

Changes in diet quality from pregnancy to 6 years post-pregnancy and associations with cardio-metabolic risk markers

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Abstract: Adopting a healthy diet during and after pregnancy is important for women's cardio-metabolic health. We related changes in diet quality from pregnancy to 6 years post-pregnancy to cardio-metabolic markers 8 years post-pregnancy. In 652 women from GUSTO cohort, we assessed dietary intakes at 26–28 weeks' gestation and 6 years post-pregnancy using 24-hour recall and food frequency questionnaire, respectively; diet quality was scored using a modified Healthy Eating Index for Singaporean women. Diet quality quartiles were derived; stable, large/small improvement/decline in diet quality as no change, >1 or 1 quartile increase/decrease. Fasting triglyceride (TG), total-, high- and low-density lipoprotein cholesterol (TC, HDL- and LDL-C), glucose and insulin were measured 8 years post-pregnancy; homeostatic model assessment for insulin resistance (HOMA-IR) and TG: HDL-C ratio were derived. Linear regressions examined changes in diet quality quartiles and cardio-metabolic markers. Compared to a stable diet quality, a large improvement was associated with lower post-pregnancy TG [−0.17 (−0.32, −0.01) mmol/L], TG: HDL-C ratio [−0.21 (−0.35, −0.07) mmol/L], and HOMA-IR [−0.47 (−0.90, −0.03)]; a large decline was associated with higher post-pregnancy TC and LDL-C [0.25 (0.02, 0.49); 0.20 (0.004, 0.40) mmol/L]. Improving or preventing a decline in diet quality post-pregnancy may improve lipid profile and insulin resistance.

Keywords: diet quality; pregnancy; post-pregnancy; adiposity, cardiometabolic

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1. Introduction

There is evidence that adopting a healthy diet during pregnancy is associated with better pregnancy outcomes such as lower risks of gestational diabetes [1] and preterm birth [2], as well as better offspring metabolic and cognitive health [3,4]. Having a healthy diet after pregnancy is also important to ensure optimal maternal health in the long term. A woman's diet after pregnancy can influence postpartum weight retention [5], which contributes to the risk of cardio-metabolic diseases later in life [6,7].

Evaluating changes in diet during transitional life stages such as from pregnancy to post-pregnancy could identify a window of opportunity for interventions to reduce disease risk. A recent systematic review examining changes in diet from pregnancy to post-pregnancy found a general decline in healthy dietary behaviors/patterns post-pregnancy [8], possibly due to the demands associated with caring for a child [9]. During the transition from pregnancy to post-pregnancy, women significantly decreased their fruit and vegetable intakes, decreased diet quality or adherence to a healthy dietary pattern, whilst significantly increasing discretionary food intakes [8]. Similarly, using data from a longitudinal mother-offspring cohort of multiethnic Asian women, we previously observed that approximately 30% of mothers decreased adherence to a dietary pattern characterized by higher intakes of fruit, vegetables, plant proteins and whole grains, as well as emergence of an “unhealthy” dietary pattern post-pregnancy which was not observed during pregnancy, suggesting poorer dietary intake post-pregnancy [10].

Whilst the aforementioned studies have assessed changes in diet from pregnancy to post-pregnancy, they have only described the correlates or determinants of these changes [8,10], and did not relate dietary changes from pregnancy to post-pregnancy with cardio-metabolic risk markers (CMRM). Evaluating the impact of dietary changes on CMRM is meaningful to determine the associated changes in risk markers when individuals make changes to their diet. Understanding how improvements in diet quality influence subsequent CMRM allows us to mimic an intervention study where individuals make real-life changes to their diet quality.

It can be expected that long term maintenance of a high-quality diet from pregnancy to post-pregnancy associate with lower cardio-metabolic risk due to mounting evidence in non-pregnant populations showing a high adherence to healthful dietary patterns to associate with lower cardiovascular disease (CVD) risk [11]. However, to consistently maintain a high-quality diet is challenging, and as aforementioned, women tended to decrease their diet quality after pregnancy. It is unclear whether a deterioration in diet quality will make a difference in women’s cardio-metabolic disease risk.

The present study aimed to examine the associations of changes in diet quality from pregnancy to 6 years post-pregnancy with CMRM (adiposity, lipid profile, glycaemia, insulin resistance and blood pressure) at 6-8 years post-pregnancy in a longitudinal cohort of multi-ethnic Asian women.

2. Materials and Methods

Study sample

We used data from the Growing Up in Singapore Towards healthy Outcomes (GUSTO) study – a mother-offspring cohort in Singapore [12]. GUSTO recruited pregnant women (≥ 18 years) in their first trimester (< 14 weeks) from the National University Hospital and KK Women's and Children's Hospital –major public maternity units in Singapore during June 2009-September 2010. Only Chinese, Malay or Indian women of Singapore citizenship or permanent residency, with homogenous parental ethnic background were eligible to participate; women receiving chemotherapy, psychotropic drugs or had type I diabetes mellitus were ineligible. Further details on the GUSTO study have been published [12]. All procedures of the GUSTO study were approved by the Institutional Review Board of the two maternity units, and in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants at study recruitment.

GUSTO recruited 1450 women initially, but the present analysis excluded women who conceived via in-vitro fertilization or had twin pregnancies ($n=106$); only 652 women had complete data for dietary intake during pregnancy and at 6 years post-pregnancy, as well as data for at least one measurement of CMRM (adiposity, lipid profile, glycaemia, insulin resistance and blood pressure) at 6-8 years post-pregnancy. For analyses with adiposity, women were further excluded if they did not have data for booking BMI and

GWG; whereas for analyses with glycaemia and HOMA-IR or blood pressure, women were excluded if they self-reported having pre-existing T2DM or hypertension at recruitment, respectively (Figure 1).

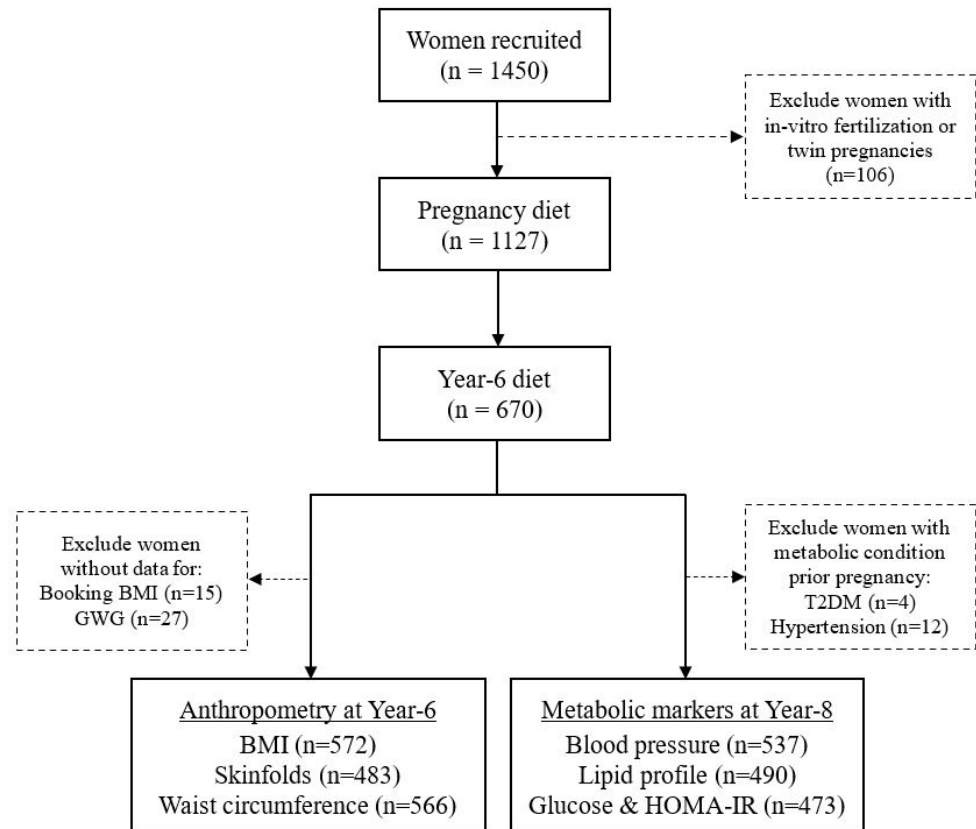


Figure 1. Participant flowchart. BMI, body mass index; GWG, gestational weight gain; HOMA-IR, homeostasis model assessment of insulin resistance; T2DM, type-2 diabetes mellitus.

Dietary intakes during pregnancy and at 6 years post-pregnancy

Women's dietary intake during pregnancy was assessed at 26–28 weeks' gestation with a 24-hour recall. The 24-hour recall was administered by trained research staff using the 5-stage, multiple-pass interviewing technique [13]. Visual aids in terms of household utensils and portion-size pictures were provided to assist in estimation of amounts consumed. Further details of the 24-hour recall procedures and analyses in the GUSTO study have been previously published [14,15].

Dietary intake of these women was re-assessed at 6 years post-pregnancy with a 133-item, semi-quantitative food frequency questionnaire (FFQ), which was administered by trained research staff [10]. Further details and validation of the FFQ have been published [10,16]. In brief, Women were asked to indicate their frequency of consuming each FFQ item in the past 1 month in an open-ended format ('never', 'number of times per month', 'number of times per week' or 'number of times per day'), and the average amount consumed. Images of household utensils and portion sizes were provided.

Nutrient analysis of the 24-hour recalls and FFQs was performed using the Diet-plan software (Forestfield Software Ltd, UK) based on a local food composition database.

Diet quality during pregnancy and at 6 years post-pregnancy

Diet quality during pregnancy was ascertained using the Healthy Eating Index for pregnant women in Singapore (HEI-SGP) [17]. The HEI-SGP was developed with reference to the Healthy Eating Index [18] and the Alternate Healthy Eating Index for

Pregnancy [19], modified according to the Singapore dietary guidelines for pregnant women [20]. The original HEI-SGP has 11 components and a maximum possible score of 90 with a higher score indicating better diet quality. Each component was scored based on nutrient density per 1,000 kcal, with the exception of total fat and saturated fat. Total fruits, whole fruits, total vegetables, and dark green leafy and orange vegetables were scored 5 if recommendations were met, 0 if no consumption, and proportionately for intermediate intakes. Total rice and alternatives, whole grains, dairy and total protein foods were scored 10 if recommendations were met, 0 if no consumption, and proportionately for intermediate intakes. Total fat and saturated fat were scored 10 if recommendations were met (<30% and <10% of energy intake, respectively), scored 0 if >40% and >20% of energy intake, respectively, and proportionately for intermediate intakes (30-40% and 10-20% of energy intake, respectively). Consumption of antenatal supplements containing iron, folate, and calcium was scored 10 if the supplements contained all three micronutrients, 5 if containing one or two of these stated micronutrients, and 0 if not consumed or the supplements did not contain these micronutrients. Details of the HEI-SGP were previously published [17].

For ascertainment of diet quality at 6 years post-pregnancy, we modified the HEI-SGP according to local recommendations for non-pregnant women [21]. The main changes were in the recommended intakes due to differences in dietary requirements between pregnant and non-pregnant women. Additionally, the dietary supplements component was removed from calculation of the modified HEI-SGP scores at 6 years post-pregnancy as there are no local recommendations for dietary supplements intake for non-pregnant women [21]. The assignment of scores and foods categorized under each specific component was similar, with differences or similarities in scoring between pregnancy and 6 years post-pregnancy shown in Supplementary Table 1.

To ensure comparability of diet quality scores between the time points for subsequent analyses, the antenatal supplements component was removed from the calculation of scores at pregnancy, resulting in maximum scores of 80 for both time points instead of the original maximum score of 90.

Adiposity at 6 years post-pregnancy

At 6 years post-pregnancy, women's weight was measured using an electronic weighing scale to the nearest 0.1 kg, and height was measured with a stadiometer (SECA Corp, Hamburg, Germany) to the nearest 0.1 cm by trained research staff. Body mass index (BMI) was calculated as weight (in kilograms) divided by height (in meters and squared). Waist circumference (WC) was measured at the uppermost lateral border of the ilium to the nearest 0.1 cm using a non-stretchable measuring tape. Skinfold thicknesses were measured to the nearest 0.2mm at four sites (biceps, triceps, subscapular and suprailiac) using a Holtain skinfold caliper following standard procedures [22]. Sum of skinfold thicknesses (SST) at all four sites were derived. For reliability, weight, height, and waist circumference were taken in duplicates, while skinfold measurements were taken in triplicates, and respective measurements were averaged.

Cardio-metabolic risk markers at 8 years post-pregnancy

At 8 years post-pregnancy, overnight fasting plasma triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), glucose and insulin were measured using standard colorimetric or enzymatic methods in a clinically-accredited laboratory. Homeostasis model assessment of insulin resistance (HOMA-IR) was calculated as (fasting insulin [mU/L] × fasting glucose [mmol/L])/22.5. Ratios of TC to HDL-C (TC: HDL-C) and of TG to HDL-C (TG: HDL-C) were derived.

Peripheral systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured in triplicates (Dinamap CARESCAPE V100, GE Healthcare, Milwaukee, WI) from the upper right arm by trained research staff following standardized protocols, and measurements averaged.

Derivation of Framingham Risk Score

The Framingham risk score (FRS) was used to estimate women's risk of CVD over 10 years, with higher scores indicating higher CVD risk [23]. The scores were calculated based on age, sex, elevated TC levels, low levels of HDL-C, cigarette smoking, and SBP or hypertension-diagnosis [23] assessed at 8 years post-pregnancy. Information on current cigarette smoking and being diagnosed with hypertension were self-reported via questionnaires administered by trained research staff. We modified the FRS, which was originally scored according to the Framingham-based NCEP ATP III 10-Year Risk Score Tables [24], to account for local clinical practice guidelines for lipids and blood pressure management. Detailed scoring of the locally modified FRS [25] as well as local clinical practice guidelines have been published [26,27].

Covariates

At study recruitment, information on women's age, ethnicity, highest education attained, monthly household income, type-2 diabetes mellitus (T2DM) and high blood pressure prior to pregnancy was collected via self-report. Parity at recruitment was retrieved from hospital delivery records. Women's BMI at first antenatal appointment (booking BMI) was determined based on weight measured at first antenatal appointment (in the first trimester), and height measured at the 26-28 weeks' gestation study visit. Inadequate, adequate and excessive gestational weight gain (GWG) were according to the cut-offs set by the Institute of Medicine recommended rate of weight gain (kg/week) in the second and third trimesters [28] based on booking BMI category. Methods deriving rate of GWG have been detailed elsewhere [29]. At 26-28 weeks' gestation, self-reported physical activity in the past 7 days were assessed with the International Physical Activity Questionnaire (IPAQ) (31). Duration and frequency of physical activity were used to derive metabolic equivalent minutes per week (MET-min/week) and categorized as follows: <600, 600-3000, and >3000 MET-min/week for insufficiently, sufficiently or highly active as detailed previously [30]. Women underwent a 2-hour 75 g oral glucose tolerance testing at 26-28 weeks' gestation to determine the presence of gestational diabetes mellitus (GDM) according to the 1999 WHO diagnostic criteria [31]. Information on hypertensive disorders of pregnancy (pre-eclampsia and pregnancy-induced hypertension) were obtained from hospital case notes. Education and household income were re-assessed at 5 years post-pregnancy, and physical activity was re-assessed at 6 years post-pregnancy. Updated parity information at 8 years post-pregnancy was derived by summing the number of births after the GUSTO birth, GUSTO birth, and parity at recruitment; as women's cardio-metabolic risk increase with increasing parity [32]. Weight changes from pregnancy to 8 years post-pregnancy was calculated as the difference between measured weight at first antenatal appointment and measured weight at 8 years post-pregnancy.

Statistical analysis

Primary analysis

Quartiles of diet quality scores at pregnancy and post-pregnancy were derived separately. A change in diet quality was computed as the difference in quartiles of scores at pregnancy and post-pregnancy. Women were categorized into 5 groups of change in diet quality as follows: stable (no change in quartile), large decrease (>1 quartile decrease), small decrease (1 quartile decrease), small increase (1 quartile increase), and large increase (>1 quartile increase).

Participant characteristics according to groups of change in diet quality were compared using one-way ANOVA for continuous variables or chi-squared tests for categorical variables.

Linear regressions were performed to examine associations of changes in diet quality (5 groups: stable, large/small decrease, large/small increase) with adiposity and CMRM at 6-8 years post-pregnancy. Models were adjusted for age at recruitment,

ethnicity, education and household income at recruitment and their changes at 5 years post-pregnancy, updated parity at 8 years post-pregnancy, physical activity at mid-pregnancy and change at 6 years post-pregnancy, booking BMI, and quartiles of pregnancy diet quality scores. Models with adiposity outcomes additionally adjusted for GWG category, whilst models with **CMRM** were additionally adjusted for weight changes from pregnancy to 8 years post-pregnancy to determine if changes in markers were a result of changes in weight, as well as 1) GDM for analysis of glycaemia and HOMA-IR outcomes, and 2) hypertensive disorders of pregnancy for analysis of blood pressure outcome.

Secondary analysis

In addition to examining the influence of dietary changes, we examined the influence of diet quality at specific time periods i.e. pregnancy or post-pregnancy on **CMRM** by performing additional analyses to separately associate diet quality at pregnancy and at 6 years post-pregnancy with adiposity and **CMRM** post-pregnancy, with mutual adjustment for diet quality at the other time point. The models associating diet quality at pregnancy with outcomes were adjusted for diet quality at 6 years post-pregnancy, ethnicity, booking BMI, mid-pregnancy physical activity; age, education, household income and parity at recruitment; and GWG category (for adiposity), or weight changes at 8 years post-pregnancy and GDM (for glycaemia and HOMA-IR) or weight changes at 8 years post-pregnancy and hypertensive disorders of pregnancy (for blood pressure). The models associating diet quality at 6 years post-pregnancy with outcomes were adjusted for diet quality at pregnancy, age at recruitment, ethnicity, booking BMI; education and household income at 5 years post-pregnancy; parity and weight changes at 8 years post-pregnancy; and GWG category (for adiposity), or GDM (for glycaemia and HOMA-IR) or hypertensive disorders of pregnancy (for blood pressure).

We also tested effect modification by parity at recruitment (0 and ≥ 1) by adding interaction terms (parity \times groups of change in diet quality) in the multivariable regression models, and subsequently performed stratified analysis for any statistically significant interactions.

To investigate how each of the 10 HEI-SGP components contributed to the association between change in diet quality and adiposity or **CMRM**, we successively excluded each component at both pregnancy and post-pregnancy and compared the attenuation in effect estimates.

Multiple imputation with chained equations (20 times) were performed for covariates with missing data: education (n=1), household income (n=14), parity (n=48) and physical activity (n=36) collected post-pregnancies. We used Stata version 14 (StataCorp LP, College Station, TX, USA) to perform all analyses, and considered two-sided $P < 0.05$ to be statistically significant.

3. Results

3.1. Primary analysis

Of the 652 women with data for at least one outcome, 18.3% (n=119) and 16.4% (n=107) had a large decrease or increase in diet quality, respectively; whilst 16.7% (n=109) and 19.6% (n=128) had a small decrease or increase in diet quality, respectively; with 29% (n=189) remaining in the same diet quality quartile from pregnancy to 6 years post-pregnancy. Comparisons of characteristics across changes in diet quality are shown in Table 1. Women with a decrease (small or large) in diet quality tended to be older and of Chinese ethnicity, whereas women with an increase (small or large) in diet quality tended to be of Malay ethnicity.

Table 1. Characteristics¹ of GUSTO women included in the analysis of change in diet quality with cardio-metabolic risk markers (n=652).

	Large decrease (n=123)	Small decrease (n=107)	Stable (n=193)	Small increase (n=124)	Large increase (n=105)	P ²
Age at recruitment, year	30.9 ± 5.0	31.9 ± 5.1*	30.2 ± 4.9	30.9 ± 5.3	29.7 ± 5.3*	0.021
Ethnicity						<0.001
Chinese	89 (72.4)	68 (63.6)	110 (57.0)	59 (47.6)	43 (41.0)	
Malay	22 (17.9)	21 (19.6)	46 (23.8)	43 (34.7)	39 (37.1)	
Indian	12 (9.8)	18 (16.8)	37 (19.2)	22 (17.7)	23 (21.9)	
Highest Education						0.160
Primary/secondary	36 (29.3)	33 (30.8)	56 (29.2)	42 (33.9)	41 (39.1)	
Post-secondary	40 (32.5)	33 (30.8)	61 (31.8)	48 (38.7)	39 (37.1)	
University	47 (38.2)	41 (38.3)	71 (39.1)	34 (27.4)	25 (23.8)	
Monthly household income, SGD						0.054
< 1999	14 (12.2)	15 (15.3)	29 (16.2)	20 (16.9)	20 (20.4)	
2000–5999	64 (55.6)	57 (58.2)	90 (50.3)	76 (64.4)	61 (62.2)	
> 6000	37 (32.2)	26 (26.5)	60 (33.5)	22 (18.6)	17 (17.4)	
Booking BMI ³ , kg/m ²	23.3 ± 4.1	23.3 ± 4.6	23.4 ± 4.4	24.9 ± 5.9	23.4 ± 4.5	0.053
Parity at recruitment						0.161
0	56 (45.5)	36 (33.6)	87 (45.1)	56 (45.2)	40 (38.1)	
≥1	67 (54.5)	71 (66.4)	106 (54.9)	68 (54.8)	65 (61.9)	
Gestational diabetes	26 (21.9)	22 (21.4)	30 (16.0)	21 (17.7)	11 (10.5)	0.313
Pregnancy hypertensive disorders	6 (4.9)	6 (5.6)	9 (4.7)	8 (6.5)	1 (1.0)	0.273
Gestational weight gain						0.324
Excessive	57 (47.9)	50 (49.5)	98 (53.3)	70 (59.3)	51 (53.1)	
Inadequate	11 (9.2)	13 (14.1)	28 (15.2)	9 (7.6)	12 (12.5)	
Normal	51 (42.9)	36 (36.4)	58 (31.5)	39 (33.1)	33 (34.4)	
Physical activity, MET-min/week						0.398
<600	39 (32.0)	32 (30.2)	64 (33.3)	40 (32.5)	24 (22.9)	
600-3000	57 (46.7)	57 (53.8)	90 (46.9)	65 (52.9)	54 (51.4)	
3000	26 (21.3)	17 (16.0)	38 (19.8)	18 (14.6)	27 (25.7)	

BMI, body mass index; GUSTO, Growing Up in Singapore Towards healthy Outcomes; MET, metabolic equivalent of task

¹ Values are mean ± SD or n (%). Characteristics were based on data obtained during study recruitment or 26-28 weeks gestation unless otherwise specified.

² P-values are for one-way ANOVA (*mean values in a row with a common symbol differ, P< 0.05 based on Bonferroni post hoc analysis) or chi-square tests

³ Based on weight measured at first antenatal appointment in the first trimester and height measured at 26-28 weeks' gestation

When examining the associations with adiposity at 6 years post-pregnancy, there were no associations of change in diet quality with BMI, sum of skinfolds and waist circumference (Table 2).

When examining the associations with **CMRM** at 8 years post-pregnancy, a “large decrease” in diet quality was associated with 0.25 mmol/L (95% CI: 0.02, 0.49) higher total cholesterol and 0.20 mmol/L (95% CI: 0.004, 0.40) higher LDL-C (Table 2), compared to a “stable” diet quality. Additionally, a “large increase” in diet quality was associated with 0.17 mmol/L (95% CI: -0.32, -0.01) lower triglycerides and 0.21 (95% CI: -0.35, -0.07) lower TG: HDL-C ratio, as well as 0.47 (95% CI: -0.90, -0.03) lower HOMA-IR, compared to a “stable” diet quality. A “small” decrease/increase in diet quality was not associated with the same **CMRM** at 8 years post-pregnancy. No associations were observed for change in diet quality with HDL-C, TC: HDL-C ratio, fasting glucose, blood pressure and FRS.

Table 2. Associations of change in diet quality from pregnancy to 6 years post-pregnancy with anthropometry and cardio-metabolic markers at 6-8 years post-pregnancy in women of the GUSTO cohort.

	Large decrease		Small decrease		Stable	Small increase		Large increase	
	β (95% CI)	P	β (95% CI)	P		β (95% CI)	P	β (95% CI)	P
Anthropometry¹									
BMI, kg/m ²	-0.34 (-0.96, 0.29)	0.294	-0.11 (-0.72, 0.49)	0.711	Reference	0.11 (-0.45, 0.68)	0.694	-0.41 (-1.05, 0.24)	0.219
Skinfolds ² , mm	-0.46 (-5.45, 4.53)	0.647	1.12 (-3.67, 5.90)	0.647	Reference	3.36 (-1.14, 7.87)	0.143	-0.93 (-6.24, 4.37)	0.730
WC ³ , cm	-0.11 (-2.08, 1.85)	0.909	0.97 (-0.94, 2.87)	0.318	Reference	0.59 (-1.17, 2.36)	0.510	-1.16 (-3.22, 0.91)	0.271
Lipid profile⁴									
Total cholesterol, mmol/L	0.25 (0.02, 0.49)	0.032	-0.08 (-0.32, 0.16)	0.520	Reference	0.04 (-0.18, 0.26)	0.731	0.05 (-0.20, 0.29)	0.707
Triglycerides, mmol/L	0.003 (-0.11, 0.12)	0.955	-0.004 (-0.14, 0.13)	0.960	Reference	-0.13 (-0.27, 0.01)	0.067	-0.17 (-0.32, 0.01)	0.038
LDL-C, mmol/L	0.20 (0.004, 0.40)	0.046	-0.07 (-0.27, 0.14)	0.524	Reference	0.05 (-0.13, 0.24)	0.581	0.06 (-0.15, 0.27)	0.578
HDL-C, mmol/L	0.05 (-0.03, 0.13)	0.222	-0.01 (-0.09, 0.06)	0.755	Reference	0.04 (-0.03, 0.11)	0.214	0.06 (-0.02, 0.14)	0.130
TC: HDL-C	0.15 (-0.08, 0.37)	0.204	-0.06 (-0.28, 0.17)	0.624	Reference	-0.13 (-0.34, 0.07)	0.192	-0.17 (-0.40, 0.07)	0.158
TG: HDL-C	-0.01 (-0.15, 0.13)	0.900	0.003 (-0.13, 0.14)	0.960	Reference	-0.16 (-0.29, 0.04)	0.012	-0.21 (-0.35, 0.07)	0.004
Glycemia⁵									
Fasting glucose, mmol/L	-0.04 (-0.35, 0.27)	0.800	0.01 (-0.30, 0.32)	0.945	Reference	0.06 (-0.22, 0.34)	0.655	-0.09 (-0.26, 0.08)	0.317
HOMA-IR	0.23 (-0.21, 0.66)	0.304	-0.002 (-0.40, 0.40)	0.991	Reference	-0.07 (-0.47, 0.33)	0.728	-0.47 (-0.90, 0.03)	0.035
Blood pressure⁶									
Systolic, mmHg	-0.55 (-4.23, 3.13)	0.769	2.43 (-1.19, 6.04)	0.188	Reference	-1.27 (-4.57, 2.03)	0.450	-0.17 (-4.03, 3.68)	0.931
Diastolic, mmHg	-1.23 (-3.89, 1.44)	0.366	0.53 (-2.09, 3.16)	0.690	Reference	-0.40 (-3.20, 2.40)	0.779	-1.85 (-4.25, 0.46)	0.070

BMI, body mass index; GUSTO, Growing Up in Singapore Towards healthy Outcomes; HDL-C, high-density-lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, high-density-lipoprotein cholesterol; TC: HDL-C, ratio of total to high-density-lipoprotein cholesterol, TG: HDL-C, ratio of triglycerides to high-density-lipoprotein cholesterol; WC, waist circumference

¹ Models adjusted for age at recruitment, ethnicity; education, household income, physical activity, parity and their changes; booking BMI, pregnancy diet quality, gestational weight gain category

² n=93 'large decrease', n=84 'small decrease', n=155 'stable', n=89 'small increase', n=62 'large increase'

³ n=109 'large decrease', n=98 'small decrease', n=175 'stable', n=106 'small increase', n=78 'large increase'

⁴ Models adjusted for age at recruitment, ethnicity; education, household income, physical activity, parity and their changes; booking BMI, pregnancy diet quality, weight changes at Year-8, ⁵GDM, ⁶hypertensive disorders of pregnancy

3.2. Secondary analysis

Compared to the lowest quartile of diet quality, being in the highest quartile of diet quality at pregnancy was associated with lower sum of skinfolds and lower waist

circumference at 6 years post-pregnancy, as well as lower FRS at 8 years post-pregnancy (Table 3), but no associations were observed for diet quality at 6 years post-pregnancy with these risk markers. Additionally, being in the highest quartile of diet quality at either pregnancy or 6 years post-pregnancy was associated with lower triglycerides, TC: HDL-C ratio, TG: HDL-C ratio, and HOMA-IR, compared to the lowest quartile of diet quality.

Table 3. Associations of diet quality at pregnancy or at 6 years post-pregnancy with anthropometry and cardio-metabolic markers at 6-8 years post-pregnancy in women of the GUSTO cohort.

	Q1	Q2		Q3		Q4	
		β (95% CI)	P	β (95% CI)	P	β (95% CI)	P
Diet quality at pregnancy							
Anthropometry ¹							
BMI, kg/m ²	Reference	-0.33 (-0.96, 0.30)	0.300	-0.21 (-0.84, 0.42)	0.512	-0.62 (-1.25, 0.01)	0.056
Skinfolds ² , mm	Reference	0.40 (-3.90, 4.70)	0.856	-1.59 (-5.98, 2.80)	0.477	-4.75 (-9.13, -0.37)	0.033
WC ³ , cm	Reference	-0.44 (-2.14, 1.26)	0.610	0.28 (-1.42, 1.97)	0.748	-1.97 (-3.70, -0.25)	0.025
Lipid profile ⁴							
Total cholesterol, mmol/L	Reference	-0.05 (-0.26, 0.15)	0.616	-0.04 (-0.25, 0.17)	0.698	-0.14 (-0.35, 0.07)	0.191
Triglycerides, mmol/L	Reference	-0.08 (-0.20, 0.04)	0.187	-0.11 (-0.23, 0.01)	0.072	-0.21 (-0.33, -0.09)	0.001
LDL-C, mmol/L	Reference	-0.02 (-0.19, 0.16)	0.863	0.02 (-0.16, 0.20)	0.856	-0.08 (-0.26, 0.10)	0.377
HDL-C, mmol/L	Reference	-0.001 (-0.07, 0.06)	0.965	-0.01 (-0.08, 0.06)	0.796	0.04 (-0.03, 0.10)	0.309
TC: HDL-C	Reference	-0.07 (-0.26, 0.12)	0.463	-0.05 (-0.24, 0.15)	0.646	-0.22 (-0.42, -0.02)	0.030
TG: HDL-C	Reference	-0.08 (-0.19, 0.04)	0.199	-0.10 (-0.22, 0.02)	0.096	-0.21 (-0.33, -0.09)	0.001
Glycemia ⁵							
Fasting glucose, mmol/L	Reference	0.09 (-0.17, 0.35)	0.502	-0.18 (-0.45, 0.09)	0.181	-0.24 (-0.52, 0.03)	0.083
HOMA-IR	Reference	0.11 (-0.30, 0.52)	0.597	-0.06 (-0.48, 0.36)	0.782	-0.35 (-0.78, -0.08)	0.017
Blood pressure ⁶							
Systolic, mmHg	Reference	1.94 (-1.20, 5.08)	0.225	-0.30 (-3.47, 2.86)	0.850	0.92 (-2.30, 4.15)	0.575
Diastolic, mmHg	Reference	1.56 (-0.73, 3.84)	0.181	-0.61 (-2.92, 1.69)	0.603	0.18 (-2.17, 2.53)	0.879
Diet quality at 6 years post-pregnancy							
Anthropometry ⁷							
BMI, kg/m ²	Reference	0.19 (-0.34, 0.72)	0.481	0.17 (-0.35, 0.71)	0.512	-0.35 (-0.90, 0.20)	0.208
Skinfold ² , mm	Reference	1.59 (-4.16, 7.33)	0.587	-3.37 (-9.11, 2.36)	0.249	-3.80 (-9.58, 1.97)	0.196
WC ³ , cm	Reference	-1.03 (-2.71, 0.66)	0.231	-0.13 (-1.82, 1.57)	0.884	-1.48 (-3.20, 0.25)	0.093
Lipid profile ⁸							
Total cholesterol, mmol/L	Reference	0.03 (-0.17, 0.24)	0.738	-0.06 (-0.27, 0.15)	0.551	-0.15 (-0.36, 0.05)	0.144
Triglycerides, mmol/L	Reference	-0.10 (-0.22, 0.02)	0.090	-0.07 (-0.19, 0.05)	0.242	-0.15 (-0.28, -0.03)	0.012
LDL-C, mmol/L	Reference	0.02 (-0.15, 0.20)	0.788	-0.05 (-0.23, 0.13)	0.556	-0.11 (-0.29, 0.07)	0.226
HDL-C, mmol/L	Reference	0.06 (-0.01, 0.12)	0.085	0.02 (-0.04, 0.09)	0.503	0.03 (-0.04, 0.09)	0.460
TC: HDL-C	Reference	-0.16 (-0.35, 0.03)	0.091	-0.16 (-0.35, 0.04)	0.113	-0.23 (-0.43, -0.04)	0.018
TG: HDL-C	Reference	-0.09 (-0.22, 0.02)	0.095	-0.11 (-0.23, 0.01)	0.084	-0.17 (-0.30, -0.05)	0.005
Glycemia ⁹							
Fasting glucose, mmol/L	Reference	-0.06 (-0.17, 0.06)	0.340	-0.03 (-0.16, 0.09)	0.603	-0.04 (-0.17, 0.08)	0.479
HOMA-IR	Reference	-0.20 (-0.49, 0.09)	0.169	-0.18 (-0.48, 0.02)	0.074	-0.24 (-0.65, -0.08)	0.039
Blood pressure ¹⁰							
Systolic, mmHg	Reference	2.47 (-0.55, 5.50)	0.108	0.80 (-2.23, 3.84)	0.604	0.52 (-2.58, 3.62)	0.742
Diastolic, mmHg	Reference	1.76 (-0.50, 4.03)	0.126	0.55 (-1.73, 2.82)	0.637	0.18 (-2.14, 2.50)	0.877

BMI, body mass index; GUSTO, Growing Up in Singapore Towards healthy Outcomes; HDL-C, high-density-lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, high-density-lipoprotein cholesterol; TC: HDL-C, ratio of total to high-density-lipoprotein cholesterol; TG: HDL-C, ratio of triglycerides to high-density-lipoprotein cholesterol; WC, waist circumference

¹ Models adjusted for age at recruitment, ethnicity; education, household income, parity, physical activity during pregnancy, booking BMI, diet quality at Year-6, and gestational weight gain category
² n=126 Q1, n=122 Q2, n=123 Q3, n=112 Q4
³ n=146 Q1, n=144 Q2, n=141 Q3, n=135 Q4
⁴ Models adjusted for age at recruitment, ethnicity; education, household income, parity, physical activity during pregnancy, booking BMI, diet quality at Year-6, weight changes at Year-8, and ⁵GDM or ⁶hypertensive disorders of pregnancy
⁷ Models adjusted for age at recruitment, ethnicity; education, household income and parity at Year 4-5; physical activity at Year-6, diet quality at pregnancy, booking BMI and gestational weight gain category
⁸ Models adjusted for age at recruitment, ethnicity; education, household income and parity at Year 4-5; physical activity at Year-6, diet quality at pregnancy, booking BMI, weight changes at Year-8, and ⁹GDM or ¹⁰hypertensive disorders of pregnancy

Parity at recruitment significantly modified the associations of changes in diet quality with total cholesterol and LDL-C (P-interaction < 0.05), whereby the associations of a “large decrease” in diet quality with higher total and LDL-cholesterol were significant and stronger among women who were parous at study recruitment (Supplementary Table 2).

Successively excluding fruit (total or whole), dairy and protein foods components at both time points attenuated the association of a “large decrease” with higher total cholesterol and LDL-cholesterol (Supplementary Figure 1). Successively excluding the dairy component and/or total rice and alternatives and protein foods components at both time points attenuated the association of a “large increase” with lower triglycerides and TG: HDL-C ratio (Supplementary Figure 2). Successively excluding the whole grains, dairy, and saturated fat components at both time points attenuated the association of a “large increase” in diet quality with lower HOMA-IR.

4. Discussion

In a cohort of multi-ethnic Asian women, we found that a large improvement in diet quality (assessed by a modified HEI-SGP) from pregnancy to 6 years post-pregnancy was associated with lower triglycerides levels and insulin resistance, whereas a large decline in diet quality was associated with higher cholesterol levels. A high diet quality during pregnancy was associated with lower sum of skinfolds and waist circumference at 6 years post-pregnancy, as well as a lower predicted 10-year CVD risk at 8 years post-pregnancy; but a change in diet quality from pregnancy to 6 years post-pregnancy was not associated with these risk markers.

To the best of our knowledge, this is the first study to examine changes in women’s diet quality from pregnancy to post-pregnancy with post-pregnancy **CMRM**. Undeniably, women who maintained a high diet quality from pregnancy to post-pregnancy have the lowest levels of risk markers (**Supplementary Table 3**), but we additionally showed that making improvements to/preventing a decline in diet quality post-pregnancy can still confer benefits on lipid profile and insulin resistance. Our results are reminiscent of findings from a longitudinal study of diet quality with metabolic outcomes in adult men and women, whereby an increase in *a priori* dietary scores (e.g. the Portfolio diet, the Dietary Approaches to Stop Hypertension diet score, or the healthy diet score) were associated with lowering of several **CMRM** [33] (e.g. triglycerides, cholesterol, glucose, HbA1c, blood pressure) as well as a lower risk of T2DM [34]. These results, when considered together with findings from randomized control trials (e.g., the PREDIMED Study [35] and the Lyon Diet Heart Study [36]) support improvements in overall diet as an important strategy to improve **CMRM**. In our study, we found that a large improvement in diet quality, rather than a small improvement, is required to achieve favourable changes in **CMRM**, which can be achieved by changing multiple dietary factors such as consuming greater amounts and varieties of fruit and vegetables, more whole grains, less fat and saturated fat. Health promotion programs supporting women to make improvements in several

388 dietary aspects post-pregnancy are needed to impact on women's long-term cardio-met- 389
abolic health.

390 An inherent issue in examining changes in diet quality is that the corresponding 391
changes in CMRM may be dependent on initial diet quality. For example, participants 392
with a larger increase in diet quality tended to be those with poorer diet quality initially. 393
However, our analyses (adjusting for diet quality at pregnancy) showed that those with a 394
large increase in diet quality had lower triglycerides and insulin resistance independent 395
of initial diet quality, suggesting that improving women's diet after pregnancy can be 396
beneficial for these risk markers. In addition, this study provides novel data showing a 397
deterioration in diet quality is associated with higher cholesterol independent of initial 398
diet quality. Concurring with our previous publication [10], in which a third of women 399
were observed to decrease adherence to a "Fruit, vegetables and legumes" dietary pattern 400
(a "healthy" diet), approximately 35% of women in the present study with 18% having a 401
large decrease in diet quality post-pregnancy. This is concerning and signifies the need 402
for more interventions and health promotion efforts to prevent a decline in diet quality 403
during the transition from pregnancy to motherhood.

404 The associations of changes in diet quality with lipids and insulin resistance did not 405
appear to be explained by weight changes from pregnancy to 8 years post-pregnancy. The 406
potential mechanisms explaining the associations may be multifactorial because the mod- 407
ified HEI-SGP includes multiple food components, for example, antioxidants fruit and 408
vegetables may reduce the oxidative stress contributing to the pathogenesis of cardio- 409
metabolic diseases [37], whilst saturated fatty acids are pro-inflammatory molecules con- 410
tributing to elevated cholesterols and insulin resistance [38].

411 We did not find significant associations between changes in diet quality and adiposity 412
at 8 years post-pregnancy, possibly because total energy intake or amounts eaten play 413
more important roles in adiposity [39], whilst the modified HEI-SGP measures diet qual- 414
ity independent of total energy intake and quantity (i.e. each dietary component was 415
standardized for energy intake). Alternatively, it is possible that adiposity reflects longer 416
term diet rather than shorter term dietary changes; as such, diet quality during pregnancy 417
may play a more important role. This is likely because we found being in the highest quar- 418
tile of diet quality scores during pregnancy were associated with lower sum of skinfolds 419
and waist circumference, independent of diet quality at 6 years post-pregnancy.

420 The association between a large decrease or increase in diet quality and FRS at 8 years 421
post-pregnancy was in the same direction as the associations with lipids and insulin re- 422
sistance but did not reach statistical significance. One possible reason could be that our 423
cohort is generally made up of participants with very low CVD risk (i.e. young partici- 424
pants with a mean age of 39.6 years and few (n=38) who smoked), hence limiting the var- 425
iation needed to detect significant associations. Another possible reason is that the risk 426
markers shown to have associations with changes in diet quality were not included as 427
components of FRS. Similar to findings with adiposity, having a high diet quality during 428
pregnancy may promote favourable cardio-metabolic outcomes later in life rather than a 429
high diet quality at 6 years post-pregnancy, highlighting the importance of early interven- 430
tion for reduction of CVD risk.

431 Additionally, neither a change in diet quality nor diet quality at pregnancy and 6 432
years post-pregnancy were associated with blood pressure, likely because the modified 433
HEI-SGP did not capture aspects of diet most closely linked to blood pressure. It is well- 434
established that a reduction in sodium or salt intake decreases blood pressure and the 435
incidence of hypertension [40], but this was not included as a component of the modified 436
HEI-SGP.

437 We noted that fruit, dairy and protein foods are important contributors to the associ- 438
ation between a large decline in diet quality and higher total and LDL cholesterol, as ex- 439
cluding these components attenuated the associations. Indeed, higher fruit intake has 440
been associated with lower total and LDL-cholesterol levels [41]. The beneficial role of 441
dairy and protein foods for total and LDL-cholesterol observed in our study may be

attributable to higher intakes of low-fat dairy and plant-based protein foods [42-44]. This may also explain the contribution of dairy in the associations between a large improvement in diet quality and triglycerides and TG: HDL-C ratio. However, the scoring of HEI-SGP did not differentiate between the types of dairy and protein foods consumed, and warrants further investigation. Additionally, whole grains and saturated fat appear to be major contributors to the associations between a large improvement in diet quality and HOMA-IR, concurring with previous studies reporting that higher intakes of whole grains and limiting intake of saturated fat may be beneficial for insulin resistance [45,46].

We found significant effect modification by parity at recruitment in that the associations of a large decline in diet quality with higher total and LDL-cholesterol levels were stronger among women who were parous at study recruitment. Previous research has shown that women with more children reported lower diet quality [19], as well as multiparity to be a risk factor of cardio-metabolic diseases later in life [47], which when considered together may have multiplicative effects on cardio-metabolic outcomes, as shown in the current study findings.

Strengths of this study include the prospective, longitudinal design with repeated measures of dietary intake. The use of a dietary index with standardised dietary components and scoring criteria allowed assessment of change in diet quality, as opposed to using data-driven dietary patterns which are often not reproducible across time points. Furthermore, unlike data-driven dietary patterns which may not necessarily define the healthiest patterns, our modified HEI-SGP was constructed according to local dietary guidelines on what constitutes a healthy diet which allows translation into practical recommendations. Several limitations should be noted. The CMRM were measured at 8 years post-pregnancy, with diet quality reassessed at 6 years post-pregnancy; there may be changes in diet between 6 years and 8 years post-pregnancy which may have changed the outcome(s) of interest which we have not accounted for. Different dietary assessment methods were used at the two time points (i.e. 24-hour recall during pregnancy and FFQ at 6 years post-pregnancy), which may have affected the comparability of diet quality scores; but we used change in quartiles of diet quality scores instead of absolute scores to account for this difference in assessment method. Furthermore, we have shown in our previous study that dietary patterns derived using the two-assessment method can be tracked longitudinally [10]. Diet was re-assessed 6 years after pregnancy which is a long time after pregnancy and we could not ascertain when the changes were made, and whether the timing of this change and how long the change has been sustained influence the associations observed. As with any longitudinal cohorts, many participants were lost to follow-up due to having a busy schedule, inconvenience, and no longer wished to participate because their children have grown up; although the current analysis is amongst 652 of 1450 women initially recruited, we have shown in a previous publication that the participant characteristics were similar between those with dietary data at both time points versus those who did not [10]. The GUSTO study did not intentionally recruit women representative of the general Singaporean population, hence our findings may not be generalizable to the general Singaporean population nor to populations of differing ethnicities and socioeconomic status.

5. Conclusions

Our study found that a large improvement in diet quality from CMRM and a large decline in diet quality with worse risk markers. This highlights the need to support women beyond the pregnancy and early postpartum period to improve overall diet quality for better CMRM, with parous women requiring greater support to improve their diet quality post-pregnancy. Pregnancy may be an opportune time to encourage adoption of high-quality diets to promote favourable long term adiposity outcomes and lower CVD risk, but this finding will require replication in other studies.

Supplementary Materials: The following supporting information can be downloaded at: 493
www.mdpi.com/xxx/s1, Table S1: Comparison of HEI-SGP scoring criteria between pregnancy and 494
6 years post-pregnancy; Table S2: Associations of change in diet quality from pregnancy to 6 years 495
post-pregnancy with anthropometry and cardio-metabolic markers at 6-8 years post-pregnancy in 496
women of the GUSTO cohort, stratified by parity; Table S3: Anthropometry and cardio-metabolic 497
markers at 6-8 years post-pregnancy according to 6 groups of change in diet quality from pregnancy 498
to 6 years post-pregnancy in women of the GUSTO cohort; Figure S1: The association of change in 499
diet quality, successively excluding individual HEI-SGP components, with total and LDL-choles- 500
terol in GUSTO women; Figure S2: The associations of change in diet quality, successively excluding 501
individual HEI-SGP components, with triglycerides, triglycerides: HDL-C ratio and HOMA-IR in 502
GUSTO women. 503

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526

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