Macronutrient composition and food groups associated with gestational weight gain: the GUSTO study

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Abstract

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Purpose—To examine the associations of energy, macronutrient and food intakes with GWG on 960 pregnant women from the Growing Up in Singapore Towards healthy Outcomes (GUSTO) mother-offspring cohort.

Methods—Dietary intake was assessed at 26–28 weeks' gestation with a 24-hour recall and 3-day food diary. GWG z-scores were calculated from first (4-13 weeks' gestation) and last (30-40 weeks gestation) measured weights; inadequate and excessive GWG were defined using the Institute of Medicine recommendations based on weights between 15 and 35 weeks' gestation. Associations were examined using substitution models for macronutrient composition, with linear or multinomial logistic regressions.

Results—Mean±SD daily energy intake was 1868±598 kcal, and percentage energy intakes were 51.8±8.9% from carbohydrate, 15.7±3.9% from protein and 32.6±7.7% from fat. Higher energy intake (per 500kcal increment) was associated with 0.18 SD higher GWG. In isocaloric diets, higher-carbohydrate and lower-fat intakes (at 5% energy substitution) were associated with 0.07 SD higher GWG, and 14% higher likelihood of excessive GWG. Concordantly, the highest tertile of carbohydrate-rich foods intake was associated with 0.20 SD higher GWG, but the highest tertile of fruit and vegetable intake was independently associated with 40% lower likelihood of inadequate GWG. Additionally, the highest tertile of dairy intake was associated with 0.18 SD lower GWG; and the highest tertile of plant-based protein foods intake was associated with 60% and 34% lower likelihood of inadequate and excessive GWG.

Conclusions—Balancing the proportions of carbohydrates and fat, and a higher intake of plant-based protein foods may be beneficial for achieving optimal GWG.

Introduction

The associations of inadequate or excessive gestational weight gain (GWG) with adverse pregnancy and child health outcomes are well-documented [1]. Inadequate GWG increases the risks of preterm birth and delivering small-for-gestational-age babies, whereas excessive GWG increases risks of gestational diabetes and caesarean delivery in mothers [1], and increases the offspring's risks of obesity, insulin resistance and cardiovascular diseases in later life [2]. Despite this, approximately 20-30% of women do not gain enough weight, while another 30-50% of women gain excessive weight during pregnancy with a disproportionately higher prevalence of excessive weight gain in women with overweight or obesity [3–5] suggesting a need for effective dietary strategies to manage gestational weight gain, and specifically targeting overweight and obese women.

Human metabolic studies have demonstrated that macronutrient composition plays an important role in weight gain by influencing satiation and thermogenesis [6,7]. For example, carbohydrates are known to be less satiating [7] and produce a smaller thermogenic response than protein [6], thus a high-carbohydrate, low-protein diet may induce excessive energy intake. A recent systematic review of intervention and observational studies examining macronutrient composition and GWG revealed that while energy intake was associated with

GWG, the evidence relating macronutrient composition to GWG was less consistent [8]. The overall quality of the included studies was low, with many not adjusting for energy intake and important confounding variables such as pre-pregnancy BMI and physical activity during pregnancy, and failing to account for the inter-relationships among macronutrients.

It is important to investigate the effects of different food components on GWG because individuals consume a combination of foods rather than individual nutrients. Yet, studies examining the types of foods consumed during pregnancy and their influence on GWG are scarce and existing results are conflicting. Furthermore, the food groups examined vary for each study with minimal overlap, making it difficult to conclude which food components are beneficial for adequate GWG. Evidence from observational studies on fried food [9,10] and sugar-sweetened beverages [11,12] are generally in line, showing higher intakes to be associated with greater weight gain or higher risks of excessive GWG. Observational findings on milk/dairy, fish, fruit and vegetables, and red meat in relation to GWG are less consistent [11,13,10]. One intervention study found dietary counseling (to reduce intakes of fast food and sweets and increase intakes of fruit, low-fat dairy and whole-wheat grains) to have no effect on GWG [14], likely due to poor compliance – a limitation inherent to intervention study [15]. Findings from cohort studies may help address this limitation by comparing usual healthy or unhealthy eating patterns. No studies to date have examined food group intakes and GWG in Asian populations, who have different food and beverage intake patterns to their Western counterparts, and thus may have different associations with GWG.

In view of the inconsistent study findings, the limitations of existing studies on macronutrient composition and the lack of Asian studies examining food groups, our study aims to address these research gaps in a multi-ethnic Asian population by 1) examining the associations of energy and macronutrient intakes during pregnancy with GWG with the use of substitution models, and 2) examining the associations between different food groups and GWG.

Subjects and Methods

Subjects

Data for the present analysis were drawn from the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study, a prospective mother-offspring cohort study in Singapore [16]. This study monitored the health and mental wellbeing of mothers and growth of their offspring during the antenatal period until the children reach nine years of age. Detailed descriptions of the GUSTO study have been published previously [17,16]. In brief, a total of 1247 pregnant women in their first trimester (<14 weeks) were recruited from KK Women's and Children's Hospital (KKH) or National University Hospital (NUH) between June 2009 and September 2010. To be eligible for the study, potential participants had to 1) be Singapore citizens or permanent residents of Chinese, Malay or Indian ethnicity with homogenous parental ethnic background; 2) have the intention to reside in Singapore for the next 5 years; 3) agree to donate birth tissues at delivery; and 4) not be receiving chemotherapy, psychotropic drugs or having type 1 diabetes mellitus. The GUSTO study has

received ethical approval from the Institutional Review Board of KKH and NUH. Written informed consent was obtained before participants were enrolled in the study.

Of the 1247 pregnant women initially recruited, our sample consists of the 960 participants who conceived naturally with singleton pregnancies and provided data on dietary intake during pregnancy, height, reported pre-pregnancy weight, and had weight measurements recorded at their first antenatal appointment, at week 15 and week 35 of gestation, and before delivery. We excluded 287 participants who did not meet these criteria (Figure 1). Those excluded from analyses tended to be younger (mean ± SD: 29.4 ± 5.4 vs 30.5 ± 5.1), of lower educational level (46.2% vs 29.5% attained secondary education or less) and had lower household incomes (28.9% vs 14.2% received less than $2000 household monthly income), compared to those included.

Dietary intake

Maternal dietary intake was assessed at 26-28 weeks' gestation using a single 24-hour recall and a 3-day food diary. The 24-hour recall was administered by trained clinical staff on a weekday or weekend day using the 5-stage, multiple-pass interviewing technique [18]. Standard household measuring utensils and food pictures of various portion sizes were presented to assist participants in quantifying their food and beverage intakes. Participants were then given the 3-day food diary (2 weekdays and 1 weekend day) to complete at home with clear instructions from the clinical staff. Completed diaries were collected at the next clinic visit. All participants completed the 24-hour recall, while only a subset (n=193) completed the 3-day food diary. Both methods of dietary assessments were completed on separate occasions. Due to the small number of participants having completed 3-day food diary, the main analyses were based on dietary intakes estimated from the 24-hour recall and subgroup analyses were based on dietary intakes estimated from 24-hour recall and 3-day food diary (refer to Statistical Analysis)

Nutrient intakes were estimated using nutrient analysis software (Dietplan, Forestfield Software, UK) based on a food composition database containing local foods with slight modifications to correct for inaccuracies. For local dishes not found in the food composition database, their nutrient compositions were calculated based on nutrition values of the ingredients from generic recipes. For individual food items not found in the database, nutrient information was obtained from either food labels or the US Department of Agriculture nutrient database (for food products commonly imported from the Western countries) [19].

Additionally, food and beverage items with similar nutrient composition and common culinary uses were combined to produce 68 sub-groups of food, which were further grouped into 8 major food groups *a priori*: animal-based protein foods (e.g. poultry, meat and fish), plant-based protein foods (e.g. legumes and nuts), fruit and vegetables, grains (e.g. bread, rice and noodles), dairy products (e.g. milk, yoghurt and cheese), fast foods and savoury snacks (e.g. burger, pizza and hot chips), desserts and sweet snacks (e.g. pastries, cakes and biscuits), and sugar-sweetened beverages (e.g. carbonated drinks, fruit juices and cordials) (Supplemental Table 1, Online Resource).

Gestational Weight Gain

Serial pregnancy weight measurements with the corresponding gestational age and date were extracted from clinical obstetric records by clinically trained midwives at various time points throughout pregnancy.

GWG z-score was calculated for each participant using the formula z = (observed weight gain - mean)/SD provided by Hutcheon *et al* [20]. Each participant's observed weight gain was defined as the difference between the weight measured at time of delivery and the weight measured at first antenatal visit, which was first natural-log transformed before substituting into the formula. Gestational-age-specific means and SDs (natural-log transformed) of the reference population were also obtained from the chart provided by Hutcheon *et al* [20], and then entered into the formula. Compared to conventional measures of GWG, the use of GWG z-score is advantageous as it is standardized for gestational age [20]. This is particularly useful in our cohort as there were large variations in timings of the weight measured at first antenatal appointment (between 4-13 weeks' gestation) and the weight measured at the time of delivery (between 30-40 weeks' gestation).

Additionally, participants were classified into groups of inadequate, adequate and excessive weight gain based on the Institute of Medicine (IOM) recommended rate of weight gain (kg/week) in the second and third trimesters according to pre-pregnancy BMI category [1]. Pre-pregnancy BMI (kg/m^2) were based on self-reported pre-pregnancy weights collected during recruitment, and height measured with a stadiometer (SECA model 213) at the 26-28 weeks' gestation follow-up visit. To compute rate of weight gain, linear mixed-effects model with the Best Linear Unbiased Predictor was used to estimate linear trajectory of GWG per week [21], using weight measurements recorded at multiple time points (2 time points) between 15 to 35 weeks' gestation for each individual. Inadequate weight gain was defined as a weight gain rate less than the recommended lower limit; whereas excessive weight gain was defined as a weight gain rate greater than the recommended upper limit. To minimize self-reporting bias, pre-pregnancy weights were not used in the estimation of weight gain rate.

Co-variates

Potential confounding variables were identified *a priori* from previous studies [22,13,23,9,10]. Information on maternal age, ethnicity (Chinese, Malay, Indian), highest education level (secondary or lower, technical college/GCE "A" levels, University), monthly household income ($<1999, $2000-5999, $>6000) and parity (0, 1) were obtained at study recruitment. Participants returned for a follow-up visit at 26–28 weeks' gestation, during which self-reported physical activity (defined as minutes of metabolic equivalents of task (MET.mins), alcohol consumption, and cigarette smoking habits during pregnancy were ascertained. Oral glucose tolerance tests were performed at the same clinic visit to determine if participants developed gestational diabetes mellitus (GDM) based on the 1999 WHO criteria [24].

Statistical analysis

Energy (per 500kcal increment) and macronutrient intakes were treated as continuous variables. Macronutrient intakes were adjusted for energy intake using the nutrient density

method, and expressed per 5% increment in energy intake. Food group intakes were divided into tertiles. A large proportion of participants reported not consuming food items in the following food groups: plant-based protein foods, dairy, fast foods and savoury snacks, desserts and sweet snacks, and sugar-sweetened beverages. Hence, for these food groups, participants with no intake were allocated into Tertile 1, and the remaining participants were allocated into Tertiles 2 and 3 with approximately the same number per tertile. For all analyses, they were entered into the statistical models as tertiles (using the lowest tertile as reference) and as ordinal variables (tests of linear trend across tertiles).

Participant characteristics, nutrients and food groups intakes according to GWG status were compared using χ^2 test for categorical variables, oneway ANOVA (for continuous variable with normal distribution) or Kruskal-Wallis (for continuous variable with skewed distribution) tests. For significant ANOVA or Kruskal-Wallis test results, *post hoc* analysis with Bonferroni correction was carried out to identify the group(s) which differed.

Multinomial logistic regression was used to examine the associations between dietary intake and the polytomous GWG status (inadequate, adequate and excessive) with adequate GWG as reference, while linear regression was used to examine associations with GWG z-scores. For analysis of macronutrient composition, substitution models [25] were used to evaluate the effects of one macronutrient relative to another in isocaloric diets (total energy held constant). Carbohydrate was entered into the model together with protein and total energy intake (Model 1) such that an increase in percentage of energy intake from carbohydrate is accompanied by a decrease in percentage energy intake from fat. The effect estimate can be interpreted as the effect of increasing carbohydrate intake at the expense of fat, while keeping total energy constant. Likewise, the effect of increasing carbohydrate intake at the expense of protein (including carbohydrate, fat and energy intakes in the model), and the effect of increasing protein intake at the expense of fat (including protein, carbohydrate and energy intakes in the model) in isocaloric diets were examined. The substitution models then included adjustment for maternal age, ethnicity, education, income, physical activity, alcohol consumption, smoking, parity and GDM status (Model 2). The models examining associations with GWG z-scores included an additional adjustment for pre-pregnancy BMI. For analysis of food groups, an unadjusted model was first created for each food group (Unadjusted); then included adjustment for maternal energy intake and confounders as per Model 2 above.

In order to test the robustness of main analyses findings, subgroup analyses were performed combining data from the 24-hour recall and 3-day food diary using the Multiple Source Method (MSM) [26], in the subset of participants who has completed both dietary assessments (*n*=193). The MSM provides an estimation of usual dietary intake combining data from multiple short-term dietary assessments and consumption frequency information. As there was no consumption frequency information available, a few *a priori* assumptions were made: (1) all individuals have frequent consumption of energy, macronutrients, and core food groups (i.e. animal-based protein foods, fruit and vegetables, grains and dairy products) based on a reported intake in 24-hour recall and 3-day food diary; (2) assume 50% of individuals not reporting an intake in the 24-hour recall and 3-day food diary (e.g. fast

foods and savoury snacks, desserts and sweet snacks, and sugar-sweetened beverages) will consume during other periods not captured by both dietary assessments.

Upon observing significant associations of higher-carbohydrate, lower-fat intakes with higher GWG z-scores and higher likelihood of excessive GWG, an *ad hoc* analysis was conducted to examine associations of 'carbohydrate-rich foods' intake (grains, desserts and sweet snacks, and sugar-sweetened beverages) with GWG status and z-scores, to determine whether the quality of carbohydrate play a role in GWG.

The IOM recommendations for GWG were based on World Health Organization's international BMI classification rather than classifications applicable to Asian populations [40] and may result in misclassification bias. As such, we further performed a sensitivity analysis using GWG status classified according to Asian BMI cut-offs.

Missing data were imputed 20 times using multiple imputation technique with chained equations (20 times) for the following confounding variables: *n*=32 education, *n*=50 income, *n*=72 physical activity, *n*=23 alcohol consumption and *n*=59 GDM. The results of the 20 analyses were pooled using the Rubin's rule [27]. All analyses were conducted using Stata version 14 (StataCorp LP, College Station, TX, USA). Two sided *P*-values<0.05 were accepted as statistically significant.

Results

Participant characteristics

Approximately 12% of participants had inadequate GWG and 64% had excessive GWG. Women with inadequate GWG were more likely to be Indian and have GDM, less likely to be overweight or obese, and had the highest physical activity level (Table 1). These women also had the lowest energy and fruit and vegetables intakes, consumed less grains compared to those with excessive GWG, and least likely to consume plant-based protein foods. Women with excessive GWG were more likely to be Malay and to be overweight or obese, less likely to have GDM, and had the lowest physical activity level. Additionally, these women had the highest energy and grains intakes, consumed more fruit and vegetables compared to those with inadequate GWG, and tended to consume less plant-based protein foods than those with adequate GWG but more than those with inadequate GWG.

Associations of energy and macronutrients intakes with GWG z-scores and status

A higher energy intake (per 500kcal increment) was associated with 0.18 SD higher GWG after adjusting for confounders (95% CI: 0.13, 0.23) (Table 2). Higher-carbohydrate, lower-fat intakes (per 5% energy substitution) in isocaloric diets were associated with 0.07 SD higher GWG (Table 2), and a 14% higher likelihood of excessive GWG in the adjusted models (Table 3). There was a weak trend towards higher-protein, lower-fat intakes and higher GWG z-scores in the adjusted model (95% CI: -0.01, 0.19) (Table 2). No significant associations were observed between a higher-carbohydrate and lower-protein intake and GWG status or z-score.

Associations of food group intakes with GWG z-scores and status

Individual carbohydrate-rich food groups such as grains, desserts and sweet snacks, and sugar-sweetened beverages did not show any independent association with GWG z-scores after adjustment for confounders. When combined together as a single food group – 'Carbohydrate-rich foods', we found an association between higher intakes of this food group and higher GWG z-scores (a 0.20 SD higher GWG in T3 compared to T1, 95% CI: 0.03, 0.37) even after adjusting for energy intake and other confounders (Table 2). Additionally, higher intakes of dairy products was associated with lower GWG (0.18 SD lower in T3 compared to T1, 95% CI: -0.34, -0.03) in the adjusted model (Table 2). No significant associations were observed for other food groups with GWG z-scores after adjustment for confounders.

When examining associations with GWG status, it was observed that higher intakes of plant-based protein foods were associated with lower likelihood of inadequate GWG (60% lower risk in T3 compared to T1, 95% CI: 0.22, 0.75) as well as lower likelihood of excessive GWG (34% lower risk in T3 compared to T1, 95% CI: 0.46, 0.94) after adjustment for confounders (Table 3). Additionally, higher fruit and vegetable intakes were associated with a lower likelihood of inadequate GWG (60% lower risk in T3 compared to T1, 95% CI: 0.22, 0.73).

Higher intakes of animal-based protein foods, and fast food and savoury snacks were independently associated with higher GWG z-scores or higher likelihood of excessive GWG in the unadjusted model (*P*-trends<0.05); these associations were attenuated after adjusting for confounders especially energy intake (Tables 2 and 3).

Subgroup and sensitivity analyses

Results were consistent in the subgroup analysis with GWG z-scores when employing the MSM method (Supplemental Table 2, Online Resource). We further observed higher intakes of fruit and vegetables, and sugar-sweetened beverages to be significantly associated with higher GWG z-scores after adjustment for confounders. Although significance was lost for the association between dairy products and GWG z-scores, the study estimates remained in the same direction.

Similarly, we observed consistent results in the subgroup analysis with GWG status (Supplemental Table 3, Online Resource). The significant associations of a higher-carbohydrate and lower-fat intake, and of a higher intake of plant-based protein foods, with GWG status were not statistically significant in the subgroup analysis but the study estimates remained in the same direction.

Similar study estimates and significance levels were observed when the main analyses were repeated using GWG status classified according to Asian BMI cut-offs (data not shown).

Discussion

In this study, higher energy intake during pregnancy was associated with higher GWG z-scores. When assessed under isocaloric conditions, higher-carbohydrate and lower-fat

intakes were significantly associated with higher GWG z-scores and a higher likelihood of excessive GWG statistically, suggesting that dietary macronutrient composition may influence GWG. This finding is consistent with those from the food group analyses, whereby the combined sum of all carbohydrate-rich foods (desserts and sweet snacks, sugar sweetened beverages, grains, fruit and vegetables) in the diet was associated with higher GWG z-scores. Additionally, we found higher intakes of dairy products to associate with lower GWG z-scores, and plant-based protein foods to associate with achieving optimal weight gain during pregnancy.

Our findings support current literature that higher energy intake during pregnancy is associated with greater absolute weight gain or a higher risk of excessive GWG [8]. Likewise, we consistently observed energy intake to be the main determinant of GWG in our food group analyses. Although we found higher intake of fast food and savoury snacks, desserts and sweet snacks, and sugar-sweetened beverages (energy-dense foods) to be associated with higher GWG or higher excessive GWG; these were attenuated with adjustment for energy intake indicating that energy intake is the main driver of these associations. Two previous studies in pregnant women also found an attenuation in association between higher intake of fried food and higher GWG and higher odds of excessive GWG after adjustment for energy intake [9,10].

Of note in this study is the significant association of carbohydrate-fat substitution model with higher GWG z-scores. Whilst a recent systematic review showed no consistent directionality of associations between carbohydrate intake and GWG in the 18 observational studies reviewed [8], it is important to highlight that most of these studies focused on single macronutrient rather than combining different macronutrients in one statistical model, which failed to consider that the effects of one macronutrient may be explained by the other nutrient it replaces in an iso-caloric model [25]. For studies that used the substitution model, one showed increasing mono-unsaturated fat at the expense of carbohydrate intakes to be associated with lower risk of excessive GWG [10]; but another found no significant association with rate of GWG when substituting carbohydrates for fats [28] possibly due to the study population being from a developing country with different sociodemographic and nutritional status to our cohort.

Furthermore, our observation of higher fruit and vegetable intakes associating with lower risks of inadequate GWG, suggest potential role of carbohydrate quality in adequate weight gain during pregnancy. Carbohydrate sources with lower glycemic index (GI) and higher fiber content such as fruit and vegetables contribute to lower energy density [29], and increased satiety by increasing gastrointestinal transit time [29,30]; thereby producing a reduction in *ad libitum* energy intake. In contrast, carbohydrate foods higher in added sugars (e.g. desserts, sweet snacks and sugar-sweetened beverages) or refined grains tend to be high in energy density [31]; thus contributing to passive over-consumption. This is supported by our finding of a significant positive association between 'carbohydrate-rich foods' and GWG z-scores.

Similarly, we found evidence that the source of protein is important in achieving optimal weight gain during pregnancy. We observed a higher intake of plant-based protein food to be

related to a lower likelihood of excessive GWG as well as a lower likelihood of inadequate GWG. The relatively low energy density [32], high fiber [29], and high micronutrients content [33] of these foods, which have been shown to play important roles in appetite regulation, metabolism and tissue maintenance, may explain the association observed with optimal weight gain. Furthermore, higher intake of dairy products was found to associate with lower GWG z-scores. The beneficial association observed may be attributable to the high content of calcium which has been shown to influence energy metabolism by stimulating lipolysis and inhibits fatty acid synthesis [34], and conjugated linoleic acid which has been shown to reduce body fat and increase lean muscle mass [35,36]. This contrasted findings from three other studies in pregnant women [10,37,38], but direct comparison of study findings was difficult due to methodological differences such as definitions of dietary exposure and GWG.

This study has several strengths. To the best of our knowledge, we are the first to use z-scores for the investigation of maternal dietary intake and GWG, which is a method of estimating weight gain independent of gestational age [20], thus allowing the use of weights measured at different time-points of pregnancy to more clearly reflect total GWG. In using macronutrient substitution model, we were able to show that GWG increases when carbohydrate intake replaces fat intake which many previous studies have not been able to elucidate [8]. The additional analysis of food groups intakes with GWG allowed findings on diet and GWG relationships to be more holistically interpreted.

Several limitations must be noted. Dietary intake was assessed mid-to-late pregnancy, while GWG captures weight gain from early to late pregnancy, thus the temporality of the associations observed remains questionable. There is, however, evidence to suggest that average intake of food and energy-adjusted nutrients did not change appreciably (<5%) from the 1st to 2nd trimester [39]. The use of the MSM approach in an attempt to improve estimation of usual dietary intake, however, was limited by the lack of consumption frequency information, and we had to make several assumptions. This may have biased the estimation of dietary intake, leading to slight discrepancies in results between the main and subgroup analysis, but it is important to note that the directions of the associations remained the same. We are limited to using IOM recommendations for GWG status because cut-off points for GWG z-scores have not been established, thus remains biased by gestational age. We therefore only used the recommendation for rate of weight gain in the second and third trimesters instead of recommendation for total weight gain. There remains the possibility of misclassification bias of GWG status using pre-pregnancy BMI category based on self-reported pre-pregnancy weight and the use of World Health Organization's international BMI classification rather than those applicable to Asian populations [40]. However, misclassification bias is likely to be minimal as we found a strong correlation in BMI (r=0.97) and a strong agreement in BMI categories (kappa=0.72) pre-pregnancy and during first trimester, and results from our sensitivity analysis provided similar study estimates to the main analyses. Furthermore, the recommended weight gain ranges were largely based upon studies of Caucasian women and may not be applicable to Asian populations; however, the lack of Asian studies for appropriate weight gain precluded the use of a regional- or country-specific GWG guideline. Lastly, as in all observational studies, residual confounding is likely to exist.

In conclusion, we found energy intake to be the main determinant of GWG, but effective dietary strategies on how to practically achieve energy balance rather than just advising to eat less are needed to effect a change. This study presents evidence suggesting that balancing the proportion of carbohydrate and fat intakes and improving the quality of carbohydrate and protein can potentially contribute to achieving optimal GWG. These findings are in line with current recommendations to consume higher amounts of wholegrains, fruit and vegetables and lean protein, and lower amounts of foods with added sugars for better health outcomes for the mother and infant; although further evidence are needed to support recommendations to reduce carbohydrate intake on the basis of sugar, fiber and GI and increasing plant-based protein for optimal GWG. The prevalence of excessive GWG in our cohort is alarmingly high; it is thus important to provide specific dietary guidance to prevent excessive weight gain especially among overweight and obese women who were observed to have the highest prevalence of excessive weight gain in our cohort. Strategies to ensure pregnant women achieve sufficient weight gain deserves equal attention considering the associated adverse pregnancy and birth outcomes. Lastly, consistent GWG definitions and measurement methods are necessary to facilitate comparison of results across studies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

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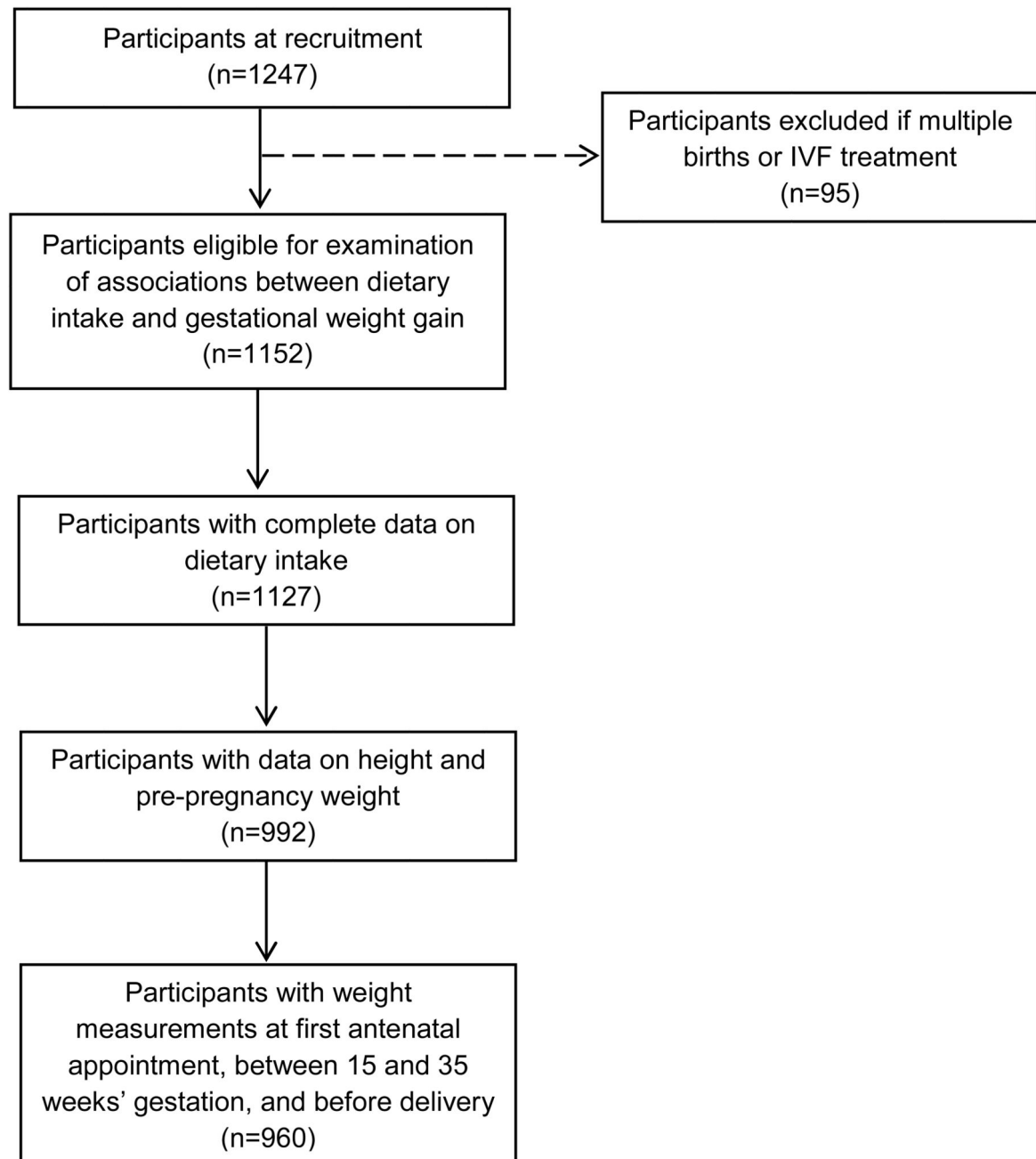
Fig. 1.
Participant flow diagram for analysis of associations between maternal dietary intake and gestational weight gain in the Growing Up in Singapore Towards healthy Outcomes study. IVF, in-vitro fertilization

Table 1

Participant characteristics, nutrients and food groups intakes according to gestational weight gain (GWG) status in the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study

Characteristics	All[a] n=960	Inadequate GWG n=114	Adequate GWG n=231	Excessive GWG n=615	p[b]
Age, year	30.5 ± 5.1	30.4 ± 5.2	30.7 ± 5.1	30.5 ± 5.1	0.791
Ethnicity					0.006*
Chinese	531 (55.3)	68 (59.6)	143 (61.8)	319 (52.1)	
Malay	252 (26.3)	22 (19.3)	44 (19.1)	185 (30.2)	
Indian	177 (18.4)	24 (21.1)	44 (19.1)	108 (17.7)	
Education					0.124
Secondary or lower	274 (29.5)	30 (27.0)	73 (33.0)	171 (28.7)	
Post-secondary	341 (36.8)	34 (30.6)	73 (33.0)	234 (39.3)	
University	313 (33.7)	47 (42.3)	75 (34.0)	191 (32.0)	
Monthly household income					0.163
<1999	129 (14.2)	18 (16.5)	31 (14.4)	80 (13.7)	
2000-5999	518 (56.9)	50 (45.9)	127 (58.8)	341 (58.3)	
>6000	263 (28.9)	41 (37.6)	58 (26.8)	164 (28.0)	
Pre-pregnancy BMI (kg/m²)					<0.001*
Underweight (<18.5)	116 (12.1)	41 (35.3)	55 (47.4)	20 (17.2)	
Normal weight (18.5-24.9)	606 (63.1)	63 (10.4)	159 (26.2)	384 (63.4)	
Overweight (25-29.9)	169 (17.6)	9 (5.5)	14 (8.5)	142 (86.1)	
Obese (>30)	69 (7.2)	1 (1.4)	3 (4.1)	69 (94.5)	
Smoked during pregnancy					0.229
Yes	21 (2.2)	5 (4.4)	4 (1.7)	12 (2.0)	
No	939 (97.8)	109 (95.6)	227 (98.3)	602 (98.0)	
Alcohol intake during pregnancy					0.227
Yes	17 (1.8)	4 (3.6)	5 (2.2)	8 (1.3)	
No	920 (98.2)	108 (96.4)	218 (97.8)	594 (98.7)	
Physical activity, MET.mins/week	1040 (329, 2673)	1386 (681, 3119)	1040 (297, 2142)[#]	891 (297, 2349)[#]	0.004*
Nulliparous					0.219
Yes	300 (31.3)	33 (29.0)	63 (27.3)	204 (33.2)	

Characteristics	All[a] n=960	Inadequate GWG n=114	Adequate GWG n=231	Excessive GWG n=615	p[b]
No	660 (68.7)	81 (71.0)	168 (72.7)	411 (66.8)	
Gestational Diabetes					
Yes	172 (19.1)	38 (35.2)	50 (23.3)	84 (14.5)	<0.001*
No	729 (80.9)	70 (64.8)	165 (76.7)	494 (85.5)	
Energy, kcal/day	1868 ± 598	1770 ± 469#	1822 ± 573#,+	1904 ± 625+	0.036*
Carbohydrate, %E	51.8 ± 8.9	50.6 ± 8.6	51.1 ± 9.0	52.2 ± 8.8	0.093
Protein, %E	15.7 ± 3.9	15.8 ± 4.2	15.7 ± 3.8	15.6 ± 3.8	0.810
Total Fat, %E	32.6 ± 7.7	33.6 ± 6.9	33.2 ± 7.8	32.2 ± 7.7	0.091
Animal-based protein foods, g/day	146.0 (76.9, 232.5)	135.6 (67.9, 225.6)	145.5 (63.0, 218.7)	147.1 (80.0, 236.1)	0.569
Fruit and vegetables, g/day	150 (52.9, 291.5)	111.8 (36.0, 226.2)	165.9 (56.1, 287.8)#	153.1 (61.1, 301.0)#	0.012*
Grains, g/day	360.0 (212.0, 478.7)	357.2 (212.0, 484.0)#	305.6 (157.8, 453.1)#,+	375.0 (218.4, 484.5)+	0.044*
Plant-based protein foods					
No intake	600 (62.5)	83 (72.8)	132 (57.1)	385 (62.5)	0.018*
Some intake	360 (37.5)	31 (27.2)	99 (42.9)	230 (37.4)	
Dairy products					
No intake	282 (29.4)	32 (28.1)	70 (30.3)	180 (29.3)	0.908
Some intake	678 (70.6)	82 (71.9)	161 (69.7)	435 (70.7)	
Fast food and savoury snacks					
No intake	533 (55.5)	70 (61.4)	137 (59.3)	326 (53.0)	0.105
Some intake	427 (44.5)	44 (38.6)	94 (40.7)	289 (47.0)	
Desserts and sweet snacks					
No intake	495 (51.6)	67 (58.8)	123 (53.3)	305 (49.6)	0.166
Some intake	465 (48.4)	47 (41.2)	108 (46.7)	310 (50.4)	
Sugar-sweetened beverages					
No intake	432 (45.0)	53 (46.5)	104 (45.0)	275 (44.7)	0.941
Some intake	528 (55.0)	61 (53.5)	127 (55.0)	340 (55.3)	

Values are n (%), means ± SDs, or medians (inter-quartile ranges).

BMI, body mass index; %E, percentage of energy intake; GWG, gestational weight gain; MET.mins/week, minutes of metabolic equivalents of task per week

[a] Sample sizes vary due to missing data.

[b] *P*-values (<0.05 with asterisk) were obtained from chi-square test, one-factor ANOVA or Kruskal-Wallis test with Bonferroni *post hoc* analysis (#, + groups with the same superscript symbol in a row indicate no significant difference).

Table 2

Associations of maternal energy, macronutrients, and food groups intakes, with gestational weight gain z-scores in 960 women of the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study

	Model 1[a]		Model 2[b]	
Energy and Macronutrients	β (95% CI)	P	β (95% CI)	P
Energy	0.23 (0.18, 0.28)	<0.001*	0.18 (0.13, 0.23)	<0.001*
Substitution of Carbohydrate for Fat	0.05 (0.004, 0.10)	0.033*	0.07 (0.03, 0.12)	0.003*
Substitution of Carbohydrate for Protein	-0.02 (-0.11, 0.06)	0.560	-0.01 (-0.09, 0.07)	0.745
Substitution of Protein for Fat	0.08 (-0.02, 0.19)	0.121	0.09 (-0.01, 0.19)	0.072
	Unadjusted		Model 2[b]	
Food Groups, g (Median; IQR)	β (95% CI)	P	β (95% CI)	P
Animal-based protein foods				
T1 (48; 0, 77)	(reference)		(reference)	
T2 (146; 124, 171)	0.13 (-0.03, 0.29)	0.115	0.04 (-0.11, 0.19)	0.636
T3 (266; 233, 321)	0.20 (0.04, 0.36)	0.017*	-0.07 (-0.23, 0.09)	0.396
	P-trend	0.015*	P-trend	0.394
Plant-based protein foods				
T1 (No intake)	(reference)		(reference)	
T2 (15; 10, 22)	0.19 (-0.01, 0.39)	0.064	0.12 (-0.07, 0.31)	0.220
T3 (76; 50, 111)	0.04 (-0.12, 0.20)	0.637	-0.06 (-0.22, 0.09)	0.437
	P-trend	0.429	P-trend	0.575
Dairy products				
T1 (No intake)	(reference)		(reference)	
T2 (200; 150, 250)	-0.06 (-0.22, 0.10)	0.479	-0.14 (-0.29, 0.01)	0.064
T3 (450; 350, 500)	-0.02 (-0.19, 0.15)	0.847	-0.18 (-0.34, -0.03)	0.022*
	P-trend	0.868	P-trend	0.024*
Fruit and vegetables				
T1 (33; 0, 53)	(reference)		(reference)	
T2 (150; 110, 184)	0.07 (-0.09, 0.24)	0.382	0.04 (-0.11, 0.19)	0.626
T3 (340; 292, 482)	0.26 (0.10, 0.42)	0.002*	0.10 (-0.05, 0.26)	0.191
	P-trend	0.004*	P-trend	0.210
Grains				
T1 (182; 99, 212)	(reference)		(reference)	
T2 (360; 312, 400)	-0.01 (-0.18, 0.15)	0.872	-0.08 (-0.23, 0.06)	0.257
T3 (547; 479, 642)	0.13 (-0.03, 0.29)	0.117	0.04 (-0.11, 0.20)	0.589
	P-trend	0.108	P-trend	0.598
Fast food and savoury snacks				
T1 (No intake)	(reference)		(reference)	
T2 (72; 50, 100)	0.16 (-0.01, 0.34)	0.058	0.002 (-0.15, 0.16)	0.980
T3 (231; 174, 316)	0.16 (-0.01, 0.32)	0.055	-0.05 (-0.21, 0.10)	0.482
	P-trend	0.035*	P-trend	0.521
Desserts and sweet snacks				

T1 (No intake)	(reference)		(reference)		
T2 (45; 27, 68)	0.04 (-0.11, 0.20)	0.591	-0.07 (-0.22, 0.07)	0.310	
T3 (189; 143, 296)	0.25 (0.08, 0.43)	0.004*	-0.03 (-0.19, 0.13)	0.731	
	P-trend	0.006*	*P*-trend	0.570	
Sugar-sweetened beverages					
T1 (No intake)	(reference)		(reference)		
T2 (210; 150, 250)	0.21 (0.05, 0.38)	0.011*	0.10 (-0.05, 0.25)	0.201	
T3 (500; 397, 700)	0.29 (0.13, 0.44)	<0.001*	0.10 (-0.04, 0.25)	0.166	
	P-trend	<0.001*	*P*-trend	0.144	
Carbohydrate-rich foods[c]					
T1 (363; 248, 450)	(reference)				
T2 (621; 564, 707)	0.23 (0.07, 0.40)	0.006*	0.09 (-0.06, 0.24)	0.257	
T3 (979; 852, 1207)	0.50 (0.33, 0.66)	<0.001*	0.20 (0.03, 0.37)	0.019*	
	P-trend	<0.001*	*P*-trend	0.029*	

CI, confidence interval; IQR, inter-quartile range; T1, tertile 1; T2, tertile 2; T3, tertile 3

Effect estimates for energy intake are per 500 kcal increment, for macronutrients are per 5% substitution for another macronutrient, and for food groups are per one tertile increase in median intake (*P*<0.05 with asterisk)

[a]Model 1 adjusted for maternal energy intake only

[b]Model 2 adjusted for maternal energy intake, age, ethnicity, education, income, smoking status, alcohol intake, physical activity, parity, gestational diabetes mellitus and pre-pregnancy BMI.

[c]The combined sum of intakes from grains, desserts and sweet snacks, and sugar-sweetened beverages.

Table 3

Associations of maternal energy, macronutrients and food groups intakes with gestational weight gain status in 960 women of the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study

Reference group: Adequate (n=231)	Inadequate (n=114)				Excessive (n=615)			
	Model 1[a]		Model 2[b]		Model 1[a]		Model 2[b]	
	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P
Energy and Macronutrients								
Energy	0.92 (0.76, 1.11)	0.380	0.88 (0.72, 1.07)	0.206	1.10 (0.97, 1.24)	0.078	1.10 (0.97, 1.25)	0.151
Substitution of Carbohydrate for Fat	0.90 (0.76, 1.07)	0.253	0.87 (0.72, 1.04)	0.119	1.13 (1.01, 1.28)	0.038*	1.14 (1.00, 1.29)	0.042*
Substitution of Carbohydrate for Protein	0.89 (0.66, 1.19)	0.423	0.88 (0.65, 1.19)	0.930	1.00 (0.82, 1.22)	0.978	0.95 (0.77, 1.17)	0.619
Substitution of Protein for Fat	0.85 (0.60, 1.23)	0.398	0.81 (0.56, 1.18)	0.278	1.08 (0.84, 1.38)	0.547	1.15 (0.89, 1.49)	0.181
	Unadjusted		Model 2[b]		Unadjusted		Model 2[b]	
Food groups, g (Median; IQR)	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P
Animal-based protein foods								
T1 (48; 0, 77)	(reference)		(reference)		(reference)		(reference)	
T2 (146; 124, 171)	0.72 (0.42, 1.25)	0.250	0.83 (0.46, 1.47)	0.517	0.85 (0.59, 1.23)	0.398	0.87 (0.59, 1.27)	0.471
T3 (266; 233, 321)	0.90 (0.52, 1.57)	0.722	1.11 (0.60, 2.05)	0.740	1.06 (0.73, 1.55)	0.751	1.03 (0.68, 1.55)	0.891
	P-trend	0.706	P-trend	0.746	P-trend	0.750	P-trend	0.891
Plant-based protein foods								
T1 (No intake)	(reference)		(reference)		(reference)		(reference)	
T2 (15; 10, 22)	0.69 (0.34, 1.40)	0.302	0.65 (0.31, 1.35)	0.251	1.02 (0.64, 1.61)	0.942	0.97 (0.61, 1.55)	0.901
T3 (76; 50, 111)	0.41 (0.23, 0.75)	0.003*	0.40 (0.22, 0.75)	0.004*	0.70 (0.49, 0.99)	0.046*	0.66 (0.46, 0.94)	0.024*
	P-trend	0.003*	P-trend	0.003*	P-trend	0.059	P-trend	0.031*
Dairy products								
T1 (No intake)	(reference)		(reference)		(reference)		(reference)	
T2 (200; 150, 250)	1.00 (0.57, 1.74)	0.996	0.96 (0.54, 1.70)	0.894	0.95 (0.66, 1.38)	0.807	0.93 (0.64, 1.35)	0.709
T3 (450; 350, 500)	1.27 (0.72, 2.24)	0.415	1.24 (0.68, 2.25)	0.490	1.18 (0.80, 1.73)	0.408	1.09 (0.73, 1.63)	0.668
	P-trend	0.410	P-trend	0.481	P-trend	0.398	P-trend	0.663
Fruit and vegetables								
T1 (33; 0, 53)	(reference)		(reference)		(reference)		(reference)	
T2 (150; 110, 184)	0.77 (0.45, 1.32)	0.346	0.76 (0.43, 1.32)	0.327	1.01 (0.69, 1.48)	0.953	0.99 (0.67, 1.46)	0.962
T3 (340; 292, 482)	0.43 (0.24, 0.76)	0.004*	0.40 (0.22, 0.73)	0.003*	0.84 (0.58, 1.22)	0.370	0.83 (0.56, 1.23)	0.362

Reference group: Adequate (n=231)	Inadequate (n=114)				Excessive (n=615)			
	Unadjusted		Model 2[b]		Unadjusted		Model 2[b]	
	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P	RRR (95% CI)	P
Grains								
T1 (182; 99, 212)	(reference)		(reference)		(reference)		(reference)	
T2 (360; 312, 400)	0.92 (0.54, 1.57)	0.757	0.98 (0.56, 1.71)	0.958	1.04 (0.72, 1.50)	0.842	0.98 (0.67, 1.44)	0.941
T3 (547; 479, 642)	0.76 (0.44, 1.33)	0.342	0.84 (0.46, 1.53)	0.572	1.09 (0.75, 1.58)	0.637	1.01 (0.68, 1.49)	0.974
P-trend		0.004*		0.003*		0.358		0.351
Fast food and savoury snacks								
T1 (No intake)	(reference)		(reference)		(reference)		(reference)	
T2 (72; 50, 100)	0.80 (0.45, 1.44)	0.469	0.76 (0.41, 1.41)	0.389	1.02 (0.70, 1.50)	0.912	0.95 (0.64, 1.40)	0.782
T3 (231; 174, 316)	1.05 (0.58, 1.87)	0.878	1.15 (0.61, 2.16)	0.656	1.61 (1.09, 2.38)	0.016*	1.46 (0.96, 2.20)	0.076
P-trend		0.953		0.866		0.025*		0.120
Desserts and sweet snacks								
T1 (No intake)	(reference)		(reference)		(reference)		(reference)	
T2 (45; 27, 68)	0.79 (0.47, 1.35)	0.393	0.79 (0.46, 1.37)	0.407	0.99 (0.70, 1.41)	0.970	0.94 (0.65, 1.34)	0.726
T3 (189; 143, 296)	0.80 (0.43, 1.51)	0.502	0.89 (0.45, 1.75)	0.738	1.43 (0.95, 2.14)	0.086	1.29 (0.84, 1.98)	0.248
P-trend		0.397		0.582		0.126		0.357
Sugar-sweetened beverages								
T1 (No intake)	(reference)		(reference)		(reference)		(reference)	
T2 (210; 150, 250)	0.93 (0.53, 1.63)	0.800	0.91 (0.51, 1.63)	0.753	1.09 (0.75, 1.58)	0.660	1.04 (0.71, 1.54)	0.820
T3 (500; 397, 700)	0.95 (0.56, 1.61)	0.858	0.98 (0.56, 1.71)	0.933	0.95 (0.66, 1.36)	0.782	0.84 (0.58, 1.23)	0.379
P-trend		0.841		0.897		0.833		0.419
Carbohydrate-rich foods[c]								
T1 (363; 248, 450)	(reference)		(reference)		(reference)		(reference)	
T2 (621; 564, 707)	0.71 (0.40, 1.28)	0.256	0.68 (0.37, 1.24)	0.206	1.11 (0.76, 1.62)	0.593	0.99 (0.67, 1.48)	0.593
T3 (979; 852, 1207)	0.73 (0.40, 1.33)	0.309	0.71 (0.35, 1.43)	0.336	1.41 (0.96, 2.08)	0.084	1.20 (0.77, 1.87)	0.430
P-trend		0.282		0.293		0.093		0.452

CI, confidence interval; IQR, inter-quartile range; RRR, relative risk ratio; T1, tertile 1; T2, tertile 2; T3, tertile 3

Effect estimates for energy intake are per 500 kcal increment, for macronutrients are per 5% substitution for another macronutrient, and for food groups are per one tertile increase in median intake (P<0.05 with asterisk)

[a]Model 1 adjusted for maternal energy intake only

[b]Model 2 adjusted for maternal energy intake, age, ethnicity, education, income, smoking status, alcohol intake, physical activity, parity and gestational diabetes mellitus.

[c]The combined sum of intakes from grains, desserts and sweet snacks, and sugar-sweetened beverages.