Adherence to a healthy eating index for pregnant women is associated with lower neonatal adiposity in a multiethnic Asian cohort: the Growing Up in Singapore Towards healthy Outcomes (GUSTO) Study

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ABSTRACT

Background: Evidence linking maternal diet quality during pregnancy with infant birth outcomes is limited in Asia.

Objective: We investigated the association of maternal diet quality with the risk of preterm birth, offspring birth size, and adiposity in a multiethnic Asian birth cohort.

Design: Dietary intakes of 1051 pregnant women were ascertained at 26–28 wk of gestation with the use of 24-h recalls and 3-d food diaries, from which diet quality (score range: 0–100) was measured by the Healthy Eating Index for pregnant women in Singapore (HEI-SGP). Gestational age was established by first-trimester ultrasound dating scan. Neonatal weight and length were measured at birth. Body composition was assessed by air displacement plethysmography in a subset of infants ($n = 313$) within 72 h after birth, and abdominal adiposity was assessed by MRI ($n = 316$) within the first 2 wk of life. Associations were assessed by multivariable linear regression for continuous outcomes and logistic regression for preterm birth.

Results: The mean ± SD maternal HEI-SGP score was 52.1 ± 13.6. Maternal diet quality during pregnancy was not associated with preterm birth or birth weight. Greater adherence to the HEI-SGP (per 10-point increment in HEI-SGP score) was associated with longer birth length [β (95% CI): 0.14 (0.03, 0.24 cm)], lower body mass index (in kg/m^2) at birth [−0.07 (−0.13, −0.01)], lower sum of triceps and subscapular skinfold thickness [−0.15 (−0.26, −0.05 mm)], lower percentage body fat [−0.52% (−0.84%, −0.20%)], lower fat mass [−17.23 (−29.52, −4.94 g)], lower percentage abdominal superficial subcutaneous adipose tissue [−0.16% (−0.30%, −0.01%)], and lower percentage deep subcutaneous adipose tissue [−0.06% (−0.10%, −0.01%)].

Conclusions: Higher maternal diet quality during pregnancy was associated with longer birth length and lower neonatal adiposity but not with birth weight and preterm birth. These findings warrant further investigation in independent studies. This trial was registered at clinicaltrials.gov as NCT01174875. *Am J Clin Nutr* 2018;107:71–79.

Keywords: maternal diet, diet quality, preterm birth, birth weight, adiposity

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Supplemental Figure 1 and Supplemental Table 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: DASH, Dietary Approaches to Stop Hypertension; dSAT, deep subcutaneous adipose tissue; GA, gestational age; GUSTO, Growing Up in Singapore Towards healthy Outcomes; HEI, Healthy Eating Index; HEI-SGP, Healthy Eating Index for pregnant women in Singapore; IAT, Internal adipose tissue; sSAT, superficial subcutaneous adipose tissue.

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INTRODUCTION

Globally, 11% of infants are born preterm (<37 wk of gestation) (1). Preterm birth and extreme birth weights are associated with higher risks of infant mortality and morbidity and of noncommunicable diseases in adulthood (1–3). Because infants with similar size can have marked variability in adiposity, increasing attention has focused on investigation of infant body composition in order to understand the relation between early-life development and later health outcomes (4). Neonatal adiposity may be associated with childhood obesity (5), and given the globally increasing trend of childhood obesity and consequent risk of chronic disease, examinations of infant body composition and adiposity are valuable and critical (6).

A substantial body of evidence has shown that maternal nutrition during pregnancy can influence birth outcomes (7) and subsequent chronic disease risk in the offspring (8). There has been growing interest in examining overall maternal diet quality (9–21) by using index scores such as the Healthy Eating Index (HEI) (7–10), the Mediterranean diet score (10–16), the New Nordic diet score (17, 18), and the Dietary Approaches to Stop Hypertension (DASH) score (19). This is because these take into account the multiplex interactions among nutrients and foods (22), an approach congruent with recommendations of the 2015 Dietary Guidelines Advisory Committee (23). Although each dietary index captures adherence to slightly different dietary guidelines, in general, these indexes indicate a good-quality diet as one that is high in vegetables, fruit, fish, and unsaturated fats and low in red and processed meat and saturated fats (9–21).

Although greater adherence to the DASH (21) and Mediterranean (18) diets has been associated with a lower incidence of preterm birth, several studies observed no association (13, 15, 16, 19). For birth size, a better-quality diet during pregnancy has generally been associated with higher birth weight (10, 14, 17) and a lower risk of fetal growth restriction (10, 14, 20), but other studies have reported no association (9, 11–14). To our knowledge, only one study has explored infant body composition; this study observed a lower HEI score (i.e., poorer diet quality) to be associated with increased infant adiposity (9).

Existing studies have been conducted in white subjects (9–21) and no study, to our knowledge, has examined the association between maternal diet quality and infant birth outcomes in Asians. Furthermore, only one study examined the association between maternal diet quality and infant body composition by using air displacement plethysmography (9); and to our knowledge, no study to date has explored abdominal adiposity. It is unclear whether similar associations are present in multiethnic Asian populations, particularly because important differences in body composition exist between Asian and white infants (24, 25). In this study (clinicaltrials.gov; NCT01174875), we investigated the association of maternal diet quality during pregnancy with the risk of preterm birth and offspring birth size and adiposity in a multiethnic Asian mother-offspring cohort study.

METHODS

Study population

We used data from the Growing Up in Singapore Towards healthy Outcomes (GUSTO) Study, a prospective mother-offspring cohort designed to investigate early developmental pathways to noncommunicable diseases (26). Women in the first trimester of pregnancy ($n = 1247$), aged 18–50 y, were recruited from 2 major public maternity units in Singapore, National University Hospital, and KK Women's and Children's Hospital, between June 2009 and September 2010. Women were ineligible if they had type 1 diabetes, were receiving chemotherapy or psychotropic drugs, or whose parents and spouses' parents had a different ethnicity (e.g., Chinese, Malay, or Indian descent). The study was approved by the National Health Care Group Domain Specific Review Board (reference D/09/021) and the SingHealth Centralized Institutional Review Board (reference 2009/280/D). All of the participants gave informed written consent upon recruitment.

Diet quality assessment

Maternal dietary intakes were ascertained at 26–28 wk of gestation with the use of 24-h recalls ($n = 1127$) and 3-d food diaries ($n = 260$) (27). Clinic staff trained by an experienced dietician administered the 24-h recall with a 5-stage multiple-pass interviewing technique (28). Standardized household measuring utensils and food pictures of various portion sizes were provided to assist women in quantifying their dietary intake. The clinic staff also guided the participants on completing food diaries at home for the following week. Nutrient analysis of the dietary records was performed by using nutrient analysis software (Dietplan; Forestfield Software Ltd.) containing a food-composition database of locally available foods (29), with modifications made for inaccuracies found.

Diet quality was measured by the Healthy Eating Index for pregnant women in Singapore (HEI-SGP) (30). The HEI-SGP has been validated to examine diet quality of pregnant women in Singapore (30) and, to date, has been associated with health outcomes such as maternal retinal microvasculature abnormalities (31) and gestational diabetes (in preparation). In brief, the HEI-SGP has 11 components with a maximum possible raw score of 90. The selection and weighting of each component are in accordance with the national (local) dietary guidelines for pregnant women as well as substantiated by other dietary quality indexes in which content validity has been established previously (e.g., HEI and Alternate HEI) (11, 32–35). Accordingly, the food groups were first classified into the following 3 categories, and under each category the score was then divided to reflect dietary adequacy and quality:

1) Fruit and vegetables (0–20 points)—adequacy components: total fruit (0–5 points), total vegetables (0–5 points); quality components: whole fruit (0–5 points), dark-green leafy and orange vegetables (0–5 points)
2) Grains (0–20 points)—adequacy component: total rice and alternatives (0–10 points); quality component: whole grains (0–10 points)
3) Meat and others (0–20 points)—adequacy component: total protein foods (0–10 points); quality component: dairy (0–10 points)

There are 2 nutrient-based moderation components that reflect compliance with recommended total fat (0–10 points) and total saturated fat (0–10 points); and last, the use of antenatal supplements containing iron, folate, and calcium (0–10 points). Scores from individual components were adjusted for energy intake by using the energy density method (36), summed and scaled up to 100 to get the total HEI-SGP score for each pregnant woman, with higher scores reflecting greater adherence to dietary guidelines, indicative of better diet quality.

Infant birth outcomes

Gestational age (GA) was determined by a dating ultrasound scan in the first trimester and preterm birth defined as delivery of a live birth <37 completed weeks of gestation. Birth weight was measured shortly after birth to the nearest 1 g (SECA model 334; SECA Corp.), whereas recumbent length was measured to the nearest 0.5 cm from the top of the head to the soles of the feet (SECA model 210). BMI at birth was calculated as birth weight divided by the square of recumbent length (kg/m^2). We derived birth weight–for-GA and birth length–for-GA *z* scores by using references from our cohort (37). Weight-for-length *z* scores were calculated with the use of an established equation (38) on the basis of *z* scores for weight and length. Within 72 h after delivery, head, abdominal, and midupper arm circumferences were measured to the nearest 0.1 cm (SECA model 212), and triceps and subscapular skinfold thicknesses were measured in triplicate to the nearest 0.2 mm on the right side of the body and summed (Holtain Skinfold Caliper; Holtain Ltd.).

Anthropometric training and standardization sessions were conducted quarterly to ensure that each anthropometrist developed and maintained their techniques for accurate and precise measurements. The high intraobserver intraclass correlation coefficient values (between 0.994 and 0.997) (39) as well as the low interobserver technical error of measurement (between 0.03 and 0.04 mm) and CVs (between 2.05% and 2.19%) affirmed that the measurements were highly reliable (40).

Infant fat mass, fat-free mass, and percentage of body fat were assessed by using an air displacement plethysmography device (Pea Pod infant body-composition system, version 3.1.0; Cosmed) within 3 d after delivery (41). Neonatal abdominal adiposity was assessed by using MRI (GE Signa HDxt 1.5 Tesla MR scanner) approximately within the first 2 wk of life (42). Subsets of 313 infants and 316 infants in this study had Pea Pod and MRI data, respectively. Superficial subcutaneous adipose tissue (sSAT), deep subcutaneous adipose tissue (dSAT), and internal adipose tissue (IAT) were quantified and expressed as percentages of abdominal adipose tissue compartment volumes. Percentages of abdominal adipose tissue compartment volumes were derived from the ratio of each compartment volume and the total abdominal volume (42). Pearson's correlation coefficients for the sum of subscapular and triceps skinfold thicknesses, total body composition measured by Pea Pod, and abdominal adiposity assessed by MRI were between 0.47 and 0.58, with the exception of IAT, which was 0.24.

Covariates

Maternal age, ethnicity, educational level, household income, and self-reported prepregnancy weights were ascertained during recruitment. Between 26 and 28 wk of gestation, maternal weight was measured to the nearest 0.1 kg (SECA 803), standing height was measured in duplicate to the nearest 0.1 cm from the top of the head to the heels (SECA 213), maternal plasma folate status was determined by competitive electrochemiluminescence immunoassay on the ADVIA Centaur Immunoassay System (Siemens) (43), and information on physical activity (44), cigarette smoking, and alcohol consumption during pregnancy was ascertained. Prepregnancy BMI was calculated as prepregnancy weight divided by height squared (kg/m^2), whereas weight gain until 26–28 wk of gestation was calculated by subtracting prepregnancy weight from weight measured between 26 and 28 wk of gestation.

Statistical analyses

Of the 1247 participants, we excluded women who underwent in vitro fertilization ($n = 85$) and who were expecting twins ($n = 10$). Of the remaining 1152 participants, 64 women dropped out during pregnancy due to personal reasons, loss to follow-up, family disapproval, and inconvenience. Women who provided 24-h recalls reported to be reflective of their typical diets and who had information on their offspring's birth anthropometric measurements ($n = 1051$), total body composition ($n = 313$), and abdominal adiposity ($n = 316$) were included in the analysis (**Supplemental Figure 1**). There were no significant differences in characteristics (birth weight, gestational age, parity, and prepregnancy BMI) between neonates who had undergone MRI and those who did not undergo MRI (42) or Pea Pod measurements (**Supplemental Table 1**). To evaluate whether possible selection bias may have affected the results, we conducted sensitivity analysis for infant birth anthropometry outcomes by limiting the analysis to a subset of participants with MRI and Pea Pod measurements ($n = 166$).

HEI-SGP scores derived from 24-h recalls were our primary source of dietary data, because only a subset of participants ($n = 259$) completed and returned their 3-d food diaries. We conducted sensitivity analyses on participants who provided their 3-d food diaries to assess the consistency and robustness of our study results.

Maternal characteristics and nutrient intakes were summarized according to quintiles of HEI-SGP scores (**Table 1**). *P*-trends were assessed by modeling the median value of the quintiles in linear regression for continuous variables or by using Cochran-Mantel-Haenszel tests for categorical variables.

The associations of maternal HEI-SGP scores with infant birth outcomes were analyzed by linear regression for continuous outcomes and logistic regression for preterm birth (**Table 2**). These models were adjusted for infant's sex and birth order and mother's age, ethnicity, prepregnancy BMI, weight gain up until 26–28 wk of gestation, height, energy intake, educational level, household income, physical activity, alcohol use, and smoking during pregnancy. Infant body composition and abdominal adiposity analyses were further adjusted for the infant's postnatal age on the Pea Pod and MRI measurement days, respectively.

Missing covariate data [i.e., maternal height ($n = 9$), physical activity ($n = 9$), educational level ($n = 14$), alcohol consumption ($n = 25$), smoking status ($n = 27$), household income ($n = 67$), prepregnancy BMI ($n = 81$), and pregnancy weight gain up until 26–28 wk of gestation ($n = 88$)] were estimated by multiple imputation (45). We generated 100 independent imputations, and the results of the pooled analyses are presented. To evaluate whether the imputation of missing data may have affected the

TABLE 1

Characteristics of the study participants according to quintiles of HEI-SGP scores[1]

	Quintile					
	1 ($n = 210$)	2 ($n = 210$)	3 ($n = 211$)	4 ($n = 210$)	5 ($n = 210$)	*P*-trend
HEI-SGP score[2]	34.4 (29.8–37.8)	44.1 (42.0–46.2)	52.4 (50.3–54.0)	60 (57.8–61.8)	70.0 (66.5–74.6)	
Age, y	28.9 ± 5.4	30.2 ± 5.0	30.4 ± 5.2	31.3 ± 5.1	31.6 ± 4.6	<0.001
Prepregnancy BMI, kg/m^2	22.8 ± 4.4	22.9 ± 4.8	23.3 ± 4.6	22.5 ± 4.6	22.0 ± 3.5	0.04
Weight gain until 26–28 wk of gestation, kg	9.0 ± 4.4	8.3 ± 5.0	9.2 ± 5.4	8.2 ± 4.3	8.6 ± 4.1	0.34
Height, cm	158.1 ± 5.3	158.3 ± 5.8	157.9 ± 5.7	157.9 ± 5.9	158.8 ± 5.4	0.40
Plasma folate, nmol/L	33.0 ± 21.6	38.9 ± 54.9	35.4 ± 23.2	44.6 ± 48.1	44.5 ± 41.2	0.002
Ethnicity, %						0.13
Chinese	44	55	49	63	65	
Malayan	43	31	28	17	13	
Indian	12	14	23	20	22	
Educational level, %						<0.001
None, primary, or secondary	40	34	35	28	17	
Postsecondary	39	43	33	35	29	
University	20	23	33	36	55	
Household income, %						<0.001
<2000 SGD	24	13	14	15	7	
2000–6000 SGD	57	66	60	52	50	
>6000 SGD	18	20	26	33	43	
Physical activity, %						0.92
Inactive (<600 MET-h/wk)	30	42	29	34	31	
Sufficiently active (600–3000 MET-h/wk)	47	43	52	49	50	
Highly active (>3000 MET-h/wk)	23	15	19	18	19	
Primiparous, %	42	41	45	41	45	0.63
Current smoker, %	4.8	4.8	2.6	0.5	0.5	<0.001
Alcohol use during pregnancy, %	2.4	1.6	2.0	1.5	2.4	0.98
Nutrient intakes						
Total energy intake, kcal/d	1976 ± 605	1832 ± 586	1791 ± 590	1814 ± 485	1824 ± 531	0.008
Carbohydrate, % of energy	46.0 ± 8.5	49.5 ± 8.0	53.5 ± 9.2	54.4 ± 7.4	56.0 ± 6.9	<0.001
Protein, % of energy	14.5 ± 3.8	15.3 ± 3.9	15.8 ± 4.2	16.1 ± 3.4	16.4 ± 3.6	<0.001
Total fat, % of energy	39.5 ± 6.6	35.3 ± 6.3	30.7 ± 7.3	29.5 ± 6.0	27.7 ± 5.2	<0.001
Saturated fat, % of energy	17.4 ± 4.5	14.0 ± 3.2	12.0 ± 3.6	11.3 ± 3.0	10.5 ± 2.8	<0.001
Dietary fiber, g/1000 kcal	6.6 ± 2.6	7.4 ± 3.2	8.9 ± 4.4	9.8 ± 4.8	11.2 ± 4.5	<0.001
Dietary calcium, mg/1000 kcal	252 ± 136	306 ± 170	328 ± 168	372 ± 180	473 ± 224	<0.001
Dietary iron, mg/1000 kcal	6.6 ± 4.6	8.2 ± 7.3	9.2 ± 7.2	9.9 ± 7.6	14.7 ± 11.1	<0.001

[1] Values are means ± SDs unless otherwise indicated; $n = 1051$. *P*-trends were assessed by modeling the median value of the quintiles in linear regression for continuous variables or with the use of the Cochran-Mantel-Haenszel tests for categorical variables. There were missing data for prepregnancy BMI ($n = 81$), weight gain until 26–28 wk of gestation ($n = 88$), height ($n = 9$), educational level ($n = 14$), household income ($n = 67$), physical activity ($n = 9$), smoking status ($n = 27$), alcohol consumption ($n = 25$), and plasma folate ($n = 82$). HEI-SGP, Healthy Eating Index for pregnant women in Singapore; MET-h, metabolic equivalent task-hours; SGD, Singapore dollars.

[2] Median (IQR).

results, we performed sensitivity analyses on participants with complete data ($n = 886$).

We investigated potential effect modification by infant sex and ethnicity by including an interaction term (ethnicity × HEI-SGP score or infant sex × HEI-SGP score) in the multivariable regression models. We also performed sensitivity analyses to examine the robustness of our results by restricting our analyses to term infants ($n = 975$) and women without medical conditions (i.e., chronic hypertension, pregnancy-induced hypertension, preeclampsia, and gestational diabetes) ($n = 773$). In addition, we alternately excluded one component of the HEI-SGP score to determine whether any individual component was driving the association between HEI-SGP and infant birth outcomes (46).

All of the statistical analyses were performed with the use of SPSS version 19.0 (IBM Corp.). Two-sided *P* values <0.05 were considered significant.

RESULTS

Characteristics of the study population

In 1051 pregnant women, the mean ± SD HEI-SGP score was 52.1 ± 13.6 (range: 12.7–94.3). Women with higher HEI-SGP scores tended to be older, nonsmokers, and have a higher educational level and household income, higher plasma folate concentrations, and higher dietary intakes of carbohydrates, protein, dietary fiber, calcium, and iron but have lower intakes of fat, particularly saturated fat (Table 1).

Associations with preterm birth and birth anthropometric measurements

In this study, 76 births (7.2%) were preterm, the mean ± SD birth weight was 3090 ± 451 g, and birth length was 48.6 ± 2.3 cm. A higher HEI-SGP score was associated with longer birth

TABLE 2

Associations between maternal HEI-SGP scores during 26–28 wk of gestation with infant birth outcomes[1]

	Value	Unadjusted model, β (95% CI)	Multivariable model,[2] β (95% CI)
Preterm birth,[3] n (%)	76 (7.2)	0.90 (0.75, 1.07)[4]	0.91 (0.75, 1.11)[4]
Infant anthropometric measures at birth[3]			
Birth weight, g	3090 ± 451	4.08 (−16.05, 24.20)	−2.00 (−22.57, 18.57)
Birth length, cm	48.6 ± 2.3	0.22 (0.12, 0.32)**	0.14 (0.03, 0.24)*
BMI, kg/m^2	13.0 ± 1.3	−0.09 (−0.15, −0.03)**	−0.07 (−0.13, −0.01)*
Head circumference, cm	33.6 ± 1.4	0.05 (−0.02, 0.11)	0.03 (−0.03, 0.10)
Abdominal circumference, cm	28.3 ± 2.4	−0.11 (−0.22, 0.0003)	−0.06 (−0.18, 0.06)
Midupper arm circumference, cm	10.8 ± 1.0	−0.01 (−0.05, 0.04)	0.002 (−0.05, 0.05)
Sum of triceps and subscapular skinfold thickness, mm	10.3 ± 2.2	−0.18 (−0.29, −0.08)**	−0.15 (−0.26, −0.05)**
Infant body composition[5]			
Fat-free mass, g	2780 ± 309	11.57 (−15.15, 38.30)	3.81 (−23.95, 31.58)
Fat mass			
g	315 ± 138	−14.25 (−26.15, −2.35)*	−17.23 (−29.52, −4.94)**
%	9.95 ± 3.62	−0.46 (−0.77, −0.15)**	−0.52 (−0.84, −0.20)**
Infant abdominal adiposity distribution,[6] %			
Superficial subcutaneous abdominal adipose tissue	9.75 ± 1.77	−0.13 (−0.27, 0.02)	−0.16 (−0.30, −0.01)*
Deep subcutaneous abdominal adipose tissue	1.66 ± 0.57	−0.04 (−0.09, 0.003)	−0.06 (−0.10, −0.01)*
Internal abdominal adipose tissue	2.85 ± 0.68	−0.01 (−0.07, 0.04)	−0.02 (−0.08, 0.04)

[1] Values are means ± SDs or linear regression coefficients (95% CIs) for continuous variables and logistic regression coefficients (95% CIs) for preterm birth per 10-point increment in HEI-SGP scores unless otherwise indicated. *$P < 0.05$; **$P < 0.01$. HEI-SGP, Healthy Eating Index for pregnant women in Singapore.

[2] The multivariable model was adjusted for infants' sex and birth order and maternal age, ethnicity, prepregnancy BMI, weight gain up until 26–28 wk of gestation, height, energy intake, educational level, household income, physical activity, alcohol use, and smoking during pregnancy. For analysis of infant body composition and abdominal adiposity distribution, the models were additionally adjusted for the infant's exact postnatal age at Pea Pod (Cosmed) and MRI measurements, respectively.

[3] $n = 1051$.

[4] OR (95% CI).

[5] $n = 313$.

[6] $n = 316$.

length (0.14 cm; 95% CI: 0.03, 0.24 cm; per 10-point increment in HEI-SGP scores), lower BMI (in kg/m^2) at birth (−0.07; 95% CI: −0.13, −0.01; per 10-point increment), and lower sum of triceps and subscapular skinfold thicknesses (−0.15 mm; 95% CI: −0.26, −0.05 mm; per 10-point increment) (Table 2). The results remained largely similar when we examined z scores, where each 10-point increment in HEI-SGP score was associated with a 0.06 SD (95% CI: 0.02, 0.11 SD) increase in birth length and a 0.09 SD (95% CI: 0.02, 0.15 SD) decrease in weight for length. No associations were observed for preterm birth, birth weight, and other neonatal body circumference measurements. There were no interactions between infant sex, ethnicity, and HEI-SGP score in relation to preterm birth and infant birth anthropometric measurements (all P-interactions between 0.12 and 0.75).

Associations with infant body composition and abdominal adiposity distribution

In the subset of infants with body-composition data ($n = 313$), a higher HEI-SGP score was associated with a lower percentage of body fat (−0.52%; 95% CI: −0.84%, −0.20%; per 10-point increment) and lower fat mass (−17.23 g; 95% CI: −29.52, −4.94 g; per 10-point increment) but not with fat-free mass (Table 2).

In 316 infants who underwent MRI, a higher HEI-SGP score was associated with a lower percentage of sSAT (−0.16%; 95% CI: −0.30%, −0.01%; per 10-point increment) and a lower percentage of dSAT (−0.06%; 95% CI: −0.10%, −0.01%; per 10-point increment) but was not associated with percentage of IAT (Table 2). There were no interactions between infant sex, ethnicity, and HEI-SGP score in relation to infant body composition and abdominal adiposity distribution (all P-interactions between 0.07 and 0.86).

Sensitivity analyses

The results remained largely similar when we restricted our analyses to participants with complete data ($n = 886$), term infants ($n = 975$), or to women without medical conditions (i.e., chronic hypertension, pregnancy-induced hypertension, pre-eclampsia, or gestational diabetes) ($n = 773$). In general, alternately excluding one component of the HEI-SGP score did not substantially change our results for all of the outcomes (**Figure 1**), with the exception of birth length. The association between HEI-SGP score with birth length was attenuated (0.02 cm; 95% CI: −0.11, 0.15 cm; per 10-point increment) after the exclusion of antenatal supplements containing iron, folate, and calcium from the HEI-SGP score.

In the subset of participants with Pea Pod and MRI data ($n = 166$), we observed a similar magnitude of association (albeit a wider CI) between a higher HEI-SGP score with a lower BMI at birth (−0.08; 95% CI: −0.23, 0.07; per 10-point increment) and a lower sum of subscapular and skinfold thickness (−0.17 mm; 95% CI: −0.43, 0.10 mm; per 10-point increment) but not with

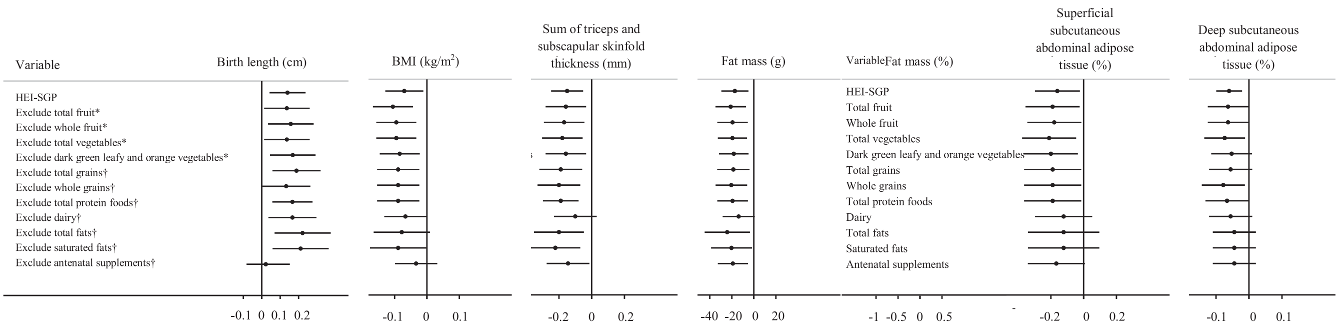

FIGURE 1 The association between maternal HEI-SGP scores alternately excluding individual components and infant birth outcomes (per 10-point increment). Black dots denote linear regression coefficients and horizontal lines denote 95% CIs. The models were adjusted for infants' sex and birth order and maternal age, ethnicity, prepregnancy BMI, weight gain up until 26–28 wk of gestation, height, energy intake, educational level, household income, physical activity, alcohol use, smoking during pregnancy, and excluded component. For analysis of infant body composition and abdominal adiposity distribution, the models were additionally adjusted for the infant's exact postnatal age with Pea Pod (Cosmed) and MRI measurements, respectively. *Effect estimates were multiplied by 100/95 to correct for the 100-point scale. †Effect estimates were multiplied by 100/90 to correct for the 100-point scale. HEI-SGP, Healthy Eating Index for pregnant women in Singapore.

birth length (−0.03 cm; 95% CI: −0.27, 0.02 cm; per 10-point increment).

When we restricted our analyses to a subset of participants with 3-d food diaries ($n = 259$), we observed a similar direction of association (albeit a wider CI) for birth length (0.10 cm; 95% CI: −0.11, 0.31 cm; per 10-point increment), BMI (−0.13; 95% CI: −0.26, −0.01; per 10-point increment), sum of skinfold thickness (−0.18 mm; 95% CI: −0.38, 0.02 mm; per 10-point increment), percentage body fat (−0.99%; 95% CI: −1.99%, −0.22%; per 10-point increment), and fat mass (−3.60 g; 95% CI: −7.52, 0.32 g; per 10-point increment) but not with sSAT (0.01%; 95% CI: −0.36%, 0.39%; per 10-point increment) and dSAT (0.02%; 95% CI: −0.09%, 0.12%; per 10-point increment), which might be due to the reduced sample size ($n < 80$) and insufficient statistical power for abdominal adiposity measures.

DISCUSSION

In this study, maternal diet quality during pregnancy, as assessed by the HEI-SGP, was not associated with preterm birth or birth weight. Higher maternal diet quality was, however, associated with longer birth length and lower neonatal adiposity, characterized by the reduction in BMI at birth, sum of neonatal skinfold thicknesses, overall body fat, and abdominal subcutaneous adipose tissue in neonates.

Consistent with others, we did not observe an association between maternal diet quality and preterm birth (13, 15, 16, 19), with the exception of 2 studies that showed a lower risk of preterm birth with greater adherence to the DASH diet (21) and a Mediterranean diet (18). The latter study was restricted to participants with low-risk pregnancies (i.e., no pre-existing health conditions, no complications during previous pregnancies, were nonsmokers, etc.), and the results may not be applicable to other populations of pregnant women (18). The intake of sweetened beverages was accounted for in the DASH diet (21) but less emphasized in other diet quality indexes (13, 15, 16, 19, 30). Earlier studies have shown that the intake of sweetened beverages during pregnancy is associated with an increased risk of preterm birth (47–49). Whether the lower intakes of sweetened beverages on the DASH diet contribute to a lower risk of preterm birth warrants further investigation in independent studies.

Previous studies in the Mediterranean area of Spain (10, 14, 17) and Norway (20) have shown that improving diet quality during pregnancy is associated with longer birth length (10, 14), higher birth weight (10, 14, 17), and a lower risk of fetal growth restriction (10, 14, 20), but most cohorts in the United States (9, 11, 12), France (13), Greece (14), and the Atlantic area of Spain (14) did not observe an association with birth size. These studies did not examine the role of individual components of the dietary indexes, and there are insufficient data to determine the reasons for the conflicting results. We showed that the association between HEI-SGP score with birth length was attenuated after excluding the use of antenatal supplements containing iron, folate, and calcium from the HEI-SGP score, which suggests that these micronutrients contributed most to the association between higher HEI-SGP score and longer birth length. This finding is also in line with our previous work (43), which showed trends between higher maternal plasma folate concentrations and longer birth length. Because the requirements for these 3 micronutrients increase during pregnancy, antenatal supplementation may be beneficial if the intake of these micronutrients from foods is inadequate. From our national nutrition survey, it was observed that ∼25% of women aged 18–39 y had insufficient dietary iron and calcium intakes (<70% of the Recommended Dietary Allowance) (50). Similarly, ∼10% of pregnant women in our cohort had low plasma folate concentrations (<13.6 nmol/L). Therefore, it is possible that a better-quality diet, including adequate intakes of these 3 micronutrients, may improve birth outcomes even in well-nourished populations.

In our cohort, a higher HEI-SGP score was associated with lower BMI at birth, a reduced sum of subscapular and triceps skinfold thicknesses at birth, and a lower percentage of body fat, fat mass, and neonatal sSAT and dSAT. Consistent with an earlier finding (9), a higher-quality maternal diet is generally associated with lower neonatal adiposity and this effect is independent of maternal prepregnancy BMI. These results did not appear to be driven by specific components of the HEI-SGP score, because alternately excluding one component of the HEI-SGP score did not materially change our results. We have previously shown that mothers with sufficient vitamin D concentrations (>75.0 nmol/L) (in review), higher maternal betaine status, or higher dietary protein intake were associated with lower neonatal adiposity in our GUSTO cohort (51, 52). This result further attests to our conclusion that neonatal adiposity is dependent on various components of the diet (i.e., the overall diet), rather than a single nutrient or diet component. Abdominal adiposity may be more closely linked to metabolic risk than peripheral adiposity (53). In particular, dSAT and visceral adipose tissue are strongly associated with insulin resistance and the development of obesity-related complications (54, 55). However, further investigation is required to determine whether the distribution of neonatal abdominal adipose tissue persists in adulthood and affects later morbidity.

The clinical significance of maternal diet quality and neonatal adiposity is unclear at present. Given the compelling epidemiologic evidence and clinical emphasis on maternal obesity and infant adiposity (56–58), we sought to compare the association between maternal HEI-SGP score and maternal prepregnancy BMI and infant body-composition outcomes but interpreted the results with caution because they have a different etiology. Among the whole cohort, the mean ± SD HEI-SGP score was 52.1 ± 13.6 and prepregnancy BMI was 22.7 ± 4.3. We noted that the effect estimates for skinfold thickness (0.21 mm per SD decrease in HEI-SGP score compared with 0.35 mm per SD increase in prepregnancy BMI), fat mass (23.3 compared with 19.2 g), percentage body fat (0.71% compared with 0.36%), sSAT (0.21% compared with 0.38%), and dSAT (0.07% compared with 0.08%) were generally comparable. These results highlight the clinical relevance and importance of maternal diet quality during pregnancy as it relates to neonatal adiposity and consequent health outcomes in adulthood.

Strengths of our study include its prospective design, which minimizes recall and interviewer bias (59); the use of first-trimester ultrasound dating, which is more precise in estimating GA (60); the comprehensive assessment of neonatal anthropometric and body-composition outcomes, including a gold-standard, nonionizing method (i.e., MRI) for assessing specific abdominal adipose tissue compartments (61); and the use of the HEI-SGP, which has adequate content validity and suitability for assessing diet quality in pregnant women in Asia because it was developed in a diverse ethnic population (30).

Several limitations of our study need to be noted. First, maternal dietary intake was obtained primarily from 24-h recalls, which may not be representative of an individual's typical dietary intake, which varies from day to day. However, sensitivity analyses in participants who completed a 3-d food diary produced similar estimates, albeit wider CIs (but not with abdominal adiposity measures, which might be due to the reduced sample size). In addition, we also showed that our 24-h recall is moderately valid and has good reproducibility in previously published results (27, 29, 30, 52, 62). Second, maternal diet was only assessed during 26–28 wk of gestation, which may not be representative of a diet followed throughout pregnancy. However, previous studies have reported that dietary intakes and patterns did not change substantially during pregnancy (63–65). Last, although we considered many potential confounding factors, our findings could still be influenced by residual confounding and causality cannot be claimed, as in any observational study.

In conclusion, we observed that maternal diet quality, as assessed by the HEI-SGP, was associated with longer birth length and lower neonatal adiposity in a multiethnic Asian cohort. However, maternal diet quality during pregnancy was not associated with birth weight or preterm birth. These findings warrant further investigation in independent studies.

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