable for use in interpreting gestational body composition was generated in this study. However, we acknowledge that there are some limitations. The time of enrollment to the study varied somewhat (between 7 and 17 gestational weeks) and although we adjusted all correlations to gestational weeks, some comparisons could have been affected by this. Some concern has also been raised about the reliability of self-reported food diaries and questionnaires regarding lifestyle[52]. However, the longitudinal design of the study with the same study personnel and the carefully collected data should increase the reliability. In this study, we analyzed GWG rate instead of the whole gestational weight gain and although this is an accurate method and in accordance to the IOM guidelines, this can influence the comparisons with the other studies conducted in different methods. Also, diet and physical activity were evaluated only twice during the pregnancy and this could be a study limitation; more frequent exploration could improve the accuracy in evaluating the associations with the body composition, although, the compliance in recordings could also be hampered.

Finally, although the participants in this study took part in an intervention study, the impact of the intervention was not the focus in this sub-study. Therefore, to avoid bias caused by intervention, we adjusted appropriate analyses for intervention group. Women in all intervention groups consumed dietary supplements or placebo thus it is unlikely that this has induced any changes in behavior, although it must be acknowledged as a potential study limitation.

In conclusion, dietary intake seems to influence body composition in pregnant women: we found that both higher protein intake and dietary quality were positively associated with FFM. Excess GWG and the related increase in FM were found in most overweight and obese women. Thus, we would like to emphasize that overall good dietary quality and GWG according to the recommendations could exert positive effects on body composition, and again may induce health benefits in both mother and child.

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Authors contributions

All the authors have approved and made substantial contributions to the final version of the paper. The study was designed and interpreted by K.L., O.P., T.R. and K.T. Acquisition of data and analysis of food diaries were carried by E.K. and K.M. Statistical analysis and analysis of data were performed by T.V. and O.P. The manuscript was drafted by O.P. and all the other authors revised it critically.

Conflict of interest

The authors declare no conflict of interest.

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Supplementary table 1. The adjusted correlation coefficients* between energy intake, macronutrients and body composition variables.

	Early gestation						Late gestation						Change					
	FM (kg)		FFM (kg)		BF%		FM (kg)		FFM (kg)		BF%		FM (kg)		FFM (kg)		BF%	
	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p
Early gestation																		
Energy (kJ)	0.029	0.775	0.242	0.015	-0.103	0.304	0.004	0.971	0.243	0.015	-0.099	0.326	-0.036	0.724	0.095	0.349	-0.009	0.927
Fat (g)	0.106	0.289	0.157	0.118	0.030	0.766	0.109	0.280	0.139	0.168	0.075	0.459	0.049	0.627	0.018	0.857	0.070	0.487
Protein (g)	-0.082	0.414	0.308	0.002	-0.307	0.002	-0.085	0.398	0.293	0.003	-0.287	0.004	-0.044	0.667	0.056	0.582	0.001	0.994
Carbohydrates (g)	0.010	0.922	0.197	0.048	-0.089	0.378	-0.033	0.747	0.218	0.029	-0.118	0.241	-0.075	0.458	0.130	0.198	-0.061	0.544
Late gestation																		
Energy (kJ)							0.114	0.256	0.241	0.015	0.001	0.992	0.094	0.353	0.136	0.179	0.066	0.513
Fat (g)							0.112	0.223	0.207	0.038	0.032	0.753	0.068	0.501	0.072	0.478	0.064	0.528
Protein (g)							0.004	0.966	0.393	<0.0001	-0.186	0.062	-0.001	0.991	0.197	0.050	-0.031	0.756
Carbohydrates (g)							0.105	0.296	0.128	0.200	0.043	0.671	0.116	0.249	0.112	0.269	0.082	0.418
Change																		
Energy (kJ)							0.174	0.092	-0.037	0.721	0.164	0.113	0.157	0.126	0.043	0.678	0.095	0.359
Fat (g)							0.084	0.415	0.016	0.878	0.052	0.617	0.061	0.556	0.068	0.509	0.012	0.908
Protein (g)							0.151	0.142	0.053	0.606	0.139	0.176	0.072	0.486	0.141	0.170	-0.009	0.932
Carbohydrates (g)							0.195	0.057	-0.102	0.322	0.205	0.045	0.209	0.040	0.010	0.926	0.150	0.142

*Pearson's partial correlation coefficients adjusted for prepregnancy BMI and gestational weeks and/or change in gestational weeks between early and late gestation.

Early and late gestation visits were conducted at mean 13.5 and 35.3 gestational weeks respectively.

FM= fat mass, FM= fat free mass, BF%= body fat percentage

Supplementary table 2. Linear models presenting the effects of physical activity, diet quality and macronutrient intake on change of body composition variables.

	ΔFM			ΔFFM			ΔBF%		
	β	95% CI	p	β	95% CI	p	β	95% CI	p
Physical activity (MET-index)	-0.013	-0.082;0.056	0.70	0.014	-0.027;0.055	0.49	-0.019	-0.066;0.029	0.44
Diet quality (IDQ-index)	-0.309	-0.662;0.043	0.13	-0.014	-0.224;0.196	0.89	-0.184	-0.428;0.060	0.14
Protein intake (g)	0.002	-0.035;0.039	0.92	-0.005	-0.027;0.017	0.64	-0.002	-0.028;0.024	0.89
Carbohydrate intake (g)	-0.008	-0.020;0.004	0.19	0.006	-0.001;0.014	0.08	-0.006	-0.014;0.002	0.15
Fat intake (g)	0.023	-0.014;0.061	0.22	-0.011	-0.033;0.011	0.31	0.019	-0.006;0.045	0.14

A separate linear model analysis has been performed for each body composition variable.

The models are adjusted for intervention group, age, height, gestational weeks at enrollment and each body composition variable in early gestation.

ΔFM= change in fat mass

ΔFFM= change in fat free mass

ΔBF%= change in body fat percentage

CI= confidence interval

Supplementary table 3. Total energy intake, diet quality and physical activity of women with inadequate, ideal or excess gestational weight gain and women with BMI classified as overweight or obese.

	Gestational weight gain				BMI classification		
	Inadequate	Ideal	Excess		overweight	obese	
Energy intake (kJ)	n=11	n=12	n=76	p[a]	n=57	n=42	p[b]
-early gestation	7780 ± 1530	7460 ± 2160	8280 ± 2030	0.347	8070 ± 1840	8210 ± 2220	0.727
-late gestation	7340 ± 1760	7560 ± 1600	8570 ± 2250	0.092	8010 ± 1800	8730 ± 2560	0.125
-change	-440 ± 1430	100 ± 2750	290 ± 2140	0.575	-60 ± 2000	510 ± 2330	0.194
Diet quality (IDQ)	n=11	n=13	n=83	p[a]	n=59	n=48	p[b]
-early gestation	10.2 ± 1.6	9.2 ± 1.6	9.8 ± 2.2	0.486	9.9 ± 2.0	9.6 ± 2.1	0.508
-late gestation	10.2 ± 1.4	9.4 ±2.3	9.8 ± 2.3	0.649	10.0 ± 2.2	9.7 ± 2.2	0.514
-change	-0.0 ± 1.5	0.2 ± 1.9	0.0 ± 1.3	0.933	0.0 ± 1.4	0.0 ± 1.5	0.966
Physical activity (MET-index)	n=10	n=13	n=84	p[c]	n=60	n=47	p[d]
-early gestation	7.8 (4.4-16.8)	4.8 (2.1-12.0)	4.9 (1.9-12.0)	0.615	6.3 (3.0-12.0)	4.8 (1.2-12.0)	0.583
-late gestation	4.5 (0.0-12.0)	4.8 (0.1-12.0)	3.0 (0.2-7.5)	0.930	3.0 (0.1-7.5)	1.3 (0.2-12.0)	0.771
-change	-4.7 (-14.8-3.0)	0.0 (-3.7-0.0)	-1.5 (-5.0-0.0)	0.622	-1.8 (-4.7-0.0)	-0.3 (-7.5-0.0)	0.700

Numbers are expressed as mean ± sd or median (interquartile range)

[a]One-Way ANOVA, [b]Independent Samples T-test, [c]Kruskal-Wallis, [d]Mann Whitney

Early and late gestation visits were conducted at mean 13.5 and 35.3 gestational weeks respectively.

Overweight BMI 25-29.9 kg m^{-2}, Obese BMI ≥ 30.0 kg m^{-2}

IDQ= index of diet quality

Women were divided into different GWG classes according to the recommendations issued by Institute of Medicine[15]