Clinical Research Article

**Maternal Adiposity and Energy Balance After Normotensive and Preeclamptic Pregnancies**

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**Abstract**

**Background:** Preeclampsia is a major pregnancy complication associated with long-term maternal cardiometabolic disease. Research generally is focused on metabolic and pathophysiological changes during pregnancy; however, there is much less focus on the early postpartum period in subjects who suffered preeclampsia. The aim of this study was to (1) characterize energy intake and expenditure 6 months following normotensive and preeclamptic pregnancies and (2) examine associations between energy balance, body composition, insulin resistance measures (HOMA-IR), and clinical characteristics.

**Design:** A cross-sectional study 6 months following normotensive (n = 75) and preeclamptic (n = 22) pregnancies was performed. Metabolic measurements included anthropometrics measures, body composition via bioelectrical impedance analysis, 24-h energy expenditure via SenseWear Armbands, energy intake via a 3-day food diary, and serum metabolic parameters.

**Results:** Six months following preeclampsia, women had a significantly higher weight (77.3 ± 20.9 kg vs 64.5 ± 11.4 kg, *P* = 0.01), fat mass percentage (FM%; 40.7 ± 7.4% vs 34.9 ± 8.1%, *P* = 0.004), and insulin resistance (HOMA-IR 2.2 ± 1.5 vs 1.0 ± 0.7, *P* = 0.003), as well as reduced HDL levels (1.5 ± 0.4 mmol/L vs 1.8 ± 0.4 mmol/L, *P* = 0.01) compared to normotensive women. Women post-preeclampsia had lower activity-related energy
expenditure ($P = 0.02$) but a decreased total energy intake ($P = 0.02$), leading to a more negative energy balance compared to their normotensive counterparts ($-1942$ kJ/24 h vs $-480$ kJ/24 h, $P = 0.02$).

**Conclusion:** Increases in insulin resistance and FM%, reduced high-density lipoprotein, and more sedentary lifestyles characterize the postpartum period following preeclamptic compared with normotensive pregnancies. Early post-preeclampsia interventions, such as lifestyle behavior change, should be implemented and assessed to determine whether they reduce long-term cardiometabolic risk in women who experienced preeclampsia during pregnancy.

**Key Words:** preeclampsia, cardiovascular disease risk, fat mass, energy expenditure, energy intake, energy balance

Preeclampsia is one of the leading causes of maternal and perinatal morbidity and mortality, complicating 2% to 5% of pregnancies worldwide (1,2). It is a clinical syndrome characterized by new-onset hypertension in the second half of pregnancy and evidence of multisystem maternal (renal, hepatic, neurological, hematological) and/or fetal involvement (growth restriction). Meta-analyses (3-6) have consistently demonstrated a 2- to 3-fold increased risk of long-term cardiovascular disease and type II diabetes mellitus following preeclampsia, compared to women who have experienced normotensive pregnancies (7). This risk becomes significant as early as 1 year after the affected pregnancy and continues lifelong (6,8).

Insulin resistance, a common precursor to cardiometabolic disease, is a physiological change associated with pregnancy (7). Research, however, suggests that there is an association between supraphysiological changes (elevated fasting insulin, glucose, and lipids) and preeclampsia, with the stress test of pregnancy unmasking early evidence of metabolic syndrome (7,9).

There is a suggested link between lifestyle factors and the development of hypertensive disorders of pregnancy, leading to alterations in maternal body composition and metabolic status (10,11). The postpartum period is characterized by an intake of energy-dense food, skewing the relative proportions of macronutrient intake and resulting in decreased micronutrient consumption (12-14). Sedentary behaviors, which characterize pregnancy, have also been seen to persist in the postpartum period with activity-related energy expenditures reportedly lower than prepregnancy levels (12,15,16).

Adiposity is likely to play a role in the long-term cardiometabolic dysfunction observed following hypertensive pregnancies, with a positive energy balance potentially driving this. Unfortunately, comprehensive postpartum assessment of these possible associations is lacking. No primary studies exist characterizing energy balance after a preeclamptic pregnancy or comparing these patients to previous normal pregnancies. An increased understanding of the underlying interactions between lifestyle factors, body composition, and preeclamptic pregnancies is essential in establishing future disease prevention, prognosis, and management strategies (17). The primary aim of this study was to characterize energy expenditure and energy intake within a postpartum population 6 months following preeclampsia and normal pregnancy. Secondary objectives included to determine associations within this postpartum population between energy balance, body composition, and metabolic biomarkers, as well as clinical features that may influence fat mobilization and energy balance such as breastfeeding.

**Study Design and Methods**

**Study Population**

A cross-sectional study was performed at a metropolitan teaching hospital in Sydney, Australia, serving an ethnically diverse population. This study is the 6-month postpartum metabolic subsection of a larger prospective cohort study, the Postpartum Physiology, Psychology and Paediatric follow-up study (P4 study) (18) and was approved by the South-Eastern Sydney Local Health District Human Research Ethics Committee (HREC/12/POWH/395).

Recruitment was conducted January 2013 to September 2018. English-speaking women who had given birth to a live singleton at St George Hospital within the preceding 6 months were eligible for inclusion.

The study population comprised women who either (1) had normotensive pregnancies or (2) were diagnosed with preeclampsia during pregnancy.

Preeclampsia was defined as a multisystem disease characterized by new-onset hypertension post-20-weeks gestation, as well as evidence of maternal or fetal end-organ dysfunction (19). “Severe” features of preeclampsia were defined as the presence of episodes of severe hypertension (>170 mmHg systolic and/or 110 mmHg diastolic—changed to $>160$ mmHg systolic and/or $110$ mmHg diastolic from May 2017 when hospital policy changed),
neurological symptoms (e.g., eclamptic seizures), the need for a magnesium sulfate infusion, or admission to the intensive care unit directly related to the diagnosis of preeclampsia. Written informed consent was obtained from all participants. Women who had been diagnosed with hypertension, endocrine, renal, or other serious maternal disease prior to pregnancy, given birth to a child with major congenital anomalies, or were pregnant again by 6 months postpartum were excluded from the study (18).

Data Collection
All maternal assessments were conducted at St George Hospital at 6 months postpartum (±3 weeks).

Sociodemographic information
A structured questionnaire was administered to collect information on sociodemographic factors including age, ethnicity, and highest educational level, past medical and obstetric history, as well as breastfeeding status at 6 months postpartum.

Biochemistry and hormonal measurements
Standard methods were used to measure fasting serum total, low- (LDL-C) and high-density lipoprotein cholesterol (HDL-C), as well as insulin and glucose levels to allow the estimation of insulin resistance using the homeostatic model (HOMA-IR). This was calculated by multiplying fasting insulin (µIU/mL) and fasting glucose (mmol/L) and then dividing the result by 22.5 (20).

Anthropometry
The pregnancy “booking-in” hospital visit (average 15 weeks gestation) body mass index (BMI) and height of all participants were obtained from the St George Hospital obstetric database, eMaternity (Meridian Health Informatics, Australia). Postpartum weight was measured with participants in light clothing without shoes using an electronic digital scale (HD-316, Tanita Corporation, Japan). Measurements were recorded to the nearest 0.1 kg. BMI was calculated as the ratio of weight (in kilograms) to height (in meters) (2).

Body composition
Body composition was assessed using a validated multifrequency body composition monitor (Fresenius Medical Care, Germany) (21). This device operates via bioelectrical impedance analysis to obtain values for normally hydrated fat-free mass. Fat mass was calculated as the difference between body weight and fat-free mass. Measurements were performed with participants in the supine position to minimize fluid shifts between body segments (22). The detector electrodes were positioned on the dorsum of the right hand at the radiocarpal joint and on the dorsum of the right foot at the talocrural joint. Two current-supplying electrodes were additionally positioned 100 cm distal to the detector electrodes. All body composition measurements were visually scanned for artefacts and repeated if required. Total body water, fat-free mass, and fat mass data for each participant were extracted for analysis.

Energy expenditure assessment
Energy expenditure was assessed using SenseWear Armbands (Model MF-SW, BodyMedia Inc, Pittsburgh, PA, USA). These multiphasic devices use in-built temperature sensors and a tri-axial accelerometer to determine energy expenditure via a patented algorithm.

The SenseWear Armbands were individually configured with participant demographics (gender, age, weight, height, handedness, and smoking status). Participants were fitted with the SenseWear Armband at the mid-humerus point over the triceps brachii muscle of their dominant hand. This armband was worn continuously for a 24-h period with participants instructed to conduct their normal, daily activities. The results were screened for compliance (armbands worn for <21 h were excluded) before the total energy expenditure, average metabolic equivalent, and activity-related energy expenditure (set as ≥3.0 metabolic equivalents) for each participant were standardized for a 24-h period and extracted for analysis.

Energy intake assessment
Energy intake was assessed via a self-reported, weighed food record. Participants received oral and written instructions on recording all food and beverages consumed in their provided food diary for 3 consecutive 24-h periods. They were instructed to maintain their typical diets and include 1 weekend day to acknowledge fluctuations in eating patterns. The records were screened for compliance, and those without adequate detail were excluded. A nutrient calculation program, FoodWorks (Version 8, Xyris Software Aust. Pty Ltd., Australia), was then used to determine each participant’s energy intake based off the AusBrands 2015 and AusFoods 2015 databases. Energy intake was expressed as a 24-h average and standardized for fat-free mass.

Statistical Analysis and Sample Size
Statistical analysis was performed using IBM SPSS software for Windows (version 25, 2017, IBM Corporation, Armonk, NY, USA). To identify any significant differences in energy intake and expenditure parameters
between previously preeclamptic and normotensive cohorts, 2-tailed, independent samples t tests were conducted. Fisher’s exact tests were performed to compare proportions between groups. Pearson’s correlations were used to determine the relationship between measures of energy balance and body composition. Hierarchical multiple regression analysis was performed to examine the association between preeclampsia and HOMA-IR, after controlling for the influence of demographic factors and modifiable cardiovascular risk factors. The significance level was set at \( P < 0.05 \).

The main P4 study was powered on the ability to detect a difference in the proportion of preeclamptic women with 24-h mean diastolic blood pressure 2 or more SDs above the mean of women who were normotensive in pregnancy (18). As such, an a priori power calculation was not performed for this substudy. Post-hoc testing, however, estimated that with 20 preeclamptic women and 60 normotensive women a difference of 15% in total energy intake or energy expenditure, 13% in fat mass percentage, 50% in HOMA-IR, and 20% in HDL-C levels between groups would be able to be detected with 80% power \(( \alpha = 0.05 \) ) (23).

### Results

From January 2013 to September 2018, 75 normotensive women and 22 women following preeclampsia completed the full metabolic study (Fig. 1). Measurements were conducted at an average of 6.7 months postpartum \(( P = 0.53 \) between groups).

### Baseline Demographic, Anthropometric, and Biochemical Characteristics

The baseline characteristics of the study population are summarized in Table 1. Women with previous preeclampsia had higher Caesarean rates \((64\% \text{ vs } 23\%, \text{ } P < 0.001)\) and a lower rate of breastfeeding 6 months postpartum \((50\% \text{ preeclamptic, } 84\% \text{ normotensive, } P = 0.001)\). Preeclamptic women also had a significantly higher booking BMI, with the mean in the overweight range. The preeclamptic group was a mix of early-onset and late preeclampsia with 4 \((18\%)\) diagnosed before 34 weeks gestation, 8 \((36\%)\) at 34 to 36 + 6 weeks, and 10 \((45\%)\) at \( \geq 37 \) weeks. Within the preeclamptic group, 10 \((46\%)\) had “severe” features; however, there was no significant demographic differences

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**Figure 1.** Seventy-five normotensive women and 22 women with previous preeclampsia who gave birth at St George Hospital completed the metabolic components of the study in full. Abbreviations: N, normotensive; PE, preeclamptic.
between the subcohorts. Consistent with their disease, more post-preeclampsia women had given birth pre-term (iatrogenic due to preeclampsia) and to a small-for-gestational-age infant. Anthropometric measurements are outlined in Table 2. Most notably, women with a history of preeclampsia had a higher mean BMI ($P = 0.002$) and fat mass percentage ($P = 0.004$) at 6 months postpartum compared to normotensive women. There was no significant difference between the postpartum body composition of women who experienced “severe” compared to “nonsevere” features of preeclampsia.

Serum biochemistry and hormones (Table 3) demonstrated that women with previous preeclampsia had fasting insulin levels almost double that of the normotensive cohort, with an average HOMA-IR score within the pathological range ($P = 0.003$). They also had markedly lower HDL cholesterol levels 6 months postpartum ($P = 0.01$), although no significant difference in total cholesterol.

### Energy Expenditure in Normotensive and Previously Preeclamptic Cohorts 6 Months Postpartum

Daily total energy expenditures of normotensive and previously preeclamptic cohorts were not significantly different 6 months postpartum, even when standardized for fat-free mass. When this value was compartmentalized, however, women with a history of preeclampsia demonstrated significantly less activity-related energy expenditure, with a mean 36% lower than normotensive women ($P = 0.02$) (Table 4, Fig. 2). Following preeclampsia, women also had a significantly lower average metabolic equivalent ($P = 0.004$), despite the average scores of both cohorts lying within the range of light intensity activities. Furthermore, breastfeeding status demonstrated no significant influence on total or activity-related energy expenditure within normotensive or previously preeclamptic groups.

### Energy Intake in Normotensive and Previously Preeclamptic Cohorts 6 Months Postpartum

Daily reported total energy intake was significantly different at 6 months postpartum between preeclamptic and normotensive cohorts with previously preeclamptic women consuming, on average, 13% fewer kilojoules than their normotensive counterparts ($P = 0.02$) (Table 5). Despite the difference in total amount consumed, there were no significant differences in the macronutrient composition of the women’s diets, with an average intake across both groups
comprising 41% carbohydrates, 21% protein, 35% fat, and 4% other.

The influence of breastfeeding on energy intake at 6 months postpartum was more notable within the previously preeclamptic group, with a significantly lower energy intake in the non-breastfeeding cohort. After controlling for fat-free mass, however, this difference was nonsignificant. Following preeclampsia, non-breastfeeding women demonstrated a significant shift in the composition of their diets. Compared to their breastfeeding counterparts, these women reported consuming an additional 8% of carbohydrates ($P = 0.02$) but a lower amount of absolute protein and fat. In contrast, the diet of non-breastfeeding normotensive women was 5% higher in protein compared to their breastfeeding counterparts ($P < 0.001$), despite a nonsignificant difference in their total energy intakes.

### Energy Balance (Energy Intake Minus Energy Expenditure) in Normotensive and Previously Preeclamptic Cohorts 6 Months Postpartum

Following preeclampsia, women had a significantly greater negative energy balance (~$-1942$ kJ) compared to normotensive women (~$-480$ kJ) 6 months postpartum. This remained significant after standardizing for fat-free mass ($P = 0.04$). Breastfeeding status demonstrated no significant influence on energy balance within normotensive and previously preeclamptic groups (data not shown).

### Table 2. Anthropometric and 6 month postpartum body composition data for normotensive and previously preeclamptic cohorts

| Parameter                      | Normotensive (n = 75) | Prior preeclampsia (n = 22) | $P$-value |
|--------------------------------|-----------------------|-----------------------------|-----------|
| Weight, kg                     | 64.5 ± 11.4           | 77.3 ± 20.9                 | 0.01      |
| BMI, kg/m$^2$                  | 24.0 ± 3.9            | 29.1 ± 6.6                  | 0.002     |
| BMI classification$^*$          |                       |                             |           |
| Underweight, n (%)             | 2 (3)                 | 0 (0)                       | 1.00      |
| Normal weight, n (%)           | 48 (64)               | 7 (32)                      | 0.01      |
| Overweight, n (%)              | 19 (25)               | 6 (27)                      | 0.86      |
| Obese, n (%)                   | 6 (8)                 | 9 (41)                      | 0.001     |
| Δ BMI booking to postpartum, kg/m$^2$ | 1.1 ± 1.7         | 1.9 ± 2.6                    | 0.08     |
| TBW, L                         | 29.9 ± 3.2            | 32.6 ± 5.7                  | 0.04      |
| FFM, kg                        | 41.3 ± 4.3            | 44.7 ± 7.6                  | 0.06      |
| FM, kg                         | 23.2 ± 9.3            | 32.6 ± 14.3                 | 0.01      |
| FM, %                          | 34.9 ± 8.1            | 40.7 ± 7.4                  | 0.004     |

Data are presented as mean ± SD for continuous data and absolute numbers (percentages) for categorical data.

Abbreviations: BMI, body mass index; FFM, fat-free mass; FM, fat mass; TBW, total body water.

$^*$Underweight, BMI < 18.5; normal weight, BMI 18.5-24.9; overweight, BMI 25.0-29.9; obese, BMI ≥ 30.0.

### Table 3. Serum biochemistry for normotensive and previously preeclamptic cohorts 6 months postpartum

| Parameter                      | Normotensive (n = 75) | Prior preeclampsia (n = 22) | $P$-value |
|--------------------------------|-----------------------|-----------------------------|-----------|
| Total cholesterol, mmol/L      | 4.6 ± 0.7             | 4.4 ± 0.9                   | 0.26      |
| LDL, mmol/L                    | 2.5 ± 0.6             | 2.5 ± 0.7                   | 0.98      |
| HDL, mmol/L                    | 1.8 ± 0.4             | 1.5 ± 0.4                   | 0.01      |
| Triglycerides, mmol/L          | 0.7 ± 0.3             | 0.8 ± 0.4                   | 0.12      |
| Insulin, µIU/mL                | 5.1 ± 3.0             | 10.0 ± 6.8                  | 0.003     |
| HbA1c, %                       | 5.1 ± 0.3             | 5.1 ± 0.3                   | 0.99      |
| Glucose, mmol/L                | 4.5 ± 0.4             | 4.7 ± 0.4                   | 0.04      |
| HOMA-IR                        | 1.0 ± 0.7             | 2.2 ± 1.5                   | 0.003     |

Data are presented as mean ± SD for continuous data and absolute numbers (percentages) for categorical data.

Abbreviations: HbA1c, glycated haemoglobin; HDL, high-density lipoproteins; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoproteins.
The Association Between Lifestyle Factors and Metabolic Parameters 6 Months Postpartum

Table 6 identifies the relationship between measures of energy balance, body composition, breastfeeding, and serological metabolic parameters at 6 months postpartum. A high fat mass percentage is moderately associated with lower activity-related energy expenditure and a decreased HDL cholesterol ($P < 0.01$). The most notable finding is the strong correlation between a high fat mass percentage and an increased HOMA-IR ($P < 0.01$). Breastfeeding was associated with measures of good metabolic health at 6 months postpartum (decreased fat mass percentage, decreased HOMA-IR, and increased HDL cholesterol levels; $P < 0.01$).

The Relationship Between Previous Preeclampsia and HOMA-IR 6 Months Postpartum

Hierarchical multiple regression analysis was performed to examine the association between preeclampsia and HOMA-IR, after controlling for the influence of demographic factors and modifiable cardiovascular risk factors (booking BMI, breastfeeding status, percentage fat mass, energy intake and expenditure controlled for fat-free mass, activity, and HDL-C and LDL-C levels at 6 months postpartum). The demographic variables in the initial model explained 16.6% of the variance in HOMA-IR. The modifiable risk factors explained an additional 32.6% of the variance in HOMA-IR, of which only an increased fat mass percentage was significant in the model. When preeclampsia was independently analyzed, it was seen to predict 4.9% of the variance in postpartum HOMA-IR, after controlling for both demographic and lifestyle factors ($P < 0.001$; data not shown).

Discussion

This study demonstrates that at 6 months postpartum, women with a previous diagnosis of preeclampsia have a significantly different body composition and metabolic...
profile compared to women who had normotensive pregnancies. The major independent associations were between preeclampsia and increased fat mass percentage, low HDL-C, and raised HOMA-IR. There is also evidence of a more sedentary lifestyle in women with previous preeclampsia, characterized by lower activity-related energy expenditures.

Due to its high-risk antenatal status, prior studies investigating the cardiometabolic profile of women with preeclampsia have largely focused on pregnancy, with few comparisons during the postpartum period. Our study determined that women with previous preeclampsia have a greater fat mass percentage 6 months postpartum compared to normotensive women. This correlated with a significantly higher BMI. Whether this finding is secondary to the development of preeclampsia or has contributed to its pathophysiology is yet to be understood; however, it is likely that these trends existed prior to pregnancy. Sween et al (24) noted that a higher first trimester fat mass percentage was associated with an increased risk of developing preeclampsia in already obese women. As such, lifestyle interventions targeted at weight reduction and optimization of risk factors during early pregnancy or as part of preconception counseling may act to reduce a woman’s risk of preeclampsia, as well as confer benefit to maternal metabolic health in the longer term with the aim to reduce cardiovascular risks.

Previous studies have found differences in body composition following preeclampsia, however not necessarily in adiposity (25,26). Barry et al (26) found no difference in intra-abdominal fat between post-preeclampsia cases and controls; however, they did note significantly increased intra-abdominal fat in women following preeclampsia with “nonsevere features.” This may reflect differing pathways to both preeclampsia and postpartum cardiovascular risk, with “nonsevere” disease predominant in women with greater preexisting cardiometabolic risk factors such as obesity. When our cohort was subanalyzed, we found no significant difference in body composition between women who experienced features of “severe” and “nonsevere” preeclampsia, or early-onset (<34 weeks) vs later-onset; however, our analysis of the early-onset group in particular was limited by sample size.

In line with these hypotheses, an increased fat mass percentage was noted to be independently associated with an unfavorable metabolic profile, using HOMA-IR as a surrogate measure for insulin resistance. HOMA-IR values greater than approximately 2.08 suggest high cardiometabolic risk in both pregnant and nonpregnant women (27,28). Our study reflects the independent association between preeclampsia and supraphysiological levels of insulin resistance with 41% of previously preeclamptic women having elevated HOMA-IR levels compared to

| Parameter | Normotensive | Prior preeclampsia | P-value (totals) | P-value (BF vs non-BF) | P-value (BF vs non-BF) |
|-----------|--------------|--------------------|-----------------|------------------------|------------------------|
| 24 hr TEI, kJ | 964 ± 222.8 | 241 ± 56 | 0.08 | 941 ± 1674 | 911 ± 1380 | 0.02 |
| Total (n = 75) BF (n = 63) | Non-BF (n = 12) | Total (n = 22) BF (n = 11) | Non-BF (n = 11) | 0.003 |
| Total (n = 22) BF (n = 11) | Non-BF (n = 11) | Total (n = 22) BF (n = 11) | Non-BF (n = 11) | 0.003 |
| Total (n = 22) BF (n = 11) | Non-BF (n = 11) | Total (n = 22) BF (n = 11) | Non-BF (n = 11) | 0.003 |
| Total (n = 22) BF (n = 11) | Non-BF (n = 11) | Total (n = 22) BF (n = 11) | Non-BF (n = 11) | 0.003 |

Data are presented as mean ± SD. Abbreviations: BF, breastfeeding; FFM, fat-free mass; TEI, total energy intake.
only 5% of the normotensive cohort. Further research is required to determine to what degree this difference reflects cardiometabolic risk secondary to preeclampsia pathophysiology vs prepregnancy cardiometabolic risk unmasked in pregnancy and, if so, its utility in antenatal screening. Nevertheless, it affirms the importance of early intervention in patients who have suffered preeclampsia, as there is significant metabolic risk that extends into the postpartum period.

The sedentary behaviors of pregnancy are known to continue in the postpartum period (12,15,16). As the first study to characterize energy balance in the postpartum period following preeclampsia, our findings further support this trend. Both normotensive and previously preeclamptic women had activity-related energy expenditures, which comprised less than 30% of their daily energy expenditure. This is below that of reported sedentary populations (29). Following preeclampsia, women were one third less active at 6 months postpartum compared to normotensive women. This could indicate preexisting sedentary trends in this group, given their higher booking BMI and postpartum adiposity. This pattern, however, may be confounded by the higher proportion of Caesarean births within this group, with literature suggestive of a strong association between Caesarean deliveries and reduced postpartum physical activity (30). It is of concern, nonetheless, if this is persisting so long postpartum and suggests a role for intervention. Additionally, it is well-established in the literature that there is an inverse relationship between HDL-C levels and cardiovascular risk, with exercise having a significant role in raising HDL-C levels (31). The sedentary trends of the previously preeclamptic women may be a contributing factor to their lower HDL-C levels, further marking this group as at high cardiovascular risk.

Our results indicate a disparity between theoretically calculated energy requirements and reported energy intakes at 6 months postpartum, with normotensive women consuming 16% less than recommended (32). This trend is exacerbated following preeclampsia, with reported intakes being a further 11% lower. This finding, however, is consistent with literature documenting postpartum energy intake (10,12-14,33-35), indicating either that normotensive women universally have insufficient energy intakes for optimum maternal health or that research is consistently limited by underreporting. It may also reflect the diet culture of the postpartum period. Our findings extend this knowledge by identifying women with previous preeclampsia as a group at higher risk of insufficient nutrient intake. Whether this trend is due to decreased postpartum health literacy or an increased desire to lose weight is an area of further research. Additionally, both groups reflect a lower carbohydrate and a higher fat intake compared to the recommended dietary guidelines (36). Possibly, more energy-dense foods are being favored due to the increased need for fat to support lactation (12-14,37).

### Strengths and Limitations

Due to the cross-sectional format, this study is unable to determine the extent to which the development of preeclampsia alters body composition or whether preeclampsia is merely the manifestation of a higher preexisting fat mass and its associated metabolic risk. Body composition, however, is predominantly influenced by genetic and lifestyle factors (25). Due to the significantly different booking BMIs between cohorts, with preeclampsia affecting a greater proportion of obese women, it is likely that these differences were already present. Longitudinal studies are required to confirm whether the trends noted are transient, isolated to the first 6 months postpartum, or persist into the long-term. Due to the cross-sectional format, this study is unable to determine the extent to which the development of preeclampsia alters body composition or whether preeclampsia is merely the manifestation of a higher preexisting fat mass and its associated metabolic risk. Body composition, however, is predominantly influenced by genetic and lifestyle factors (25). Due to the significantly different booking BMIs between cohorts, with preeclampsia affecting a greater proportion of obese women, it is likely that these differences were already present. Longitudinal studies are required to confirm whether the trends noted are transient, isolated to the first 6 months postpartum, or persist into the long-term.

### Table 6. Relationship between body composition, energy balance, and metabolic parameters at 6 months postpartum

|         | %FM | 24-h TEE | AEE  | 24-h TEI | LDL  | HDL  | HOMA-IR | Breastfeeding |
|---------|-----|----------|------|----------|------|------|---------|--------------|
| %FM     | 1   |          |      |          |      |      |         |              |
| 24-h TEE| 0.20*| 1        |      |          |      |      |         |              |
| AEE     | -0.49** | 0.38** | 1    |          |      |      |         |              |
| 24-h TEI| -0.22*| 0.17     | 0.18 | 1        |      |      |         |              |
| LDL     | 0.14 | 0.02     | -0.06| 0.10     | 1    |      |         |              |
| HDL     | -0.49** | -0.21*  | 0.14 | 0.17     | -0.19| 1    |         |              |
| HOMA-IR | 0.55**| 0.20     | -0.23*| -0.19   | 0.19 | -0.44**| 1        |              |
| Breastfeeding | -0.27** | 0.01   | 0.22* | 0.34**  | -0.07| 0.43**| -0.33** | 1            |

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Abbreviations: AEE, activity-related energy expenditure; FFM, fat-free mass; FM, fat mass; HDL, high-density lipoproteins; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoproteins; TEE, total energy expenditure; TEI, total energy intake.
to our smaller sample size limiting the power of our body composition findings, a study of a larger number may be required to confirm the differences in fat mass percentage found between our cohorts. An increased fat mass percentage, however, is consistent with the other metabolic abnormalities noted, including low HDL-C and high HOMA-IR indices, where our findings did reach statistical significance.

Our data is the first to characterize energy balance following preeclampsia. A strength of the study was its comprehensive assessment of body composition, energy expenditure, and energy intake, designed to maximize objective measurements and results. Nevertheless, it is an inherent limitation of metabolic research that energy intake and expenditure data may reflect patterns that are not consistent with population norms due to misreporting or respondent fatigue (38). Although to our knowledge this study is to date the most substantive, in-depth analysis of a post-preeclampsia vs normotensive pregnancy cohort, it remains limited by post-preeclampsia sample size, particularly with regards to examining any differential outcomes of early-onset preeclampsia, and this is an area for further study. However, it should be noted that our cohort is reflective of the 80% of preeclampsia that is of later onset, and it is well established in epidemiological studies that term/near-term preeclamptics are at increased risk of the long-term metabolic and cardiovascular complications (39,40). Finally, women who volunteered to participate in our study are likely to be those more motivated and health-literate than the general population, possibly reducing the external validity of the results obtained.

Conclusions

Postpartum care has been described as inconsistent and inadequate, primarily targeted toward the health of the newborn and maintenance of lactation with little specifications regarding maternal health (41). Current postpartum guidelines (42) for care following preeclampsia are brief and nonspecific. There has also been limited research into developing formal guidelines for weight management and lifestyle behavior change in the postpartum period, particularly within such high-risk groups.

Given the results of the present study, sedentary trends and their resultant increased fat mass percentage, reduced HDL-C levels, and insulin resistance may play a significant role in the cardiometabolic risk following preeclampsia. Longitudinal studies will be essential in confirming these associations in the long term. As is protocol for gestational diabetes, women with a history of preeclampsia would benefit from education about their diagnosis and its future risks, as well as early surveillance and cardiometabolic monitoring. This study highlights the need for continuation of care beyond that of the 6 week postnatal visit. Interventional strategies and counseling targeted toward lifestyle modification and weight management specifically following preeclampsia, as well as the utility of preconception screening and optimization of women’s metabolic risk factors are research areas of great potential benefit (43). The cardiometabolic health of reproductive-aged women is an area that is severely underrepresented in primary prevention guidelines and postpartum follow-up protocols. With increased understanding of the role that preeclampsia plays as a red flag for cardiometabolic health comes the increased potential for improvement in maternal health, both in the interpregnancy interval and for the longer term.

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