ORIGINAL ARTICLE

Early pregnancy body mass index modifies the association of pre-pregnancy dietary patterns with serum polyunsaturated fatty acid concentrations throughout pregnancy in Brazilian women

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Abstract

Dietary patterns (DPs) have been described as an important factor that may influence polyunsaturated fatty acid (PUFA) concentrations and body mass index (BMI) during pregnancy. We aim to evaluate the association between pre-pregnancy DPs and serum PUFA percentages throughout pregnancy considering early pregnancy BMI as a possible effect modifier. A prospective cohort of 154 pregnant women was followed (5th–13th, 20th–26th, and 30th–36th gestational weeks). Serum PUFA concentrations (total n-3 and total n-6, eicosapentaenoic + docosahexaenoic acids) were measured in each trimester and expressed as percentages. The n-6/n-3 ratio was calculated. Longitudinal linear mixed-effects models including interaction terms between DPs and early pregnancy BMI were employed. Serum PUFA percentages declined, whereas the n-6/n-3 ratio, mono-unsaturated, and saturated percentages increased throughout pregnancy for all BMI categories. Three pre-pregnancy DPs were identified by principal component analysis (*common Brazilian*, *healthy*, and *processed*). Overweight women with higher adherence to the *common-Brazilian* and to the *healthy* DPs presented reduced n-3 PUFA percentage and increased n-6 percentages and n-6/n-3 ratio compared to under or normal weight women. Obese women with higher adherence to the *processed* DP presented a more pronounced decrease of total n-3 percentage compared to under or normal weight women. Early pregnancy BMI modified the effect of pre-pregnancy DPs on PUFA profile throughout gestation. Higher adherence to the *healthy* pattern was associated with increased n-3 percentage, except for overweight women. Only for *processed* DP was the behaviour of PUFA the same for all BMI categories, showing a worse evolution profile, that is, increased n-6 and reduced n-3 fractions.

KEYWORDS

body mass index, dietary patterns, essential fatty acids, longitudinal analysis, nutritional epidemiology, pregnancy

1 | INTRODUCTION

The polyunsaturated fatty acids (PUFAs) of the n-3 and n-6 series play an important role during pregnancy. Linoleic acid (LA; 18:2 n-6) and alpha-linolenic acid (ALA; 18:3 n-3) are not endogenously synthesised by the human body and must be obtained from the diet (Kremmyda, Tvrzicka, Stankova, & Zak, 2011). Their long-chain derivatives are in

high demand during pregnancy, especially docosahexaenoic acid (DHA, derived from ALA; 22:6 n-3) and arachidonic acid (derived from LA; 20:4 n-6; Gil-Sánchez, Koletzko, & Larqué, 2012; Uauy, Mena, & Rojas, 2000).

Dietary studies have demonstrated the influence of food sources of PUFA (particularly fish products) on the increase of DHA and eicosapentaenoic acid (EPA; 20:5 n-3) and EPA + DHA concentrations

(Chien et al., 2013; Klebanoff et al., 2011). Pounis et al. (2014) identified two dietary patterns (DPs) that explain the variation in n-3 fatty acid (FA) concentrations in plasma and red blood cells in European adult populations. The authors observed that the fish, the main source of n-3 PUFA, was one of the food items that comprised the red blood cell model. However, the plasma model was composed of components that are not considered as rich in n-3 PUFA (cabbages and root vegetables, chocolate, coffee and tea, and mayonnaise). This finding may indicate that in a complex diet, foods may not necessarily be the source of a particular nutrient but may collaborate to increase its availability; that is, the interaction of the nutrients may increase or reduce the bioavailability of one another.

Some authors have identified that an adequate nutritional status of essential n-3 and n-6 PUFA and a DP characterised by healthy foods and fish or seafood is associated with a lower risk for the occurrence of preterm newborns (Grieger & Clifton, 2015), depression, and anxiety (Kendall-Tackett, 2010; Vaz et al., 2013; Vilela et al., 2014; Vilela et al., 2015). Furthermore, some studies suggest that higher concentrations of n-3 PUFA are associated with a lower risk of developing gestational diabetes and preeclampsia and that DHA is related to neurological and visual foetus development (Bo et al., 2001; Innis, 2003; Kar, Wong, Rogozinska, & Thangaratinam, 2016; Oken et al., 2007). However, to the best of our knowledge, we found no studies that have investigated the influence of pre-pregnancy DPs on PUFA concentrations throughout pregnancy.

The pre-pregnancy nutritional status can affect PUFA concentrations. Women with excessive weight tend to accumulate more lipids in the placenta when compared to normal weight women (Dubé et al., 2012). However, n-3 PUFA fractions seem to decrease in those women (Calabuig-Navarro et al., 2016; Wijendran et al., 1999). Consequently, these lipid alterations can lead to a worse inflammatory profile (Calabuig-Navarro et al., 2016; Dubé et al., 2012; Tortosa-Caparrós, Navas-Carrillo, Marín, & Orenes-Piñero, 2016).

Considering the biological relevance of essential FA during pregnancy for both the mother and the foetus and the well-known evidence that overweight or obesity prevalence has increased worldwide, it is important to evaluate whether pre-pregnancy nutritional status modifies the effect between dietary intake and serum FA. The present study aimed to evaluate the association between pre-pregnancy DPs and PUFA serum percentages measured throughout pregnancy in a group of low-income Brazilian pregnant women. We also tested if early pregnancy body mass index (BMI) acts as an effect modifier between DPs and the PUFA profile.

2 | METHODS

2.1 | Study design and eligibility criteria

The study comprised a prospective cohort of pregnant women monitored at a public health care centre located in the city of Rio de Janeiro, Brazil. The women were evaluated during the following gestational weeks: 5th–13th, 20th–26th, and 30th–36th. The recruitment began in November 2009 and ended in October 2011.

Key messages

- Early pregnancy body mass index acted as an effect modifier on the association between dietary patterns and polyunsaturated fatty acids during pregnancy.
- Higher adherence to the pre-pregnancy *healthy* dietary pattern was associated with an increase in n-3 fatty polyunsaturated fatty acids during pregnancy, except in overweight women.
- The higher adherence to the pre-pregnancy *processed* dietary pattern was associated with a reduction in the n-3 fraction of polyunsaturated fatty acids and with an increase of the n-6 fraction.

Two hundred and twenty-nine pregnant women who met the following eligibility criteria were invited to participate in the study: (a) being between 5 and 13 weeks of gestation; (b) between 20 and 40 years of age; and (c) without any known infectious or chronic noncommunicable diseases (other than obesity). From those 299 women, 70 women were excluded after enrolment for the following reasons: suffered miscarriages ($n = 25$), presented missing information of FA or dietary intake ($n = 3$), had chronic arterial hypertension (systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg; $n = 2$), had multiple gestation ($n = 4$), were diagnosed with an infectious or noncommunicable disease ($n = 11$), had advanced pregnancy (≥ 14 weeks of gestation; $n = 15$), or missed the baseline interview ($n = 10$). Additionally, 41 women (initially enrolled according to the same eligibility criteria as stated above) were screened for depression risk (Edinburgh Postnatal Depressive Scale score ≥ 9) and were disregarded from the analyses because they were invited to participate in a nested randomised clinical trial associated with this cohort with the aim to investigate the effect of n-3 PUFA on postpartum depression. Thus, the baseline sample comprised 188 pregnant women. From the baseline to the second trimester visit, 18 additional exclusions were implemented, and 15 follow-up losses occurred, leaving 155 women at the second trimester visit. Finally, from the second to third visit, 11 follow-up losses occurred, and 10 women who missed the second visit interview returned. Therefore, our final sample at the third trimester comprised 154 women (Figure 1).

The Maternity Hospital Ethics Committee from the Rio de Janeiro Federal University (Protocol number: 0023.0.361.000-08) and the Municipal Secretary of Rio de Janeiro city Ethics Committee (Protocol number: 0139.0.314.000-09) approved the study protocol. All participants signed an informed consent about participation in the study.

2.2 | Serum FA composition

A technician collected blood samples at the three trimesters after 12 hr of fasting. The serum was separated after 5 min of centrifugation (5,000 rpm) and subsequently stored at -80°C until analysis. The samples were shipped in dry ice to the Section of Nutritional Neurosciences, Laboratory of Membrane Biochemistry and Biophysics of the National Institute on Alcohol Abuse and Alcoholism of the National

FIGURE 1 Flowchart illustrating the process of recruitment and follow-up of pregnant women attending at a public prenatal care in Rio de Janeiro. Asterisk (*) indicates women that missed the second trimester follow-up but returned to the study at the third trimester follow-up

Institutes of Health (USA) to determine the serum FA composition. A trained technician using a high-throughput robotic direct methylation method coupled with fast gas-liquid chromatography that was developed and validated by the National Institutes of Health analysed these FA compositions. The HP 6890 Plus gas LAN equipped with three flame ionisation detectors (Agilent Technologies, Santa Clara, CA, USA) coupled to a fused silica capillary column (Agilent 127-32 H2, 15 m, 0.1 mm, 0.1 mm) was used. This method showed an inter-assay variance of <5% (Lin et al., 2012; Masood, Stark, & Salem, 2005).

We evaluated the serum concentrations of EPA + DHA, total n-3 PUFA (18:3 n-3 + 20:5 n-3 + 22:5 n-3 + 22:6 n-3), and total n-6 PUFA (18:3 n-6 + 20:2 n-6 + 20:3 n-6 + 20:4 n-6 + 22:4 n-6 + 22:5 n-6). The n-6/n-3 ratio was calculated. We also evaluated monounsaturated (16:1 n-7, 18:1 n-9, 18:1 n-7, 20:1 n-9, 24:1 n-9) and saturated (14:0, 16:0, 18:0, 20:0, 22:0, 24:0) FAs. We expressed all FA concentrations as relative values (% of total FA) because the metabolism of the various unsaturated FAs depends on the balanced amount of each FA precursor and/or product (Arterburn, Hall, & Oken, 2006). EPA and DHA were analysed combined because both are products of ALA conversion and are related to the reduced risk of undesirable maternal foetal outcomes.

2.3 | Pre-pregnancy diet and dietary patterns

Women reported their food intake during the 6 months prior to the gestational period by completing a semiquantitative food frequency questionnaire (FFQ) consisting of 82 food items administered at

baseline. This instrument refers to an updated version of a validated FFQ developed for the Rio de Janeiro adult population (Sichieri & Everhart, 1998). The FFQ validation process was performed on a sample of 88 employees (42 men and 46 women) from Rio de Janeiro State University. The FFQ was compared to four 24-hr recalls, which is the gold standard for food intake assessment. Pearson's correlations coefficients were analysed for energy and all nutrients. Significant correlations were found between the assessment tools for all nutrients except for vitamin A (Sichieri & Everhart, 1998).

The DPs have been widely used in epidemiological studies, as they allow a better dietary description as a whole, when compared with methods of analysis of specific nutrients and isolated components of the human diet (Newby & Tucker, 2004; Slattery, 2010; Tucker, 2010).

Three DPs were previously identified in the pre-pregnancy period using factor analysis by principal component analysis, and each woman received a score in each of the three mutually independent patterns (Vilela et al., 2014). The first DP was labelled as *common-Brazilian* (rice, beans, meats and eggs, and spice vegetables). The second was labelled *healthy* (roots and tubers, vegetables and green vegetables, fruits and fruit juice, dairy products, fish, tea, pasta, cakes and cookies, crackers and candies, and was inversely related with coffee intake). This DP was composed mostly of healthy food groups although a few unhealthy items were present. The third DP was called *processed* (bread, sugar, fat, fast food and snacks, soft drinks, and sausages and deli meats).

2.4 | Assessment of covariates

Structured questionnaires were administered by trained interviewers to obtain the following covariates: age (years), marital status (married or stable partnership/single), per capita family income (U.S. dollars), education (≤ 8 / > 8 years), smoking habit during pregnancy (non-smoker/current or ex-smoker), alcohol consumption during pregnancy (no/yes), inter-partum interval (nulliparous or ≥ 48 months/ < 48 months), self-reported skin colour (white/black or mixed), and self-reported alteration of glycaemia (no/yes).

The pre-pregnancy total energy intake (kilocalories) was calculated on the basis of the FFQ administered in the first trimester, referring to the 6 months prior to pregnancy. The food composition was based on the Brazilian Food Composition Table—TACO database (TACO, 2011). For food items that were not found in TACO, the United States Department of Agriculture National Nutrient Database for Standard Reference was employed (USDA, 2011).

The gestational age (weeks) was calculated on the basis of the first obstetric ultrasonography performed prior to 24 weeks of pregnancy ($n = 169$; 89.9%). If this information was not available, the reported date of the last menstrual period was used ($n = 19$; 10.1%).

The women were weighed on a digital scale at each gestational trimester (Filizzola PL 150, Filizzola Ltda, Brazil), and their height was measured in duplicate using a portable stadiometer (Seca Ltd., Hamburg, Germany) at baseline. Anthropometric measurements were performed according to standardised procedures (Gordon, Chumlea, & Roche, 1988). Early pregnancy BMI (kg/m^2 ; weight [kg]/height [m^2]) was calculated using the measures obtained in the first trimester. The cut-off points proposed by the Institute of Medicine (IOM, 2009) were used to classify the initial nutritional status as follows: under or normal weight ($\text{BMI} < 25 \text{ kg}/\text{m}^2$), overweight ($\text{BMI} = 25.0\text{--}29.9 \text{ kg}/\text{m}^2$), or obese ($\text{BMI} \geq 30.0 \text{ kg}/\text{m}^2$).

2.5 | Statistical analyses

2.5.1 | Descriptive and longitudinal analysis

Baseline characteristics were described using medians and interquartile ranges for continuous variables and frequency for categorical variables according to tertiles distribution of each DP score. The medians and proportions of baseline variables between adherence groups were compared using Kruskal–Wallis and chi-squared tests. Dietary intake for total n-3 and total n-6 PUFA was calculated and included in the descriptive analysis but not in the longitudinal models because only two fractions of dietary n-6 PUFA (20:4 n-6 and 18:2 n-6) could be calculated.

The pregnant women were compared regarding the final rate of losses to follow-up. This rate was calculated as the proportion between the number of losses to follow-up and the total number of observations at baseline. We calculated this rate for the following variables: women's age, smoking habit, skin colour, alcohol consumption, inter-partum interval, marital status, per capita family income, education, total pre-pregnancy energy intake, total n-3 and total n-6 PUFA dietary intake, pre-pregnancy DP score, and PUFA serum concentrations. The Kruskal–Wallis and the chi-squared tests were used.

The pre-pregnancy DPs were the exposure variables, and the changes of EPA + DHA, total n-3 PUFA, total n-6 PUFA, and n-6/n-3 ratio during pregnancy were the outcomes. All linear mixed-effects models considered gestational age and quadratic gestational age as the time variable of the model because the change of FA over time approaches a parabola. The gestational age was modelled as random and fixed effect to adjust for overall and individual changes in serum FA concentrations during pregnancy. The pre-pregnancy DP scores and all the other covariates were fitted only as fixed effects. The models were also adjusted for the following variables, identified as potential confounders in the bivariate analysis considering a p value $< .2$: women's age, smoking habit, skin colour, alcohol consumption, inter-partum interval, marital status, per capita family income, education, total pre-pregnancy energy intake, and self-reported alteration of glycaemia. The linear mixed-effects model was chosen due to its ability to capture both between and within individual changes and to consider that the repeated measures of the same individual are correlated. Moreover, this model allows the inclusion of time-dependent and time-independent covariates and unbalanced time intervals (Pinheiro & Bates, 2000; Singer & Willet, 2003; Twisk, 2003).

Interaction terms between pre-pregnancy DPs and early pregnancy BMI were tested to evaluate a possible effect modifier of early pregnancy BMI in the associations between DP and FA according to BMI categories. Marginal effect plots were used to illustrate these associations. Furthermore, scatter plots were created to illustrate the pattern of change in serum FA percentages (PUFAs and monounsaturated and saturated fractions), throughout pregnancy according to early pregnancy BMI.

The analyses were performed using the Stata Data Analysis and Statistical Software version 12.0 (2011, StataCorp) and R version 3.1.3 (2015, R Core Team). We considered a p value $< .10$ as statistically significant for interaction terms (Twisk, 2006) and < 0.05 for the main effect variables.

3 | RESULTS

The women had a median (interquartile range) age of 25.5 years (22.0–31.0) and per capita family income of US\$287.4 (175.4–414.5). A total of 57.4% of the pregnant women had > 8 years of education, and 57.4% were under or normal weight, 28.2% overweight, and 14.4% obese (Table S1).

We found no differences between the socio-economic and FA profile of those women that reached the final follow-up and those classified as losses of follow-up (Table S2).

The EPA + DHA (Figure 2a), total n-3 PUFA (Figure 2b), and the total n-6 PUFA (Figure 2c) percentages declined, whereas the n-6/n-3 ratio (Figure 2d) and the monounsaturated and saturated FA percentages increased across trimesters for all BMI categories (Figure S1).

It was observed that early pregnancy BMI modifies the association between DPs and FA. In overweight women, compared to the under or normal weight (reference group), as the adherence to the *common Brazilian DP* increased, the percentages of total n-3 PUFA and EPA + DHA decreased (Table 1; Figures S2a and S3a) and total n-6 PUFA and n-6/n-3 ratio increased (Table 2; Figures S4a and 5a).

FIGURE 2 Longitudinal change of serum PUFA according to early pregnancy BMI of pregnant women followed at a public health centre in the city of Rio de Janeiro, Brazil, 2009–2012. (a) EPA + DHA; (b) total n-3; (c) total n-6; (d) n-6/n-3 ratio. BMI = body mass index; DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid; PUFA = polyunsaturated fatty acids. Early pregnancy BMI was obtained at the study baseline (5th–13th gestational week) under or normal weight (BMI < 25 kg/m²); overweight = BMI 25–29.9 kg/m²; obese = BMI ≥ 30 kg/m²

In overweight women, the higher the score of the *healthy* pattern, an inverse association with EPA + DHA and total n-3 PUFA percentages and a direct association with the n-6/n-3 ratio were found (Tables 1 and 2; Figures S2b, S3b, and S5b).

Obese women with higher adherence to the *processed* pattern, when compared to the reference group, presented a more pronounced decrease in the percentage of total n-3 PUFAs (Table 1; Figure S3c). Both overweight and obese women, when compared to those with

normal weight, exhibited a greater rise in the n-6/n-3 ratio as the score for the *processed* DP increased (Table 2; Figure S5c).

4 | DISCUSSION

The main result of the present study is that early pregnancy BMI acted as an effect modifier on the association between DPs and FAs. This

TABLE 1 Longitudinal regression models between dietary patterns and relative n-3 serum concentrations (EPA + DHA^a and total n-3 PUFA) of pregnant women followed at a public health centre in the city of Rio de Janeiro, Brazil, 2009–2012

Fixed effect	EPA + DHA (% of total FA)			Total n-3 (% of total FA)		
	β^b	95% CI	p^c	β^b	95% CI	p^c
<i>Common-Brazilian pattern</i>	.053	[-0.035, 0.142]	.237	.083	[-0.000, 0.166]	.051
Gestational age	-.001	[-0.021, 0.020]	.956	.000	[-0.028, 0.028]	.990
Quadratic gestational age	-.001	[-0.001, -0.000]	.030	-.001	[-0.001, 0.000]	.064
Early pregnancy BMI ^d						
Overweight	.145	[-0.002, 0.292]	.054	.114	[-0.024, 0.253]	.105
Obese	.074	[-0.137, 0.286]	.490	.018	[-0.180, 0.217]	.856
Interaction terms						
Dietary pattern # early pregnancy BMI ^d						
Overweight	-.164	[-0.325, -0.002]	.047	-.185	[-0.338, -0.033]	.017
Obese	-.018	[-0.221, 0.185]	.862	.014	[-0.172, 0.199]	.884
<i>Healthy pattern</i>	.145	[0.042, 0.249]	.006	.173	[0.061, 0.285]	.002
Gestational age	-.001	[-0.022, 0.019]	.922	-.001	[-0.024, 0.022]	.951
Quadratic gestational age	-.001	[-0.001, -0.000]	.032	-.001	[-0.001, -0.000]	.026
Early pregnancy BMI ^d						
Overweight	.134	[-0.011, 0.279]	.069	.104	[-0.053, 0.261]	.196
Obese	.092	[-0.115, 0.299]	.382	.036	[-0.186, 0.260]	.756
Interaction terms						
Dietary pattern # early pregnancy BMI ^d						
Overweight	-.227	[-0.386, -0.068]	.005	-.266	[-0.438, -0.094]	.002
Obese	-.028	[-0.227, 0.171]	.782	-.057	[-0.272, 0.158]	.605
<i>Processed pattern</i>	-.017	[-0.112, 0.079]	.734	-.010	[-0.102, 0.082]	.829
Gestational age	-.001	[-0.021, 0.020]	.954	.001	[-0.027, 0.029]	.959
Quadratic gestational age	-.001	[-0.001, -0.000]	.030	-.001	[-0.001, 0.000]	.058
Early pregnancy BMI ^d						
Overweight	.137	[-0.012, 0.285]	.071	.106	[-0.033, 0.245]	.135
Obese	.110	[-0.102, 0.323]	.308	.083	[-0.119, 0.284]	.422
Interaction terms						
Dietary pattern # early pregnancy BMI ^d						
Overweight	-.054	[-0.215, 0.108]	.514	-.097	[-0.249, 0.054]	.207
Obese	-.161	[-0.368, 0.046]	.127	-.209	[-0.398, -0.020]	.030

Note. All models were adjusted for gestational age and quadratic gestational age in weeks and for women's age, smoking habit, skin colour, alcohol consumption, inter-partum interval, marital status, per capita family income, self-reported alteration of glycaemia, and total energy intake. Number of observations = 451; number of groups = 161; average of 2.8 observations per group. BMI = body mass index; CI = confidence interval; DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid; FA = fatty acids; PUFA = polyunsaturated fatty acid.

^aEPA + DHA: the sum of EPA and DHA serum concentrations.

^b β = longitudinal linear regression coefficient.

^c p value refers to maximum likelihood estimator.

^dEarly pregnancy BMI obtained at the study baseline (5th–13th gestational week)—the reference category was under or normal weight (early pregnancy BMI < 25 kg/m²); overweight = early pregnancy BMI 25–29.9 kg/m²; obese = early pregnancy BMI ≥ 30 kg/m². PUFA were measured at first, second, and third trimesters of gestation.

The bold emphases refers to the label of the dietary patterns and the p -value < 0.05 or borderline of the dietary pattern or BMI.

study has three additional main findings. First, it was found that overweight women with higher adherence to the *common-Brazilian* DP showed a slightly reduced n-3 PUFA percentage and substantially enhanced total n-6 PUFA percentage and n-6/n-3 PUFA ratio compared to under or normal weight women. Second, women with higher adherence to the *healthy* DP tended to have higher n-3 PUFA and lower total n-6 PUFA and n-6/n-3 ratio during pregnancy, whereas overweight women presented a decrease of n-3 PUFA and an increase of the n-6/n-3 ratio. Finally, obese women with higher adherence to the *processed* DP presented a more expressive decrease of the percent

EPA + DHA in serum in relation to under or normal weight women, whereas overweight and obese women presented a higher n-6/n-3 ratio.

The DP that most explained the habitual intake observed in our study was the *common Brazilian*, which is commonly observed for the Brazilian adult population. In agreement, the Household Budget Survey conducted in 2008–2009, which is the most important and recent study relating to the Brazilian diet, showed that the main food items that composed the Brazilian diet were rice, beans, coffee, bread, meat, juices, and soft drinks (Souza, Pereira, Yokoo, Levy, & Sichieri, 2013).

TABLE 2 Longitudinal regression models between dietary patterns and relative serum concentrations of total n-6 PUFA and n-6/n-3 ratio of pregnant women followed at a public health centre in the city of Rio de Janeiro, Brazil, 2009–2012

Fixed effect	Total n-6 (% of total FA)			n-6/n-3 ratio		
	β^a	95% CI	p^b	β^a	95% CI	p^b
<i>Common-Brazilian</i> pattern	0.293	[-0.285, 0.870]	.321	-0.206	[-0.569, 0.156]	.265
Gestational age	-0.250	[-0.377, -0.123]	<.001	-0.084	[-0.157, -0.011]	.024
Quadratic gestational age	0.003	[-0.000, 0.006]	.090	0.003	[0.001, 0.005]	.001
Early pregnancy BMI ^c						
Overweight	-0.569	[-1.536, 0.397]	.248	-0.420	[-1.026, 0.185]	.174
Obese	-1.624	[-2.987, -0.260]	.020	-0.429	[-1.285, 0.428]	.326
Interaction terms						
Dietary pattern # early pregnancy BMI ^c						
Overweight	1.643	[0.583, 2.704]	.002	0.997	[0.333, 1.661]	.003
Obese	0.386	[-0.902, 1.673]	.557	0.049	[-0.766, 0.864]	.906
<i>Healthy</i> pattern	-0.288	[-1.015, 0.438]	.437	-0.620	[-1.052, -0.189]	.005
Gestational age	-0.252	[-0.379, -0.125]	<.001	-0.084	[-0.157, -0.011]	.025
Quadratic gestational age	0.003	[-0.000, 0.006]	.082	0.003	[0.001, 0.005]	.001
Early pregnancy BMI ^c						
Overweight	-0.444	[-1.475, 0.588]	.399	-0.344	[-0.956, 0.268]	.271
Obese	-1.549	[-3.012, -0.085]	.038	-0.461	[-1.381, 0.189]	.298
Interaction terms						
Dietary pattern # early pregnancy BMI ^c						
Overweight	-0.279	[-1.403, 0.844]	.626	0.776	[0.109, 1.443]	.023
Obese	-0.165	[-1.577, 1.248]	.819	0.146	[-0.692, 0.984]	.733
<i>Processed</i> pattern	0.407	[-0.256, 1.071]	.229	0.196	[-0.195, 0.587]	.326
Gestational age	-0.254	[-0.381, -0.127]	<.001	-0.085	[-0.158, -0.012]	.022
Quadratic gestational age	0.003	[-0.000, 0.006]	.078	0.003	[0.001, 0.005]	.001
Early pregnancy BMI ^c						
Overweight	-0.441	[-1.465, 0.583]	.398	-0.334	[-0.941, 0.273]	.281
Obese	-1.568	[-3.033, -0.103]	.036	-0.631	[-1.498, 0.236]	.154
Interaction terms						
Dietary pattern # early pregnancy BMI ^c						
Overweight	0.412	[-0.701, 1.524]	.468	0.587	[-0.072, 1.246]	.081
Obese	0.259	[-1.113, 1.632]	.711	0.735	[-0.091, 1.560]	.081

Note. All models were adjusted for gestational age and quadratic gestational age in weeks and for women's age, smoking habit, skin colour, alcohol consumption, inter-partum interval, marital status, per capita family income, self-reported alteration of glycaemia and total energy intake. Number of observations = 451; number of groups = 161; average of 2.8 observations per group. BMI = body mass index; CI = confidence interval; FA = fatty acids.

^a β = longitudinal linear regression coefficient.

^b p value refers to maximum likelihood estimator.

^cEarly pregnancy BMI obtained at the study baseline (5th–13th gestational week)—the reference category was under or normal weight (early pregnancy BMI < 25 kg/m²); overweight = early pregnancy BMI 25–29.9 kg/m²; obese = early pregnancy BMI ≥ 30 kg/m². PUFA were measured at first, second, and third trimesters of gestation.

The bold emphases refers to the label of the dietary patterns and the p -value < 0.05 or borderline of the dietary pattern or BMI.

Additionally, data from the previous Household Budget Survey 2002–2003 identified a traditional Brazilian DP that is composed of food items and is similar to the *common-Brazilian* DP derived in our study (Marchioni, Claro, Levy, & Monteiro, 2011; Nascimento, Barbosa, Sichieri, & Pereira, 2011).

Our results showed that greater adherence to the *common-Brazilian* DP was associated with a slight increase in total n-3 serum content in normal and obese pregnant women. Fresh meat and eggs, which are alternative sources of n-3 PUFA (Lepsch et al., 2015), are food items found in the *common-Brazilian* DP and, therefore, could have contributed to the positive impact on n-3 FA. On the basis of the reduced rank regression

analysis, Pounis et al. (2014) identified that the DP that most explained the variations in n-3 PUFA in plasma included food items not considered as main sources of n-3 PUFA, such as cabbages and root vegetables, dairies, vegetable oils, chocolate, coffee and tea, and mayonnaise, which is in accordance with our results regarding the *common-Brazilian* DP.

A recent report from a large cohort with a Brazilian sample of men and women showed that greater adherence to the *common-Brazilian* DP was associated with higher frequencies of newly diagnosed diabetes cases and other markers of metabolic syndrome (Drehmer et al., 2017). In this study, the *common-Brazilian* DP was composed of processed meats, in addition to white rice, beans, and fresh meat, which

could explain the apparent contradictory results when compared to the health benefits we found following the *common-Brazilian* pattern. Accordingly, we observed that pregnant women with greater adherence to the *processed* DP tended to present a decrease in n-3 PUFA and an increase in the n-6/n-3 ratio.

The *processed* DP used in this study can be considered as a typical Western diet, characterised by low consumption of fish and high in sugar and saturated and trans fats (Simopoulos, 2009). This type of diet is usually associated with poor essential FA status due to the low intake of fish and high intake of vegetable oils rich in n-6 FAs. Vyncke et al. (2014) observed that savoury snack intake was positively associated with the precursor of n-6 PUFA and negatively associated with EPA + DHA in European adolescents, which could explain the associations that we found with the *processed* DP. Indeed, obese women with higher adherence to the *processed* DP presented a greater decrease in EPA + DHA content in relation to under or normal weight women.

We observed in our study that, except for overweight women, greater adherence to the *healthy* pattern led to higher n-3 and lower n-6 PUFA contents and to a decreased n-6/n-3 ratio. Serum and erythrocyte n-3 FAs respond positively to an increased intake of EPA + DHA and their precursor ALA and respond negatively to an increase in n-6 FA LA intake (Arterburn et al., 2006). Therefore, the higher intake of n-3 PUFA, in foods such as fish, and the decreased intake of n-6 FAs in the *healthy* DP favoured the improved n-3 status in the pregnant obese women. An increased intake of n-3 PUFA prevents adverse outcomes for the mother and foetus (Saccone & Berghella, 2015; Salvig & Lamont, 2011), and studies have shown that the maternal diet strongly influences the concentrations of n-3 and n-6 PUFA (Gibson, Muhlhausler, & Makrides, 2011; Innis & Elias, 2003). According to Brenna et al. (2009), the intake of foods that are composed mostly of DHA may be an effective way to increase DHA serum concentrations. In accordance, our results showed that women with under or normal weight and obese women with higher adherence to the *healthy* DP tended to present higher n-3 PUFA and lower n-6/n-3 ratio.

There are important differences in the responses comparing overweight and obese pregnant women. The higher adherence to the *common-Brazilian* and the *healthy* DP in overweight women are associated with poor essential FA status. On the other hand, an inverse relationship was found in the obese women with higher adherence to the *healthy* DP. It is well established that maternal BMI is positively associated with systemic inflammation in the mother and in the placenta (Aye et al., 2014; Bhattacharya, Campbell, Liston, & Bhattacharya, 2007) and that placental FA metabolism is disturbed in overweight and obese women (Lager et al., 2016). These metabolic alterations negatively impact n-3 FA status. Therefore, one can postulate that in obese women, the *healthy* DP improved essential FA status by decreasing the inflammatory insult posed by obesity. On the other hand, in overweight women, the inflammatory milieu could be more heterogeneous, producing the differences regarding essential FA maternal status. The metabolic heterogeneity in the overweight group could have also explained the negative impact on essential FA status with higher adherence to the *common-Brazilian* DP.

The fact that the literature published to date has not clearly addressed maternal metabolism and pregnancy outcomes in the context of overweight and obesity separately makes it difficult to explain

these differences in depth (King, 2006). On the other hand, our results clearly showed that maternal DP in overweight and in obese women posed different metabolic scenarios associated with maternal essential FA status and, consequently, to foetal essential FA metabolism, representing a promising area to be explored.

Some limitations and strengths of this study must be highlighted. First, there were participants who did not complete the follow-up, which is an inherent problem in studies utilising longitudinal data. However, it should be mentioned that the losses to follow-up happened at random. Second, we had to exclude some women who participated in a nested randomised clinical trial associated with this cohort. Third, the FFQ administered in this cohort was validated only for the adult population of Rio de Janeiro but not for pregnant women. However, we have previously demonstrated that this FFQ may be used as a possible indicator of serum concentrations of n-3 FA in early pregnancy (Lepsch et al., 2015). In contrast, the longitudinal design with repeated measures and the availability of serum concentrations of FA at three time points are the main strengths of this study. Additionally, the instruments employed to measure dietary intake, social, and behavioural data were validated and highly accurate. Previous studies from our research group using the same sample of the present study have shown that BMI may exert an influence on essential FA concentrations (Lepsch et al., 2015; Pinto et al., 2015). To the best of our knowledge, this is the first study to show that early pregnancy BMI influences essential FA status throughout pregnancy according to DPs.

In conclusion, this study suggests that early pregnancy BMI modifies the effect of pre-pregnancy DP influence on the PUFA profile throughout gestation. Higher adherence to the *healthy* pattern was associated with a better FA profile (i.e., increased concentrations of n-3 PUFA) that should be more advisable for women of reproductive age who plan to get pregnant. The *common-Brazilian* pattern was associated with slight changes in PUFA throughout pregnancy, demonstrating that the Brazilian diet is not sufficiently appropriate in terms of quality in relation to FA. Higher adherence to the *processed* pattern was associated with decreased concentrations of n-3 PUFA and with an increase in the n-6/n-3 ratio. Thus, this DP should be discouraged. More epidemiological and clinical studies are necessary to confirm our findings and elucidate the differentiated behaviour of overweight women.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

CB, JSV and GK formulated the research question, designed the study, and developed the protocol. CB conducted the statistical analysis, and

AAFV, TJPP, and DRF provided support for statistical analysis. AAFV, TJPP, JL, and TEB assisted in the literature searches and writing of the manuscript. All authors contributed to and have approved the final manuscript.

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