Health and Developmental Correlates of Child Food Insecurity from Pregnancy to Early Childhood

Barbara A. Laraia, Ph.D., MPH, RD. Associated Professor of Public Health Nutrition, School of Public Health, UC Berkeley, California.

Cindy W. Leung, Sc.D, MPH, Postdoctoral Scholar, UC San Francisco Center for Health and Community and UC Berkeley Dr. Robert and Veronica Atkins Center for Weight and Health

Amanda Murphy, RD. MPH student, UC Berkeley, School of Public Health

This paper was commissioned for the Workshop on Research Gaps and Opportunities on the Causes and Consequences of Child Hunger. The workshop was convened by the Committee on National Statistics and Food and Nutrition Board, on April 8-9, 2013 in Washington, DC with support from the Economic Research Service and the Food and Nutrition Service of the U.S. Department of Agriculture.

Introduction

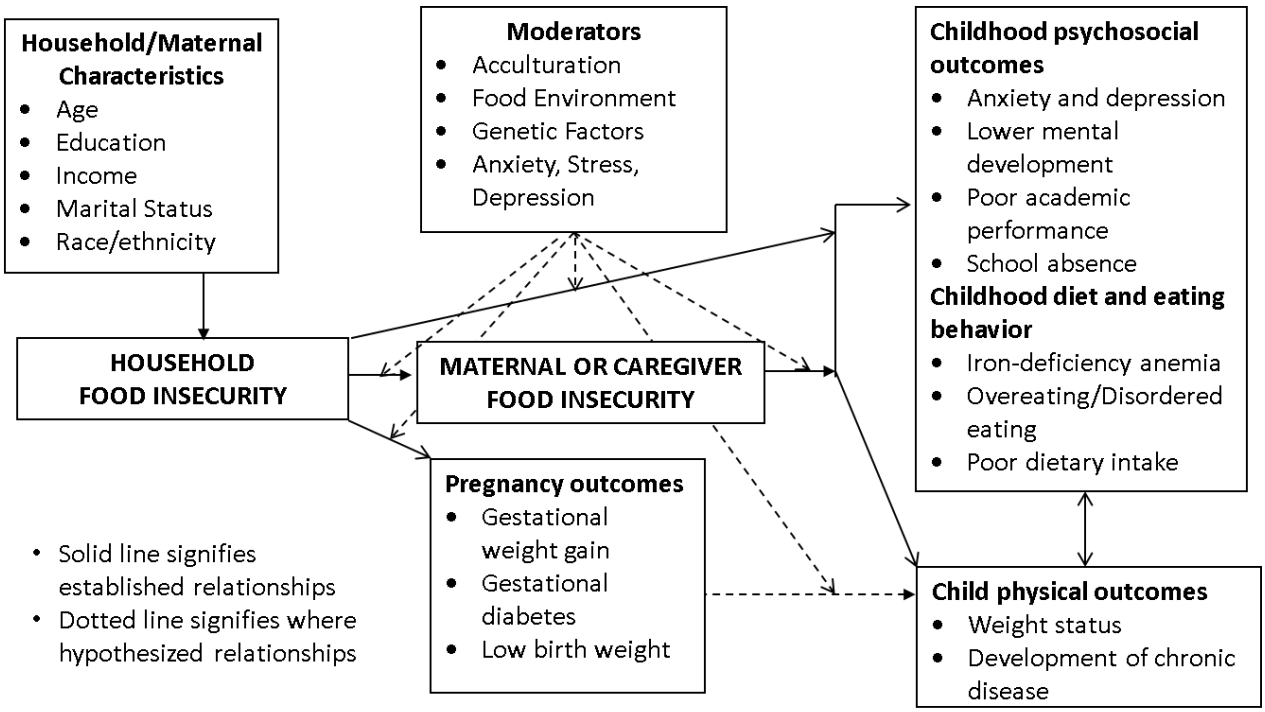
This review is a commissioned paper based on the presentation for the National Academies of Science (NAS) steering committee on Research Gaps and Opportunities on the Causes and Consequences of Child Hunger. This review focuses on the current state of evidence and potential research questions for impacts of childhood food insecurity and hunger on dietary intake, diet related disease, obesity, and chronic disease development, and addresses mechanisms/pathways (biological, psycho-emotional, via caregivers) including reference to windows of vulnerability such as pre-pregnancy and prenatal influences. The paper will provide an overview of what is currently known, and will focus in particular on identifying the most important research questions and data needs in this area going forward.

Household food insecurity is a significant source of stress for individuals in the household. Household food insecurity has consistently been associated with higher levels of perceived stress, depression and anxiety among women (Huddleston-Casas 2009, Bronte-Tinkew 2007, Laraia 2006, Whitaker 2006, Casey 2004, Stuff 2004). Both animal and human studies have shown that the stress of household food insecurity can be directly experienced by children or indirectly through the experience of a caregiver (Fram 2011, Kaufman 2007). Food insecurity is hypothesized to activate the hypothalamus-pituitary-adrenal (HPA) axis, or stress pathway, whereby causing secretion of stress related hormones and neural transmitters, including corticotrophin releasing hormone (CRH) from the hypothalamus, adrenocorticotropic hormone (ACTH) from the pituitary, and cortisol from the adrenal glands (Epel 2012). Cortisol plays a direct role in metabolism and at increased levels disrupts normal metabolic process. Elevated cortisol also activates CRH production and release from the placenta which has been implicated in signaling early delivery (Hobel 2008). The stress of household food insecurity can also change eating behaviors and lead to non-homeostatic eating, defined as eating without caloric need (Adam 2007). In animal and human studies the influence of stress on overeating has been well described, especially in the presence of highly palatable foods, defined as energy-dense foods of minimal nutritional value (Tomiyama 2011, Kuo 2008, Adam 2007, Kuo 2007, Epel 2001). New research on stress-related non-homeostatic eating posits that stress activation of the limbic system, or HPA axis, overrides the prefrontal cortex, which is the rational and decision making center of the brain (Epel 2012). Under conditions of stress, the nucleus accumbens, which is the pleasure or reward center of the brain, is stimulated and highly palatable foods are experienced as a reward that dampens the stress response. The nucleus accumbens is part of the basal ganglia that is the learning center related to routine habits. Therefore, under conditions of chronic stress, not only are highly palatable food eaten to relieve stress, using highly palatable foods to do so becomes a learned behavior. Not surprising, stress is also associated with weight gain, especially among women (Tomiyama 2013).

The relationship between household food insecurity and child health outcomes is complex with multiple pathways and critical periods of exposure. Several conceptual frameworks have been developed to illustrate pathways between exposure to household food insecurity and child health outcomes (Perez-Escamilla 2012, Bronte-Tinkew 2007). We present in Figure 1 a simplified illustration of the direct influence of household food insecurity on children health and the indirect influence through fetal exposure or through their caregivers. The experience of food insecurity may have a differential effect on health outcomes if potentiated by one of several modifiers such as acculturation, genetics, food environment, and the level of stress, anxiety or depression experienced by the caregiver or child. Each of these could

compound the way in which food insecurity influences dietary intake, eating behaviors and/or how food is metabolized.

Figure 1: Conceptual Framework of the influence of Household and Maternal Food Insecurity on Childhood Health Outcomes



The influence of household food insecurity on the drive to eat and/or overeat highly palatable foods is influenced by biological process, learned behavior and contextual factors. As mentioned, stress-related hormones, especially cortisol, other related hormones, and neurotransmitters play a direct role in metabolism. Household food insecurity is a substantial stress experience that is hypothesized to influence food choice that favors energy-dense foods, induces disordered eating behavior, and shifts metabolism to store energy as visceral fat. In addition to the biological drive to eat highly palatable foods under stress, which can be viewed as evolutionarily adaptive, exposure to household food insecurity in a food environment full of abundant inexpensive, processed, energy-dense foods increases the likelihood that individuals may eat more high energy-dense and less nutrient-dense foods. Over time, this learned behavior may contribute to higher weight gain and development of chronic conditions. The exposure of household food insecurity and a poor local food environment can be further compounded by the cyclical nature of the food stamp allotment for those who participate in SNAP, which increases the stress of uncertainty of having adequate food. In addition, food prices and the timing of income and resources play a direct role in food selection. In the following sections we review the literature on 1) the influence of household food insecurity on pregnancy outcomes, 2) the influence of household food insecurity on child dietary intake and eating behavior, 3) the influence of household food insecurity on child weight status with a focus on longitudinal studies, 4) the influence of household food insecurity on diet-related disease in childhood, namely anemia, and 5) the influence of household food insecurity on chronic disease

management in childhood. We conclude the paper with a discussion of the significant gaps in our understanding of how household food insecurity may be causally link to childhood outcomes and suggestions of how to best target interventions to address household food insecurity among families with young children.

Impact of Household Food Insecurity on Pregnancy

Food insecurity during pregnancy is a global concern. Programs that aim to reduce food insecurity during pregnancy are a national priority. Yet, little is known about the prevalence of household food insecurity during pregnancy, critical periods during pregnancy when food insecurity is most detrimental, the association between of food insecurity and diet during pregnancy, and the causal relationship of food insecurity on pregnancy related weight gain, complications and adverse birth outcomes. Using data from the continuous National Health and Nutrition Examination Study (NHANES) from 1999-2010 that collected household food security data using the full 18-item USDA food security core module, we estimated the prevalence of household food insecurity among pregnant women and found that 76.6% were fully food secure, while 8.8% were marginally food secure, 10.2% low food secure, and 4.4% very low secure (See Table 1).

Table 1: Prevalence of household food insecurity among pregnant women in the U.S. by income level, data from 1999-2010 National Health and Nutrition Examination Study

	Full food Security	Marginal food security	Low food security	Very low food security
Entire Sample Weighted % (Raw n)	76.6 (1013)	67.3 (631)	56.1 (368)	46.9 (178)
≤400% FLP Weighted % (Raw n)	8.8 (154)	12.3 (135)	16.4 (113)	17.7 (178)
≤ 200% FPL Weighted % (Raw n)	10.2 (178)	14 (156)	20 (146)	24.5 (95)
≤ 100% FPL Weighted % (Raw n)	4.4 (72)	6.3 (64)	7.6 (58)	10.9 (43)

As expected, the prevalence of household food insecurity among pregnant women increases with lower household income, with roughly 44% of pregnant women at or below 200%, and 53% of pregnant women at or below 100% of the income poverty ratio experiencing some level of uncertainty about having enough to eat or changing behaviors because of uncertainty. The high rate of food insecurity during pregnancy has tremendous implications for the federal food programs, especially for the WIC program because it was designed to address food insecurity and traditional suboptimal dietary intake in these populations. Monitoring progress toward program goals should be a national priority. Current research should be utilized to improve WIC to minimize the impact of food insecurity on maternal, infant, and child health.

Braveman et al. (2010) analyzed data from the 2002-2006 California Maternal Infant Health Assessment, a population based postpartum survey drawn from state-wide birth records, and found that 29% of women between 101-200% of the federal poverty level and 35% of women <100% of the federal poverty level experienced food insecurity during pregnancy, which are very similar percentages to the national average in Table 1 (Braveman 2010). During pregnancy, experiencing food insecurity is hypothesized as a strong stressor evidenced by the significant positive association with depression (Hromi-Fiedler 2011, Laraia 2006), anxiety, perceived stress, and significant inverse association with mastery and self-esteem (Laraia 2006). Stress during pregnancy is associated with elevated risk of preterm birth and low birth weight (Glynn 2008, Hobel 2008, 2004, 2003) as well as other adverse birth events. Elevated cortisol levels stimulate production and release of CHR from the placenta, which in turn can alter fetal growth and delivery (Hobel 2008). Limited food availability, especially prolonged periods without food, specifically 13 hours or more, is associated with elevated CHR that increases risk for preterm birth (Herrmann 2001). In one study conducted between 1999 and 2004, a random sample of 1,363 women who attended one of nine community health centers in Illinois and who received welfare were followed, 294 of which became pregnant (Borders 2007). The study assessed the association between significant sources of stress and low birth weight controlling for age as it was the only demographic variable associated with low birth weight. Food insecurity was significantly associated with increased risk of low birth weight (adjusted odds ratio, AOR 2.6, 95% CI 1.7-3.5), as were other forms of stress such as child with a chronic illness (AOR 3.1, 95% CI 2.3–4.0), unemployment (AOR 3.7, 95% CI 2.7–4.7), and poor coping skills (AOR 4.0, 95% CI 3.1–4.9). The association between household food insecurity and preterm birth suggests that food insecurity may disrupt fetal development and influence the timing of preterm delivery. More studies are needed to determine the timing and severity of food insecurity during pregnancy on pregnancy related outcomes.

During pregnancy, increased stress, prolonged fasting, and micronutrient deficiency, especially iron, folate, and calcium, are associated with a number of adverse birth outcomes such as neural tube defects, anencephaly, and heart defects. Carmichael et al. (2007) conducted a population-based case-control study, using a continuous measure of food insecurity and detected a significant positive association with each additional food insecurity score and a number of birth defects including spina bifida, anencephaly, cleft palate, and two conotruncal heart defects: d-transposition of the great arteries, tetralogy of Fallot, but not with cleft lip (with or without cleft palate), after adjustment for maternal race/ethnicity, education, body mass index (BMI), intake of folic acid-containing supplements, dietary intake of folate and energy, neighborhood crime, and stressful life events. Important research questions that aim to identify specific stress-reducing techniques and protective, nutritious foods and nutrients to promote during pregnancy still need to be addressed. Since we have strong federal food assistance policies in the U.S., and since the birth related adverse outcomes associated with food insecurity are so severe and have lasting effects from childhood through adulthood, more attention must be paid to optimizing current programs to achieve the best results. Identifying the role that WIC can play to improve linkage to mental and physical health care, and to increase referrals to community programs may be an important area of focus.

In addition to being a strong stressor, food insecurity is hypothesized to influence health through compromised dietary intake; however, no studies were found that investigated the relationship between household food insecurity and dietary outcomes during pregnancy. One small study assessed dietary intake among WIC participants, although not all women were

pregnant, and found that food insecurity was associated with poorer perceived diet quality compared to women from food secure households (Kropf 2007). More studies are needed that investigate the effect of food insecurity on diet throughout pregnancy. Although NHANES samples pregnant women, there are no survey questions on pre-pregnancy weight or health, or the week gestation that the survey is being collected. Additional questions could be added to NHANES to estimate the relationship between household food insecurity, dietary intake and gestational weight gain for the period of pregnancy when the survey is conducted for pooled analysis of pregnant women. Often weight status is used as a proxy for overall nutrition stores. Laraia et al. (2010) found that food insecurity during pregnancy was associated with higher levels of gestational weight gain and observed-to-recommended weight gain ratio, but not excessive weight gain. In a subsequent study by Laraia et al. (2013), a strong and significant interaction between household food insecurity and dietary restraint before pregnancy was found with regard to gestational weight gain. Dietary restraint is an eating behavior construct that measures restrained eating, focused on dieting, disinhibited eating and weight cycling, and is viewed as a measure of failed dieting. The differential effect of experiencing household food insecurity and scoring low on dietary restraint was associated with a significantly lower weight gain (<4.5 pounds on average), a greater likelihood of gaining appropriate weight compared to pregnant women from food secure households. Conversely, food insecurity and scoring high on dietary restraint was associated with a significantly higher weight gain (>11 pounds on average) and greater likelihood of gaining excessive gestational weight compared to pregnant women from food secure households. Food insecurity during pregnancy has also been associated with developing gestational diabetes mellitus (Laraia 2010). In utero exposure to maternal diabetes during pregnancy (type I, type II or gestational diabetes mellitus), excessive gestational weight gain, or a pregnancy that results in low birth weight has profound implications for the offspring resulting in increased risk of reduced insulin sensitivity (Gluckman 2008), raised glucose levels as adults (Roseboom 2011), development of obesity and type II diabetes (Portha 2011), and higher risk of chronic disease in adulthood (Roseboom 2011, Gluckman 2008). Epigenetic mechanisms, such as a mismatch between poor nutrient fetal environment and calorically abundant postnatal environment may create conditions that lead to greater chronic disease risk. For example, in a population-based sample in Quebec, a significant interaction between low birth weight (<2500 g) and household food insufficiency during preschool was significantly associated with greater odds of being overweight at age 4.5 years (AOR 28.0, 95% CI 6.2-125.3) (Dubois 2006).

Influence of Household Food Insecurity on Child Health

The diets of American children aged 2 to 17, like those of adults, are on average very poor as evidenced by a 55.9 mean score of a possible 100 using the Healthy Eating Index-2005 (HEI-2005), a measure that assesses overall compliance with 2005 Dietary Guidelines for Americans (Fungwe 2009). Among low-income children the mean HEI-2005 score was about the same: 56.4 (Guenther 2008). Using NHANES 2001-2004 data, Kirkpatrick et al. (2012) found that a small percent of children met dietary guidelines for nutritious plant-based foods. On average, only 0.5% met guidelines for whole grains, 1.0% for dark leafy green vegetables, 4.2% for orange vegetables, 5.1% for dry beans, 6.6% for total vegetable, 28.7% for total fruit, while 37.1% met guidelines for milk, 42% for starchy vegetables, 43.8% for meat/dry beans, and 80.7% for total grains. Strikingly, the percent of low-income children that met guidelines was either roughly equivalent or higher to their upper income peers. Similarly, results of a nationally

representative study of low-income, SNAP-eligible children using NHANES 1999-2008 data showed low median intake of whole grains between 0.3 and 0.4 servings/day; median intake of fruit ranged from 0.6-0.8 servings/day; and median intake of vegetables was 0.6 servings/day, with median HEI-2005 scores ranging from 45.6-47.2 points (Leung 2013). Although income level is not consistently associated with lower diet quality scores, the definition of household food insecurity includes the dimension of a reduction in the quantity and/or quality of food intake by household members. For this reason, researchers often hypothesize that household food insecurity would have adverse effects on children's dietary intake independent of household income. However, the literature describing the influence of household food insecurity on children's diets has not always been consistent.

Several studies have examined the association between household food insecurity status and diet using data from state-wide or nationally representative surveys (Cunningham 2012, Eicher-Miller 2011, 2009, Lorson 2009, Kirkpatrick 2008, Bhattacharya 2004). Using data from the third NHANES, no associations were reported among children aged 2-5 years or 6-11 years between food insecurity—using the one-item food insufficiency measure augmented with questions on meal skipping—and the HEI after adjusting for poverty (Bhattacharya 2004). In adolescents aged 12-17 years, family report of adults skipping meals was associated with a 4.1-point higher HEI score, while family report of children skipping meals was associated with a 4.5-lower HEI score among adolescents, complicating the true nature of the association. Three other studies have used continuous NHANES data, which implemented the full 18-item food security core module, to examine the association between household food insecurity and various characteristics of dietary intake. One study found no association between household food insecurity and the likelihood of children meeting MyPyramid fruit and vegetable recommendations (Lorson 2009). Two other studies set out clearly defined hypotheses regarding the influence of food insecurity on diet-related disease and found significant associations between household food insecurity and lower intakes of calcium (Eicher-Miller 2011) and iron (Eicher-Miller 2009). However, differential associations were found by age and gender without a clear pattern or explanation for these differences. Most recently, a study examined maternal food security and toddler's dietary intake using data from the 2006-2008 Oregon Pregnancy Risk Assessment Monitoring System (PRAMS) survey, a population-based sample of 1,522 mothers of two year old children. Maternal food insecurity was significantly associated with lower odds of toddler's intake of vegetables and canned or fresh fruit, and higher odds of toddler's intake of soda on at least 4 days of the week (Cunningham 2012).

A number of studies have examined household food insecurity and diet among convenience samples of Hispanic children. Similar to the population-based studies, these studies generally show that food insecurity is negatively associated with food availability or children's dietary intake in Hispanic households. For example, in these studies, household food insecurity has been associated with lower availability (Kaiser 2003, Matheson 2002) and consumption of nutrient-dense foods (i.e. fruits, vegetables, dairy, grains, and meats) (Dave 2009, Kaiser 2002). Household food insecurity has also been associated with higher availability (Kaiser 2003) and consumption of energy-dense foods (i.e. sodas, sweets, fried snacks, and alcohol) (Rosas 2009). While most of these studies have focused on foods rather than nutrients, one study of Mexican-origin children in Texas border Colonias found that food-insecure children had significantly higher intakes of total energy, calcium, and percentage of calories from added sugars when compared to food-secure children. No associations were observed for intakes of protein, dietary fiber, vitamin D, potassium, sodium, and vitamin C (Sharkey 2012). More research is need to

understand the causal association between household food insecurity—the timing during the month, level of severity and who in the household is affected—and dietary intake among children.

Because household food insecurity and dietary intake are measured concurrently, oftentimes in large health surveys, researchers are limited in their ability to make causal inferences about how household food insecurity affects children's dietary intake over time. Most studies have reported at least one detrimental aspect of children's dietary intake associated with household food insecurity. While these results generally fit the hypothesized direction of association, the foods or nutrients identified are not always consistent across studies. In addition, these studies often examine associations with many different foods and nutrients, which are all either assumed to be "good" or "bad" for children's dietary intake. However, these studies lack a conceptual framework that promote how household food insecurity may influence dietary intake, and oftentimes, there are only a few dietary components that are significantly associated with household food insecurity, the majority of which are null associations. Thus, it is difficult to know from the state of the literature if household food insecurity truly leads to poorer dietary intake among children.

Based on the stress-eating related literature and economic studies, a priori hypotheses can be postulated as to which foods may be more strongly associated with the experience of household food insecurity among children. Future studies should consider the magnitudes of the associations, consistency of findings with previous studies and the use of causal methods in order to identify which "good" or "bad" foods and nutrients are most strongly influenced by children's experiences of food insecurity. These studies hold important public health implications about providing incentives for "good", nutrient-dense foods and/or promoting restrictions for "bad", non-nutrient-dense foods in order to concurrently alleviate household food insecurity and improve children's dietary intake.

An emergent literature describing the extent to which household food insecurity influences disordered eating behaviors, meal patterns, and food coping strategies may shed light on intervention strategies. Mechanisms through which household food insecurity promote detrimental eating behaviors suggests that the experience of household food insecurity during critical periods of development may establish lifelong eating patterns. A recent qualitative study demonstrated that children are aware of household food insecurity and exhibit coping mechanisms that may be different than that of adults (Fram 2011). These include various means of the children taking responsibility for managing food resources, including participating in adults' strategies to stretch resources, children initiating strategies to stretch resources, and generating more resources for food by borrowing food or working for money. A study of homeless Minnesotan youth identified that the three most common coping strategies for food insecurity were: 1) eating snacks like chips, candy, and pop when hungry, 2) overeating at meal times to avoid being hungry later, and 3) eating anything if hungry (Smith 2008). Other studies have also shown that food-insecure children report lower frequencies of breakfast consumption and of family meals (Grutzmacher 2011, Widome 2009). A recent experimental study by Kidd et al. (2013) used a classic marshmallow paradigm—a measure of delayed gratification among four year olds for a second marshmallow—developed in the 1960s to test whether delayed gratification and self-control were rational under conditions of uncertainty. In the study, children age four were given poor quality art supplies and asked to wait for better supplies. Children were randomly assigned to be given better supplies or be told that better supplies were not found. Children were then exposed to a second incident of uncertainty and then they were given the

marshmallow test. A single marshmallow was given to the children and they were told if they wait to eat the marshmallow they would be given a second marshmallow. Children who received the better art supplies waited on average 12 minutes to eat the marshmallow, while children assigned to the uncertain condition waited on average 3 minutes. The experiment was stopped at 15 minutes and 64% of the children who were given the better art supplies waited the total 15 minutes so it is unclear how much longer they may have waited. This study suggests that individual characteristics such as delayed gratification and self-control, which are protective mechanisms, and have been found to predict intelligence, academic performance, social competence, and healthy weight status, are not innate characteristics and they may be important modifiable risk factors on the pathway between food insecurity and health. Experimental studies can help to identify mechanisms by which food insecurity alters dietary intake, food choice, and eating behavior.

Although household food insecurity may influence dietary intake and eating behaviors, findings on its influence on children's weight status are inconsistent. Two recent review studies that assessed the association between household food insecurity and children's weight status, based mostly on cross-sectional studies concluded that the inconsistent results do not support an association between household food insecurity and children's weight status (Eisenmann 2011, Larson 2011). Longitudinal studies, however, tend to produce more consistent findings that could possibly link food insecurity to children's weight status. These longitudinal studies offer a life-course framework and allow us to pay special attention to critical periods of growth and development, which is not possible in the cross-sectional studies. Of the six longitudinal studies we examined, three studies reveal a positive association between exposure to food insecurity and children's weight status while the remaining three studies found no association. The null associations may be explained by two reasons: 1) surveyed children in cohorts are too young and 2) very short time lapses between measurement periods. First, both longitudinal studies using the Early Child Longitudinal Study-Birth Cohort (ECLS-B) data (Hernandez 2009, Bronte-Tinkew 2007), measure and survey the children at 9 and 24 months of age. Although the children were exposed to food insecurity during this 15-month time period, it may be too soon to observe the effects of food insecurity on weight status before 2 years old. While infants and toddlers exposed to household food insecurity are affected during a critical growth period, we may not expect to find a concurrent elevated weight at this point, but hypothesize to find elevated weight during the next critical growth period between 5 to 10 years old. Second, the longitudinal study using the Early Child Longitudinal Study-Kindergarten Cohort (ECLS-K) data (Winicki 2003) measures and surveys the children in the fall and spring semesters of their kindergarten year with only 6 months between measurement periods. This short 6-month lapse may not allow sufficient time for any exposure to food insecurity to develop into any significantly measureable effect on children's weight status.

Longitudinal studies that do find a positive association of food insecurity on weight status sample older children (1.5 to 9 years old) and have longer time lapses between measurement periods (2 to 4 years). One longitudinal study that sampled children from several Massachusetts WIC clinics with first measurement at infancy and later measurement between 2 to 5 years old, found children with persistent household food insecurity had 1.22 greater odds (OR 1.22, 95% CI 1.06-1.41) of being overweight (BMI>95%ile on CDC growth curves) when compared to children with persistent household food security (Metallinos-Katsaras 2012). Another longitudinal study, which sampled children from the Longitudinal Study of Child Development in Quebec (LSCDQ) at 1.5 and then 4.5 years old, found children with household food

insufficiency at some point during these early preschool years had nearly double the odds (OR 1.96, 95% CI 1.1-3.6) of being overweight at 4.5 years (Dubois 2006). The final longitudinal study, which sampled children from the ECLS-K during kindergarten and then 3rd grade, found that girls with who experienced household food insecurity during kindergarten had 0.384 kg/m^2 greater gain in BMI ($p<0.014$) and 0.740 kg gain in weight ($p<0.016$), while boys from households that transitioned into food insecurity had 0.430 kg/m^2 greater gain in BMI ($p<0.06$) and 1.165 kg gain in weight ($p<0.02$) (Jyoti 2005). The authors point out that for girls the effect of household food insecurity during kindergarten on subsequent weight gain persisted even when accounting for household food insecurity during third grade, and they suggest that a change in food security status had little effect on weight. Conversely, these findings might indicate that kindergarten is an important developmental period for girl when the influence of household food insecurity might be particularly strong.

Household food insecurity has been consistently associated with one diet-related condition during childhood: iron deficiency anemia (IDA). IDA continues to be common in the U.S. with prevalence of 9% of toddlers and 9% of adolescent girls (CDC 2002). Three of the four studies that we identified showed a significant positive association between household food insecurity and IDA (Eicher-Miller 2009, Park 2009, Skalicky 2006). Iron deficiency during childhood is associated with being an important factor in long-term neurodevelopment, behavior, motor and mental development among children (CDC 2002). The four studies examining household food insecurity and IDA were all of cross-sectional design. Two of these studies used nationally representative samples from NHANES, which included boys and girls from 2 to 19 years old, stratified by age categories (Eicher-Miller 2009, Bhattacharya 2004). The other two studies used a convenience sample from Children's Sentinel Nutrition Assessment Program (C-SNAP), which included boys and girls from 6 to 36 months old (Park 2009, Skalicky 2006). The only null association was found in the study that used NHANES III data from 1988-1994, which used the one-item food insufficiency measure (Bhattacharya 2004). This one-item measurement tool was later replaced by the currently used 18-item food insecurity measure, which is regarded as a more accurate measurement of food security (Gundersen 2011). In the three studies that analyzed data from surveys utilizing the 18-item food insecurity measure, all concluded that children experiencing household food insecurity had greater odds of IDA compared to children without household food insecurity, ranging from a 2-folds greater odds (OR 1.98, 95% CI 1.11-3.53) (Park 2009) to a 10.71 fold greater odds (OR 10.71, $\rho=0.02$) (Eicher-Miller 2009). In the study that stratified by age, younger children with household food insecurity were more susceptible to have greater odds of IDA (OR 10.71 in 3-5 year olds, $\rho=0.02$) than the older children (OR 2.95 in 12-15 year olds, $\rho=0.02$) (Eicher-Miller 2009).

Although chronic conditions are not prevalent among children, there is emerging evidence that household food insecurity greatly influences the ability of vulnerable families to manage disease risk among children with diabetes and HIV. In a small Canadian study, a significantly higher prevalence of household food insecurity was found among families who had a child with diabetes in Nova Scotia, compared to the Canadian population (22% vs. 9.2%) (Marjerrison 2011). In this population, food insecurity was associated with significantly higher hospitalization rates (30% vs. 10.5%), higher levels of glycosylated hemoglobin (9.5% vs. 8.9%), which is an important marker of diabetes management, and a higher percent of adults in the household with a medical condition (50% vs. 35%), all of which are suggestive of greater likelihood of disease progression. In a recently published, small pilot study of HIV management among children in Texas (n=90), food insecurity was significantly associated with lower CD4

counts (β -0.23, 95% CI -0.40, -0.01) and greater odds of incomplete viral suppression (OR 4.07, 95% CI 1.02, 13.92), both markers of poor disease management, after controlling for demographic indicators using backward stepwise elimination (Mendoza 2013). Future studies should identify how best to assist families with a child with special health care needs who are subject to food insecurity.

Discussion

We address the cross-cutting themes posed by the committee and answer each in turn:

- Does how we measure food security, the unit (household vs. child hunger), and the severity/threshold matter for our understanding of the topic?

Most studies from large state-wide or nationally representative surveys assess household food insecurity using the standard 18-item USDA food security module, which typically uses a reference period of the past 12 months. Assessing the severity and threshold can be conducted when using the full scale and should be encouraged when possible. However, the duration of household food insecurity may be more detrimental during crucial periods of children's growth and development, such as pregnancy, early childhood, or adolescence. Assessments of food insecurity during these time periods, either prospectively or retrospectively, may provide important insight on the influence of household food insecurity on children's behaviors and health outcomes. In addition, assessment of household food insecurity over the past 30 days is important to understand how it relates to time-varying outcomes, such as children's diet, often measured at the time of the survey. For example, assessing concurrent 12-month household food security status with that of a 12-month food frequency questionnaire provide better estimates for usual occurrence, while assessing 30-day household food security status with multiple 24 hour recalls during the same time period may provide better consistency between measures for actual exposure-diet relationship.

Special attention should be paid to the time of the month when dietary recall is captured. It is possible that influence of food insecurity on children's diet will be most profound during the third and fourth week of the month, while diet quality and quantity might be better during the first week of the month, possibly even overeat during the first week. If there is a strong influence of when dietary recall is collected, and this isn't taken into account, the averaged intake might obfuscate any relationship between household food insecurity and diet quality or quantity.

- Is existing evidence sufficient to make causal claims, or merely associational?

Most of the studies reviewed in this article were cross-sectional and although the study design accounted for a number of important covariates, most did not employ analysis techniques that modeled the relationship between food insecurity and health outcomes causally. Therefore, causality cannot be determined between household food insecurity and pregnancy outcomes, gestational weight gain, child dietary intake, child weight gain or child chronic disease managements. Analytic techniques such as marginal structural models—inverse probability weighting, structural nested models and g-estimation—and instrumental variable methods, could be used to estimate casual relationships (Glymour 2006). However, the validity of these methods, especially inverse probability weighting and g-estimation, still relies on important assumptions

that may or may not be met with the available data, including that of no unmeasured confounders. On the other hand, instrumental variable methods do not require a set of measured confounders but rather, rely on strong unverifiable conditions or assumptions for a valid instrument that may be unlikely to hold in most research settings. Instrumental variables also tend not to handle time-varying exposures such as household food insecurity, well (Hernan and Robins 2006). Several studies did pay attention to specifying a priori hypotheses and used longitudinal data, which clarifies temporality in the relationship between household food insecurity and weight gain. Future studies should emphasize strong a priori hypotheses, employ causal modeling methods, and use population-based longitudinal studies when available and appropriate.

A focus on early life (e.g., pregnancy, infancy) exposure to and intervention that minimize the impact of food insecurity on health outcomes at ages five to ten will help solidify the importance of and methods to intervene during this time period. These types of longitudinal studies can better identify causal mechanisms of how food insecurity influences health and can better inform federal food programs. Well-designed longitudinal observational and controlled intervention studies can be conducted within the context of WIC to help optimize this program. At a minimal, the short food security scale should be asked of WIC participants in order to understand the prevalence, mitigation, or transitory nature of food insecurity in this population.

In addition to needed longitudinal and intervention studies that can be used to understand causal direction, efforts should be paid to linking large health and administrative datasets. Linking data from WIC, SNAP, Medicaid, birth record data, school data, and other electronic sources can now be accomplished. Compiling a longitudinal data from these sources may be a challenge but may be an important cost-effective first step toward understanding the impact of food insecurity on child outcomes.

- Are there important data gaps? Longitudinal, experimental, demonstrations, administrative, linked admin-survey data, qualitative?

1) Research is needed to address the research questions: To what extent does household food insecurity contribute to preterm birth and low birth weight? During what time frame during pregnancy is food insecurity the most detrimental and impacts fetal development and increases risk of adverse birth outcomes? Future studies should focus on understanding mechanisms and how federal food programs can be optimized to reduce excessive gestational weight gain, gestational diabetes, disordered eating patterns among women, as well as birth defects, preterm birth, and low birth weight. Using current research to optimize WIC should be a first line of defense to minimize the impact of food insecurity on maternal, infant, and child health.
2) No studies were found that investigated the relationship between household food insecurity and dietary intake during pregnancy. Future studies are needed to assess the influence of food insecurity on dietary intake and identify to what extent food-insecure pregnant women may be at risk of consuming more nutrient-poor, energy-dense foods, or not consuming enough of recommended nutrient-dense foods rich in calcium, iron, folate and other nutrients important during pregnancy. This information may better inform diet interventions during pregnancy as well as the foods promoted through WIC.
3) Important research is needed to identify specific stress reducing techniques and important foods and nutrients to promote during pregnancy in order to improve fetal and offspring outcomes in the future. What value added components are needed in WIC, such as referral

system for mental health services including stress reduction classes, “prescriptions” for physical activity programs, and other related stress reduction activities? Assessing new intervention components in WIC or prenatal care should focus on the influence of health outcomes for the mother and infant.

4) Although cross-sectional data might be used to assess causality under strong assumptions, understanding the extent to which the exposure to food insecurity experienced during critical periods of growth and development (e.g., pregnancy, infancy, toddler, and adolescence) leads to poor health outcomes during the next period cannot be modeled with cross-sectional data. For some research questions a sufficient lag time is necessary to identify the full effect of household food insecurity on child outcomes. Based on animal and human students (Kaufman 2007, Dubois 2006), the lag time could be from 2 to 10 years. Food insecurity experienced during pregnancy or infancy (<12 months of age) may be the most critical periods. The following are a few ideas for future studies:

- Further studies are needed to understand to what extent long term exposure of household food insecurity in early life influences weight status during childhood and pre-adolescences. Emphasis on identifying and measuring underlying mechanisms such as change in diet pattern, stress related eating, the cyclic food availability and eating, or other mechanisms are needed to inform programs and interventions.
- The WIC population could be an excellent population to engage for studying the influence of food insecurity on child health outcomes through five years of age. A representative sample of WIC clinics could be identified, selected, and staff could be trained to carry out prospective data collection assessing food security status, diet, and a few additional socio-economic and mental health factors.
- Additionally, WIC clinics could be ideal for conducting intervention studies that aim to minimize the deleterious effects of food insecurity on child health.
- Linking administrative data from WIC, SNAP, PRAMS, birth records, maternal and pediatric medical charts, Medicaid records, and school records in the era of “big data” is another alternative to model and identify important determinants and modifiable risk factors upon which to intervene.
- The USDA could work and collaborate with the National Institutes of Health to identify appropriate longitudinal studies to which the food security core module or a shorter version can be added. Approach the NIH National Cancer Institute measurement core and the Office of Behavioral and Social Science Research (OSBSSR) to promote use of the FSCM in research. Adding food security measures could be a value added approach.
- Add the FSCM, shorter food security scales and documentation to ongoing initiatives within NIH that promote measures such as:
  - PhenxToolkit https://www.phenxtoolkit.org/
  - NIH Office of Strategic Coordination's PROMIS: Patient-Reported Outcomes Measurement Information System. https://commonfund.nih.gov/promis/

5) Modest and inconsistent findings of the association between food insecurity and dietary intake among children fail to help inform how federal funds can be targeted. Interventions may be needed to restrict highly palatable foods of low nutrient value or to promote fresh foods of high nutrient value. Qualitative research on differences in dietary intake by age, food security status, various program usage and contextual factors are needed in order to optimize interventions.

Longitudinal studies are needed that capture cyclic patterns of food insecurity and its influence on shaping dietary intake and eating behavior to better understand the mechanisms that lead to poor health.
6) Longitudinal examination of development of eating patterns related to coping skills that children implement to help caregivers combat the impact of household food insecurity are needed. To what extent do various coping skills adopted by children influence dietary intake, food choice and eating patterns?
7) Studies are needed to understand how improving delayed gratification and self-control might improve eating behaviors. Experimental studies, such as that of Kidd et al. (2013) could help us understand mechanisms through which food insecurity influences child behavior that might better identify modifiable risk factors that should be the target of interventions.

- How should USDA prioritize research efforts? What are the critical questions in each topic area, and what kind of research could begin to answer them?

Monitoring progress toward federal food program goals, especially WIC should be a national priority. A priority area for the USDA is to tackle the relationship between the level of individual and household food security status and dietary intake among pregnant women, infants, and children, paying special attention to the timing of data collection and stage of the life cycle. In addition, interventions and pilot studies that test innovative strategies are needed and their results will help inform how best to improve and optimize the influence federal food programs have on participants' diets and health outcomes. For example, using current and future research, USDA can optimize how WIC can influence dietary intake as this program is the first of line defense to minimize the impact of food insecurity on maternal, infant and child health.

A second area of importance is to develop research questions that aim to identify specific stress reducing techniques and ways to reduce the impact of food insecurity on critical gestational periods during pregnancy. Since the birth-related outcomes associated with food insecurity are so severe and have lasting effects in childhood through adulthood in terms of health outcomes, psychosocial effects, and health care costs, more attention must be paid to optimizing current programs to achieve the best results. Identifying the role of WIC in improving linkages to mental and physical health care and increasing referrals to community programs may be an important area of focus.

References

Adam TC, Epel ES. Stress, eating and the reward system. Physiol Behav 2007;91(4):449-458.

Bhattacharya J, Currie J, et al. Poverty, food insecurity, and nutritional outcomes in children and adults. J Health Econ 2004;23(4):839-862.

Borders AE, Grobman W A, et al. Chronic stress and low birth weight neonates in a low-income population of women. Obstet Gynecol 2007;109(2 Pt 1):331-338.

Braveman P, Marchi K, et al. Poverty, near-poverty, and hardship around the time of pregnancy. Matern Child Health J 2010;14(1):20-35.

Bronte-Tinkew J., Zaslow M, et al. Food insecurity works through depression, parenting, and infant feeding to influence overweight and health in toddlers. J Nutr 2007;137(9):2160-2165.

Carmichael SL, Yang W, et al. Maternal food insecurity is associated with increased risk of certain birth defects. J Nutr 2007;137(9):2087-2092.

Casey P, Goolsby S, et al. Maternal depression, changing public assistance, food security, and child health status. Pediatrics 2004;113(2):298-304.

Centers for Disease Control and Prevention (CDC). Iron deficiency--United States, 1999-2000. MMWR Morb Mortal Wkly Rep 2002;51(40):897-899.

Cunningham TJ, Barradas DT, et al. Is maternal food security a predictor of food and drink intake among toddlers in Oregon? Matern Child Health J 2012;16 Suppl 2:339-346.

Dave JM, Evans AE, et al. Associations among food insecurity, acculturation, demographic factors, and fruit and vegetable intake at home in Hispanic children. J Am Diet Assoc 2009;109(4):697-701.

Dubois L, Farmer A, et al. Family food insufficiency is related to overweight among preschoolers. Soc Sci Med 2006;63(6):1503-1516.

Eicher-Miller HA, Mason AC, et al. Food insecurity is associated with iron deficiency anemia in US adolescents. Am J Clin Nutr 2009;90(5):1358-1371.

Eicher-Miller HA, Mason AC, et al. Food insecurity is associated with diet and bone mass disparities in early adolescent males but not females in the United States. J Nutr 2011;141(9):1738-1745.

Eisenmann JC, Gundersen C, et al. Is food insecurity related to overweight and obesity in children and adolescents? A summary of studies, 1995-2009. Obes Rev 2011;12(5):e73-83.

Epel E, Lapidus R, et al. Stress may add bite to appetite in women: a laboratory study of stress-induced cortisol and eating behavior. Psychoneuroendocrinology 2001;26(1):37-49.

Epel ES, Tomiyama AJ, Dallman MF. Stress and reward neural networks, eating, and obesity. In: Food and Addiction: A Comprehensive Handbook, Eds. Kelly Brownell & Mark Gold. Oxford University Press, USA. 2012.

Fram MS, Frongillo EA, et al. Children are aware of food insecurity and take responsibility for managing food resources. J Nutr 2011;141(6):1114-1119.

Fungwe T, Guenther PM, Juan W, Hiza H, Lino M. The Quality of Children's Diets in 2003-04 as Measured by the Healthy Eating Index-2005. Nutrition Insight 43, CNPP USDA; Alexandria, VA. 2009.

Gluckman PD, Hanson MA. Developmental and epigenetic pathways to obesity: an evolutionary-developmental perspective. Int J Obes (Lond) 2008;32 Suppl 7:S62-71.

Glymour MM. Natural experiments and instrumental variable analyses in social epidemiology. Book Chapter 17. In Methods in Social Epidemiology (Eds) J Michael Oakes and JS Kaufman. Jossey-Bass, San Francisco, CA. 2006.
Glynn LM, Schetter CD, et al. Pattern of perceived stress and anxiety in pregnancy predicts preterm birth. Health Psychol 2008;27(1):43-51.
Grutzmacher S, Gross S. Household food security and fruit and vegetable intake among low-income fourth-graders. J Nutr Educ Behav 2011;43(6):455-463.
Guenther PM, Juan W, Lino M, Hiza HA, Fungwe T, Lucas R. Diet Quality of Low-Income and Higher Income Americans in 2003-04 as Measured by the Healthy Eating Index-2005. Nutrition Insight 42, CNPP USDA; Alexandria, VA. 2008.
Gundersen C, Ribar D. Food Insecurity and Insufficiency at Low Levels of Food Expenditures. Review of Income and Wealth 2011;57(4):704-726.
Hernan MA, Robins JM. Instruments for causal inference - An epidemiologist's dream? Epidemiology 2006;17(4):360-372.
Hernandez DC, Jacknowitz A. Transient, but not persistent, adult food insecurity influences toddler development. J Nutr 2009;139(8):1517-1524.
Herrmann TS, Siega-Riz AM, et al. Prolonged periods without food intake during pregnancy increase risk for elevated maternal corticotropin-releasing hormone concentrations. Am J Obstet Gynecol 2001;185(2):403-412.
Hobel C, Culhane J. Role of psychosocial and nutritional stress on poor pregnancy outcome. J Nutr 2003;133(5 Suppl 2):1709S-1717S.
Hobel CJ. Stress and preterm birth. Clin Obstet Gynecol 2004;47(4):856-880.
Hobel C.J, Goldstein A, et al. Psychosocial stress and pregnancy outcome. Clin Obstet Gynecol 2008;51(2):333-348.
Hromi-Fiedler A, Bermudez-Millan A, et al. Household food insecurity is associated with depressive symptoms among low-income pregnant Latinas. Matern Child Nutr 2011;7(4):421-430.
Huddleston-Casas C, Charnigo R, et al. Food insecurity and maternal depression in rural, low-income families: a longitudinal investigation. Public Health Nutr 2009;12(8):1133-1140.
Jyoti DF, Frongillo EA, et al. Food insecurity affects school children's academic performance, weight gain, and social skills. J Nutr 2005;135(12):2831-2839.
Kaiser LL, Melgar-Quinonez H, et al. Food insecurity and food supplies in Latino households with young children. J Nutr Educ Behav 2003;35(3):148-153.
Kaiser LL, Melgar-Quinonez HR, et al. Food security and nutritional outcomes of preschool-age Mexican-American children. J Am Diet Assoc 2002;102(7):924-929.
Kaufman D, Banerji MA, et al. Early-life stress and the development of obesity and insulin resistance in juvenile bonnet macaques. Diabetes 2007;56(5):1382-1386.
Kidd C, Palmeri H, et al. Rational snacking: young children's decision-making on the marshmallow task is moderated by beliefs about environmental reliability. Cognition 2013;126(1):109-114.
Kirkpatrick SI, Dodd KW, et al. Income and race/ethnicity are associated with adherence to food-based dietary guidance among US adults and children. J Acad Nutr Diet 2012;112(5):624-635 e626.
Kirkpatrick SI, Tarasuk V. Food insecurity is associated with nutrient inadequacies among Canadian adults and adolescents. J Nutr 2008;138(3): 604-612.

Kropf ML, Holben DH, et al. Food security status and produce intake and behaviors of Special Supplemental Nutrition Program for Women, Infants, and Children and Farmers' Market Nutrition Program participants. J Am Diet Assoc 2007;107(11): 1903-1908.
Kuo LE, Czarnecka M, et al. Chronic stress, combined with a high-fat/high-sugar diet, shifts sympathetic signaling toward neuropeptide Y and leads to obesity and the metabolic syndrome. Ann N Y Acad Sci 2008;1148:232-237.
Kuo LE, Kitlinska JB, et al. Neuropeptide Y acts directly in the periphery on fat tissue and mediates stress-induced obesity and metabolic syndrome. Nat Med 2007;13(7):803-811.
Laraia B, Epel E, et al. Food insecurity with past experience of restrained eating is a recipe for increased gestational weight gain. Appetite 2013;65:178-84.
Laraia BA, Siega-Riz AM, et al. Household food insecurity is associated with self-reported pregravid weight status, gestational weight gain, and pregnancy complications. J Am Diet Assoc 2010;110(5):692-701.
Laraia BA, Siega-Riz AM, et al. Psychosocial factors and socioeconomic indicators are associated with household food insecurity among pregnant women. J Nutr 2006;136(1):177-182.
Larson NI, Story MT. Food insecurity and weight status among U.S. children and families: a review of the literature. Am J Prev Med 2011;40(2):166-173.
Leung CW, Blumenthal SJ, et al. Associations of food stamp participation with dietary quality and obesity in children. Pediatrics 2013;131(3):463-472.
Lorson BA, Melgar-Quinonez HR, et al. Correlates of fruit and vegetable intakes in US children. J Am Diet Assoc 2009;109(3):474-478.
Marjerrison S, Cummings EA, et al. Prevalance and associations of food insecurity in children with diabetes mellitus. J Pediatr 2011;158(4):607-611.
Matheson DM, Varady J, et al. Household food security and nutritional status of Hispanic children in the fifth grade. Am J Clin Nutr 2002;76(1):210-217.
Mendoza JA, Paul ME, et al. Food Insecurity, CD4 Counts, and Incomplete Viral Suppression Among HIV+ Patients from Texas Children's Hospital: A Pilot Study. AIDS Behav 2013, forthcoming.
Metallinos-Katsaras E, Must A, et al. A longitudinal study of food insecurity on obesity in preschool children. J Acad Nutr Diet 2012;112(12):1949-1958.
Park K, Kersey M, et al. Household food insecurity is a risk factor for iron-deficiency anaemia in a multi-ethnic, low-income sample of infants and toddlers. Public Health Nutr 2009;12(11):2120-2128.
Perez-Escamilla. Chapter 72. Food insecurity in children: Impact on physical, psychoemotional, and social development. In: Pediatric and Adolescent Disorders. 2013, forthcoming.
Perez-Escamilla R, Pinheiro de Toledo Vianna R. Food Insecurity and the Behavioral and Intellectual Development of Children: A Review of the Evidence. Journal of Applied Research on Children: Informing Policy for Children at Risk. 2012; 3(1). Article 9.
Portha, B., A. Chavey, et al. (2011). Early-life origins of type 2 diabetes: fetal programming of the beta-cell mass. Exp Diabetes Res 2011: 105076.
Rosas LG, Harley K, et al. Dietary associations of household food insecurity among children of Mexican descent: results of a binational study. J Am Diet Assoc 2009;109(12):2001-2009.
Roseboom TJ, Painter RC, et al. Hungry in the womb: what are the consequences? Lessons from the Dutch famine. Maturitas 2011;70(2):141-145.

Sharkey JR, Nalty C, et al. Children's very low food security is associated with increased dietary intakes in energy, fat, and added sugar among Mexican-origin children (6-11 y) in Texas border Colonias. BMC Pediatr 2012;12:16.
Skalicky A, Meyers AF, et al. Child food insecurity and iron deficiency anemia in low-income infants and toddlers in the United States. Matern Child Health J 2006;10(2):177-185.
Smith C, Richards R. Dietary intake, overweight status, and perceptions of food insecurity among homeless Minnesotan youth. Am J Hum Biol 2008;20(5):550-563.
Stuff JE, Casey PH, et al. Household food insecurity is associated with adult health status. J Nutr 2004;134(9):2330-2335.
Tomiyama AJ, Dallman MF, et al. Comfort food is comforting to those most stressed: evidence of the chronic stress response network in high stress women. Psychoneuroendocrinology 2011;36(10):1513-1519.
Tomiyama AJ,Puterman E, et al. Chronic psychological stress and racial disparities in body mass index change between black and white girls aged 10-19. Ann Behav Med 2013;45(1):3-12.
Whitaker RC, Phillips SM, et al. Food insecurity and the risks of depression and anxiety in mothers and behavior problems in their preschool-aged children. Pediatrics 2006;118(3): e859-868.
Widome R, Neumark-Sztainer D, et al. Eating when there is not enough to eat: eating behaviors and perceptions of food among food-insecure youths. Am J Public Health 2009;99(5): 822-828.
Winicki J, Jemison K. Food insecurity and hunger in the kindergarten classroom: Its effect on learning and growth. Contemp Econ Policy 2003;21(2):145-157.