

# The Interplay between Maternal Nutrition and Stress during Pregnancy: Issues and Considerations

Karen L. Lindsay<sup>a</sup> Claudia Buss<sup>a, b</sup> Pathik D. Wadhwa<sup>a</sup> Sonja Entringer<sup>a, b</sup>

<sup>a</sup>UC Irvine Development, Health and Disease Research Program, University of California, Irvine, CA, USA; <sup>b</sup>Charité – Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health (BIH), Institute of Medical Psychology, Berlin, Germany

## Keywords

Pregnancy · Nutrition · Dietary intakes · Psychosocial states · Perceived stress · Anxiety · Depression · Fetal programming

## Abstract

**Background:** Several studies about humans and animals have separately examined the effects of prenatal nutrition and stress on fetal development, pregnancy, and birth outcomes, and subsequent child health and disease risk. Although substantial evidence from non-pregnant literature supports the presence of bidirectional interactions between nutrition and stress at various psychological, behavioral, and physiological levels, such interaction effects have not yet been systematically examined in the context of pregnancy. **Summary:** This paper discusses the multifaceted and multi-level relationship between nutrition and stress. It then reviews the currently available observational and experimental evidence in animals and humans regarding the interplay between maternal psychosocial stress, dietary intake, and nutritional state during pregnancy, and implications for maternal and child health-related outcomes. **Key Messages:** During pregnancy, maternal psychosocial stress, dietary behavior, and nutritional state likely regulate and counter-regulate one another. Emerging evidence suggests that omega-3 fatty acids may attenuate maternal psychosocial stress, and that high maternal pre-pregnancy body mass index ex-

acerbates unhealthy dietary behaviors under high-stress conditions. Longitudinal studies are warranted in order to understand the interplay between prenatal psychosocial stress, diet, and stress- and nutrition-related biomarkers to obtain further insight and inform the development and design of future, more effective intervention trials for improved maternal and child health outcomes. © 2017 S. Karger AG, Basel

## Introduction

Substantial evidence suggests that conditions during intrauterine life play a major role in shaping not only all aspects of fetal development and birth outcomes but also subsequent newborn, child, and adult health outcomes and susceptibility for many of the complex, common disorders that confer the major burden of disease in society (i.e., the concept of fetal, or developmental, origins of health and disease risk) [1–4]. In this context, 2 of the most frequently studied factors in pregnancy are maternal stress and maternal nutrition. The vast majority of these studies have investigated only one or the other but not both of these factors concurrently, and the few studies that have included both have treated one of the factors as the primary variable of interest and the other as a potential confounder/covariate. It is now increasingly apparent

that the causation of complex, common disorders could not and in fact does not reside in any single risk factor or in the mere additive effects of numerous factors, but likely lies at the interface between multiple risk factors (interaction, or multiplicative effects) [5, 6]. Growing evidence supports the existence of interactions between stress- and nutrition-related processes at multiple levels across and over time; however, this issue has not yet been adequately addressed in the pregnancy and fetal programming literatures.

The importance of concurrently considering prenatal stress and nutrition interactions is based, in part, on concepts from evolutionary biology and developmental plasticity. Development describes the journey from genotype to phenotype, and developmental plasticity describes the process of phenotypic specification (of structure and function) conditioned upon genotype and environment. Key environmental conditions that have shaped evolutionary selection and developmental plasticity include variation in energy substrate availability (i.e., nutrition) and other challenges that have the potential to impact the structural or functional integrity and survival of the organism (i.e., stress) [7, 8]. Thus, it is likely and plausible that prenatal stress and nutrition interactions represent an important aspect of the intrauterine environment that would be expected to influence many, if not all, developmental outcomes [9–11]. This formulation is consistent with empirical data in humans and animals. Variation in maternal nutrition (e.g., maternal over- and undernutrition, variation in dietary quality, micronutrient intake) is associated with offspring health- and disease risk-related outcomes [12–17]. Variation in maternal stress and stress-related biological processes during pregnancy is also associated with a multitude of developmental and health outcomes in the offspring [6, 7, 18–22]. Furthermore, evidence from studies in non-pregnant individuals demonstrates the substantial intertwining of the relationship between stress, dietary behavior, and nutritional biochemistry [23–25].

Addressing the role of prenatal conditions that may impact phenotypic specification is critical to optimize or improve the health of future generations [13]. Pregnancy is often described as a “window of opportunity” to promote healthful maternal states and behaviors for the benefit of the offspring [26, 27]. However, many studies focusing on prenatal dietary and/or exercise interventions fail to consider maternal stress or other psychological states, which may impact intervention effectiveness due to poor motivation, self-efficacy, or altered metabolic pathways [28, 29]. This paper first discusses the multifac-

eted relationship between nutrition and stress in humans. It then reviews the evidence present in observational studies in animals and humans that have investigated the interplay between maternal stress and dietary intake during pregnancy, and the implications thereof for adverse outcomes relating to maternal and child metabolic health. Lastly, it reviews findings from intervention trials that have utilized nutritional components to alter psychosocial or biological stress parameters in pregnancy.

### **The Interplay between Nutrition and Stress**

Evidence from studies of non-pregnant humans strongly supports the presence of a recursive, bidirectional relationship between nutrition and stress [23–25]. It is important to appreciate that “nutrition” and “stress” are broad terms that may be operationalized in various ways. Nutrition may refer to an individual’s biophysical status (ranging from underweight to obesity), nutrient status within the body (e.g., circulating fatty acids), dietary intake of foods and nutrients, and metabolic response to ingested foods (e.g., digestive processes). Similarly, stress has 3 key components: the occurrence of potentially stressful situations or events, the individual’s perception of the nature and magnitude of distress following such events or regarding chronic life circumstances (perceived stress), and the consequent psychological (e.g., depression, anxiety) or biological (e.g., stress hormone concentrations) responses. Thus, studies examining nutrition-stress associations may describe interactions across various combinations of these different components. For example, Groesz et al. [30] found that among women, perceptions of higher chronic stress exposure affected dietary intake, leading to greater hunger, binge-eating, and intake of palatable non-nutritious foods. Poor diet quality, with preponderance for consumption of unhealthy foods high in fat and sugar, is frequently reported across various cohorts in relation to perceived and/or experimental stress induction [31–35]. Experimental challenges of exposure to psychological stress have been shown to alter the digestive and metabolic responses to ingested food, including delayed gastric emptying, slower motility and transit throughout the gastrointestinal tract [36], reduced rate of triglyceride clearance from the blood [37, 38], and disturbed postprandial regulation of insulin [39]. Moreover, stress-induced disturbances of normal digestion and metabolism may ultimately influence the metabolic fate of nutrients in target organs and tissues. For example, moderately elevated levels of circulating cortisol

(as seen in chronic stress conditions) amplify insulin action on the liver by increasing liver gluconeogenesis and lipogenesis [40]. In adipose tissue, insulin and cortisol stimulate adipocyte differentiation and lipid deposition via elevated lipoprotein lipase activity [41]. Similarly, the nutritional state can influence the stress response at multiple levels. Nutritional status may alter the perception of the degree of stressfulness of an event or situation, thus modulating the biological stress hormone cascade. As mentioned above, psychosocial stress tends to increase the desire to consume palatable foods high in fat and sugar, the intake of which subsequently dampens the stress response, reduces feelings of anxiety and distress, and thus leads to “emotional eating” [42, 43].

Furthermore, it is also recognized that specific nutrients play a critical role in modulating mood, stress, and development of psychological disorders. In this regard, polyunsaturated fatty acids (PUFAs) have received particular attention due to their multiple roles in brain function, including the modification of membrane fluidity, membrane enzyme activity, the number and affinity of receptors, the function of neuronal membrane ionic channels, and the production of neurotransmitters and ionic peptides [44]. The long-chain omega-3 docosahexanoic acid (DHA), which is primarily found in oily fish, appears to be the most critical of the PUFAs due to its high concentration in phospholipids of neural cells [45]. Its incorporation in the brain occurs almost exclusively in perinatal life [46], and consequently, DHA deficiency during this critical stage of early neurodevelopment has been associated with heightened vulnerability toward depression, aggression, and stress in later life [47]. Dietary intake of omega-3 fatty acids throughout life remains important to replenish the daily loss of brain DHA [48, 49], thereby maintaining normal neurological function. Dietary omega-3 may also increase adaptation to chronic stress, as demonstrated in a study in which rats fed an omega-3-enriched diet experienced less stress-induced weight loss and a lower plasma corticosterone peak compared to rats fed either a standard control or an omega-3-deficient diet [50]. This study also found that the omega-3-deficient rats exhibited a significantly greater startle response to a stressor, highlighting the role of omega-3 fatty acids in modulating behavioral responses in addition to stress-related physiological and biochemical processes. Indeed, reduced dietary intake of oily fish, commonplace across many Western populations today, is associated with increased prevalence of anxiety and depressive disorders [51, 52]. Deficiencies in various micronutrients, including B-complex vitamins, vitamin D,

zinc, chromium, and iodine, have also been found to be associated with stress-related disorders like depression, anxiety, and other neuropsychiatric disorders [53], and prenatal supplementation of such nutrients may prevent many brain and central nervous system impairments in the offspring [54].

### **Nutrition-Stress Interactions during Pregnancy**

Based on the evidence reviewed above, it is evident that the relationships between stress, diet, and nutrition are complex and multifaceted. In the context of pregnancy and fetal development, although nutrition and stress have been separately studied for their effects on maternal and child health outcomes, relatively few studies have considered their combined or interactive effects. Due to the limited number of published studies and heterogeneity in study design across both animal and human studies on the topic of nutrition-stress interactions during pregnancy, a systematic review was not feasible. To provide an overview of the available literature on this topic, we instead performed a comprehensive literature review across several online databases (PubMed, Ovid, Science Direct) to identify English language publications describing experimental, observational, and intervention studies addressing the interplay between nutrition and stress in the perinatal period in animals or humans. No limit on the date of publication was applied to the literature search and all studies that presented data on any aspect of psychosocial stress in conjunction with any diet-related measure in pregnancy were considered.

#### *Animal Studies*

Although a large number of experimental studies in animals have examined the effects of stress induction during pregnancy on offspring metabolic health and obesity risk [55–60], we were able to identify only a couple of studies that addressed the issue of stress-nutrition interactions. Amugongo and Hlusko [61] reported that rats exposed to stress in early but not late gestation displayed a 12.5% reduction in daily food intake compared to controls, resulting in reduced weight gain in the early gestation stressed animals. Tamashiro et al. [57] examined the separate and combined effects in rats; experimentally-altered prenatal stress and diet on both maternal and offspring metabolic health outcomes were examined. Pregnant rats were fed either standard chow or high-fat diet, and half the number of rats of each group were subjected to a variable stress exposure paradigm over several days

in late gestation. Regarding maternal outcomes, only the high-fat-stress group experienced significantly higher body weight gain during gestation compared to the control group (standard chow, no prenatal stress), supporting the importance of studying stress by nutrition interactions. Among the neonatal offspring, those born to mothers fed a high-fat diet with or without stress exposure had higher fasting glucose, insulin, and leptin, while in adulthood, female offspring exposed to prenatal high-fat-stress had greater percent body fat compared to the standard-chow-control offspring. Furthermore, pups weaned onto a high-fat diet were observed to have impaired glucose tolerance if exposed to stress and/or high-fat diet during gestation [57]. While this experimental animal model of prenatal stress and dietary manipulation demonstrates various adverse metabolic outcomes in offspring, the effects appear to vary in terms of offspring sex and postnatal diet, and it is not clear whether the combination of prenatal stress and high-fat diet produces consistently worse outcomes in the offspring compared to one of the exposures in isolation. Furthermore, it is difficult to extrapolate such results from rodents to humans, particularly given that the composition of a standard “high-fat” experimental rodent diet (e.g., 60% energy from fat derived entirely from lard and soybean oil) is highly unrepresentative of human dietary intake, regardless of phenotype (e.g., obesity) or other exposures (e.g., psychosocial stress) [62, 63]. Thus, there is a compelling need for human pregnancy studies examining the interactions among prenatal stress, dietary behaviors, and nutrient state.

#### *Human Studies*

As summarized in Table 1, we identified 8 observational studies examining stress-nutrition associations in human pregnancy. Each of these studies focused only on maternal outcomes and did not extend to the postnatal period, thus precluding the possibility of studying fetal programming effects in the offspring. The majority of these studies were cross-sectional in design, evaluating dietary intake of specific nutrients, food groups, broader dietary patterns, or eating behaviors at a single time point in pregnancy, and then examining their relationship with various psychosocial outcomes.

In the earliest published study, Hurley et al. [64] administered several validated psychosocial questionnaires and a food frequency questionnaire to healthy pregnant women in mid-gestation. Higher overall energy intake, which is likely due to the result of greater consumption of the “fats, oils, sweets, and snack” food group, correlated with higher ratings of perceived stress, which persisted

after adjusting for maternal body mass index (BMI), age, parity, and education. These findings corroborate those in non-pregnant humans associating increased consumption of energy-dense, palatable, unhealthy foods with psychosocial stress [31, 32]. More recently, Chang et al. [65] used path analysis techniques in a cohort of low-income overweight and obese pregnant women and identified maternal depression as a mediator of the positive relationship between dietary fat intake and perceived stress in the first but not second and third trimesters of gestation. Increased maternal BMI in pregnancy has previously been associated with unhealthy dietary patterns and suboptimal nutrient intake [66], whereas a low socioeconomic status is associated with increased psychosocial stress, depression, and anxiety among both non-pregnant and pregnant women [67, 68]. However, one limitation of the Chang et al. [65] study is that they only assessed diet using a Rapid Food Screener tool, which limited dietary intake questions only to the intake of fruit and vegetables and high-fat foods (with no specification for type or quality of dietary fat); thus, they were unable to identify more nuanced associations between psychosocial state and specific food and nutrient intakes. In particular, they were unable to investigate the differential effects of stress on intake of fatty acid subtypes, which may be particularly relevant, given the important role of omega-3 PUFAs in early neurological development, prevention of depression, and optimal adaptation to stress [47, 51, 52]. Indeed, 2 reports from a very large pregnancy cohort found that women with low or no dietary intake of omega-3 PUFA from fish experienced significantly higher levels of anxiety [69] and depression symptoms [70] during pregnancy.

In another cross-sectional study of pregnant women in the third trimester, Goncalves et al. [71] identified various maternal traits (e.g., emotional problems), states (e.g., higher BMI), and attitudes (e.g., negative affect towards the baby) that correlated with dysfunctional eating behaviors. In this study, it was the combination of increased maternal BMI, greater gestational weight gain, and negative perception of body image that explained greatest variation (32%) in the eating disorder global score. However, given the cross-sectional nature of the study, it was not possible to ascertain whether one set of exposures preceded the other. Based on empirical, observational, and experimental evidence from the non-pregnancy literature [31–35], we propose that a vicious cycle of psychosocial stress and eating behavior may manifest among susceptible women during pregnancy. For example, in the study by Goncalves et al. [71], negative emotions and

**Table 1.** Review of observational human pregnancy studies of maternal psychosocial states associated with dietary intake or behaviors

Publication and study design	Study population	Psychosocial assessment	Dietary assessment and timing	Covariates considered	Results
Hurley et al. [64]; prospective observational	134 low-risk pregnant women in the United States	Validated questionnaires commenced at 24 weeks gestation and repeated at monthly intervals to assess: anxiety, perceived stress, negative mood, pregnancy social support, social desirability, pregnancy experiences	FFQ at 28 weeks to reflect intake over pregnancy; nutrient intakes and 7 food groups quantified	Age, parity, BMI, education	Greater fatigue and perceived stress associated with higher intake of total energy, macronutrients and zinc, but lower folate (for fatigue); anxiety was negatively correlated with vitamin C. Perceived stress and anxiety were associated with greater intake of the “breads, fats, oils and snacks” food group
Chang et al. [65]; cross-sectional	213 low-income overweight and obese pregnant women enrolled in women infants and children centers in the USA	Perceived stress of stressful life situations over past month; Sleep Quality Index; Edinburgh Postnatal Depression Scale to assess depression	24 item Rapid Food Screener to assess fat intake and fruit and vegetable intake administered at each trimester of pregnancy (different participants in each trimester)	Nil	Depression was related to fat intake in the 1st trimester, which mediated the relationship between stress and fat intake. Perceived stress was associated with sleep disturbance in all women included in the model
Vaz Idos et al. [69]; retrospective cross-sectional	9,530 women from ALSPAC in the United Kingdom	Crown-Crisp Experiential Index assessed anxiety at 32 weeks gestation	FFQ at 32 weeks; PCA assessed 5 dietary patterns (health conscious, traditional, processed, confectionery, vegetarian) and total omega-3 PUFA from seafood were quantified	Various demographic, socioeconomic, lifestyle, and pregnancy factors	Health-conscious and traditional patterns were protective against high anxiety, even accounting for omega-3 PUFA intake. There were no associations with processed or confectionery dietary patterns. Women with no omega-3 intake had OR of 1.5 for high anxiety compared to > 1.5 intakes/week
Golding et al. [70]; retrospective cross-sectional	9960 women from ALSPAC in the United Kingdom	Depressive symptoms assessed by Edinburgh Postnatal Depression Scale at 32 weeks gestation	FFQ at 32 weeks to assess intake of omega-3 PUFA from seafood	Age, education, smoking, alcohol, ethnicity, housing tenure, house crowding, parity, previous pregnancy outcomes, childhood life events, current life events	Lower omega-3 intake from seafood was associated with higher depressive symptoms. Women with no seafood intake were 1.5 times more likely to experience depression than those with > 1.5 intakes, adjusting for covariates
Goncalves et al. [71]; cross-sectional	105 women in 3rd trimester in Portugal	Brief symptom inventory assessed psychological symptoms; maternal adjustment and maternal attitudes towards pregnancy	Eating disorders examination questionnaire administered in the 3rd trimester, which assesses 4 subscales: food restriction, food pre-occupation, shape concern, weight concern	Pre-pregnancy BMI and GWG	Disordered eating occurred in 30% and was associated with higher BMI and GWG, negative body image, negative attitude toward pregnancy, somatisation, obsessive-compulsive, sensitivity, depression, anxiety hostility, paranoia, psychoticism. Accounting for BMI and GWG, the strongest predictor model of disordered eating included negative body image and attitude toward pregnancy

**Table 1.** (continued)

Publication and study design	Study population	Psychosocial assessment	Dietary assessment and timing	Covariates considered	Results
Chatzi et al. [73]; retrospective observational	529 women from Rhea pregnancy cohort in Greece; all had healthy pregnancy outcome and no medical history of depression or psychiatric condition	Postpartum depression assessed by Edinburgh Postnatal Depression Scale 8–10 weeks postpartum	FFQ in mid-pregnancy, PCA identified 2 dietary patterns: health conscious and Western	Various demographic, socioeconomic, lifestyle, and pregnancy factors, total energy intake	Olive oil intake >40 g/day reduced risk of postpartum depression, while sugar intake >29 g/day increased the risk. High adherence to a health-conscious dietary pattern was associated with a higher depression score
Vilela et al. [72]; prospective observational	207 healthy pregnant women in Brazil	State Trait Anxiety Index administered in trimesters 2 and 3 and at 1–2 months postpartum	FFQ in trimester 1 (5–13 weeks) to assess diet intake over 6 months preconception. PCA identified 3 dietary patterns: common Brazilian, healthy, and processed	Age, education, parity, marital status, smoking, alcohol, BMI, energy intake, desire to become pregnant	Brazilian and healthy dietary patterns were negatively associated with an increase in anxiety from the prenatal to postpartum period
Laraia et al. [74]; prospective observational	550 pregnant women followed until 1 year postpartum in the United States	Food insecurity assessed at 27–30 weeks by Core Food Security Model, repeated 12 months postpartum. Perceived Stress Scale to assess stress in pregnancy and postpartum	Block FFQ at 24–29 weeks gestation, 3–12 months postpartum. Eating attitude test assessed disordered eating at 3–12 months postpartum	Race, age, marital status, education, parity, physical activity, smoking, poverty level	Food insecurity during pregnancy and postpartum had a positive association with perceived stress, disordered eating, and higher fat intake postpartum

ALSPAC, Avon Longitudinal Study of Pregnancy and Children; BMI, body mass index; FFQ, food frequency questionnaire; GWG, gestational weight gain; PCA, principle component analysis; PUFA, polyunsaturated fatty acids.

attitudes toward pregnancy may alter biological stress responses that influence unhealthy food selection and poor overall dietary quality as an “emotional eating” coping mechanism, subsequently leading to increased gestational weight gain, re-enforcing the negative perception of body image and disordered eating behaviors, and, in turn, exacerbating the negative emotions and psychosocial states.

Prospective studies over the prenatal and postpartum periods have attempted to examine maternal nutrition-stress associations on the basis of broader dietary patterns. In a cohort of Brazilian pregnant women, Vilela et al. [72] reported that adherence to pre-pregnancy “traditional Brazilian” and “healthy” dietary patterns was inversely associated with state trait anxiety scores across pregnancy and into the postpartum period. Similarly, in a Mediterranean Greek pregnant population, higher maternal adherence to the “health-conscious” dietary pattern in mid-pregnancy was associated with lower risk of postpartum depression symptoms, after adjusting for a wide range of potential confounding factors [73]. The authors postulated that among foods contributing to the health-conscious dietary pattern in this study (vegetables, fruit, pulses, nuts, dairy products, oily fish, and olive oil), the high intake of omega-3 PUFAs from oily fish and potent antioxidant compounds (carotenoids, alpha-tocopherol and polyphenols) present in the monounsaturated fatty acid-rich olive oil, were significant contributors to the reduction in depressive symptoms, thus corroborating with the findings of Golding et al. [70] and Vaz Jdos et al. [69].

Lastly, Laraia et al. [74] conducted a prospective study of the impact of food insecurity during pregnancy on psychosocial and diet-related outcomes in the postpartum period. Food insecurity is a multidimensional construct that captures anxiety associated with the uncertainty of being able to obtain, purchase, and consume an adequate diet due to financial and socioeconomic constraints, often accompanied by a dependence on low-cost, calorie-dense foods, and disordered eating patterns such as binge eating [75]. This study found that higher food insecurity was a consistent and independent predictor of maternal postpartum perceived stress, negative eating attitudes, and dietary intake of total fat as a percentage of energy intake [74]. Furthermore, higher maternal prepregnancy BMI was positively associated with food insecurity status. Although the composition of dietary fat intake was not distinguished, it is unlikely that healthy fats such as those from oily fish and olive oil contributed to the higher fat intake among women experiencing food insecurity. This study highlights the importance of considering maternal

socioeconomic status-related factors as contributors to, and/or moderators of, prenatal nutrition-stress interactions.

None of the human pregnancy studies in this review examined biochemical parameters or neonatal/child outcomes arising from observed nutrition-stress interactions. Thus, to our knowledge, there are no human pregnancy studies to date, which concurrently investigate putative psychosocial stress and nutrition interactions underlying fetal programming of offspring health and disease-related outcomes, despite strong empirical evidence for such mechanisms [6, 9, 10].

### Prenatal Interventions

There remains a paucity of interventional studies attempting to systematically test whether maternal nutrition- or stress-related states in pregnancy vary as a function of one another.

#### *Effect of Prenatal Nutrition Interventions on Stress-Related Outcomes*

To our knowledge, only a small number of randomized controlled trials in humans have investigated the impact of specific prenatal nutritional supplementation (e.g., different fatty acid combinations) on maternal biological and psychosocial stress outcomes. We were unable to find any published trials investigating the impact of dietary-based interventions on maternal stress-related outcomes.

In a small placebo-controlled RCT in a Chinese cohort ( $n = 36$ ), the impact of a daily omega-3 supplement taken over 8 weeks was examined on depressive symptoms among women diagnosed with severe depressive disorder during pregnancy and not treated with psychotropic medications [76]. Women randomized to the omega-3 supplements (2.2 g EPA + 1.2 g DHA) had significantly decreased depression scores on both clinically measured and self-reported scales. Meanwhile, in a low-income African-American cohort in the United States ( $n = 64$ ), a daily 450 mg DHA + 15 IU Vitamin E supplement reduced women’s level of perceived stress and modulated their physiological stress response (salivary cortisol concentrations) to a laboratory-based psychosocial stress paradigm [77]. Neither trial assessed dietary intakes among the cohorts, although the latter study excluded women who reported consuming greater than 2 servings of fish per week, which could have further elevated women’s DHA intakes [77]. Together, these trials provide the first evidence that

a targeted nutritional supplement intervention during pregnancy may modulate maternal stress perceptions as well as physiological stress responses.

More recently, 3-armed prenatal RCTs of lipid-based nutrition supplements (containing omega-3 and 6 fatty acids, protein and 22 micronutrients) have been conducted in several low- and middle-income countries. In 2 of these studies among Malawian and Ghanian cohorts, maternal salivary cortisol concentrations were measured in addition to neonatal outcomes, in order to compare the effects of the lipid-based supplement to a standard multiple-micronutrient (containing 18 micronutrients) or iron-folic acid only supplements [78, 79]. These studies did not identify any significant differences in salivary cortisol concentrations across gestation between intervention groups, indicating that the lipid-based nutrition supplement did not affect the inverse relationship between maternal cortisol and length of gestation and birthweight in this obstetric cohort at high risk for adverse neonatal outcomes, including pre-term birth and low birthweight.

#### *Effect of Prenatal Psychosocial Interventions during Pregnancy on Nutrition or Metabolic Outcomes*

To our knowledge, there are currently no published studies investigating the impact of a psychosocial intervention during pregnancy on maternal dietary behaviors or other nutrition-related outcome. However, we identified one open trial registered on ClinicalTrials.gov (NCT01307683), which will utilize a mindfulness-based eating and stress-reduction program with the aim of reducing gestational weight gain among low-income, overweight pregnant women. The researchers from this trial have published the findings of a pilot qualitative study exploring the target population's perception of such an intervention [80]. Overall, women strongly identified with struggles relating to the complex interplay of emotions, stress, and eating behaviors in their lives, expressed concern regarding the impact of their stress and dietary behaviors on weight gain and health of their developing babies, and were enthusiastic and optimistic about a stress-reduction intervention with group support to provide meaningful skills and target the emotional components of eating during pregnancy.

#### **Conclusions**

Maternal dietary intake, nutritional status, and psychosocial states and conditions during pregnancy are likely to play critical roles in influencing maternal meta-

bolic health, fetal development, and offspring health outcomes; yet the complex relationships and interactive effects between these factors have not yet been studied in humans or animals. The small number of studies identified in this review that examined such interactions support the concept that prenatal psychosocial stress is associated with unhealthy dietary intakes and eating behaviors, such as "comfort eating" of highly palatable foods. It appears likely that women who become pregnant with an increased BMI may be more susceptible to unhealthy dietary behaviors potentially driven by poor psychosocial states, which may exacerbate the already elevated risk for adverse pregnancy and infant outcomes related to maternal obesity. With respect to specific dietary components, emerging evidence from human pregnancy studies suggests that omega-3 PUFA may play a critical role in not only fetal neurodevelopment, but also for supporting positive maternal mood and decreasing the risk of unfavorable psychological states such as perceived stress, anxiety, and depression in the pre- and postnatal periods. Although the mechanisms underlying the effects of omega-3 PUFA during pregnancy on moderating these outcomes remain to be elucidated, it is likely associated with their multiple important roles in supporting normal brain function [44], which are perhaps compromised during pregnancy when PUFA deficiency or insufficiency occurs secondary to increased fetal demands [81, 82].

Longitudinal observational studies with comprehensive evaluation of maternal psychosocial stress and diet across pregnancy and stress- and nutrition-related biomarkers will likely provide better insight to the nature and magnitude of their inter-relationships. Such studies could then better inform the development of specific hypotheses and design of future, more effective intervention trials of maternal psychological state in combination with dietary and lifestyle factors for improved maternal and child health outcomes.

#### **Disclosure Statement**

The authors declare no conflicts of interest.

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