MATERNAL RISK FACTORS FOR POOR BIRTH OUTCOMES IN MODERATELY
MALNOURISHED PREGNANT WOMEN IN SIERRA LEONE

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Candice Rodriguez
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TITLE: Maternal Risk Factors for Poor Birth Outcomes in Moderately Malnourished Pregnant Women in Sierra Leone

AUTHOR: Candice Rodriguez

DATE SUBMITTED: March 2020

COMMITTEE CHAIR: Peggy Paphatakis, Ph.D., RD
Professor of Nutrition

COMMITTEE MEMBER: Angelos Sikalidis, Ph.D., FACN
Associate Professor of Nutrition

COMMITTEE MEMBER: Immanuel Williams, Ph.D.
Lecturer of Statistics
ABSTRACT

Maternal Risk Factors for Poor Birth Outcomes in Moderately Malnourished Pregnant Women in Sierra Leone

Candice Rodriguez

Background: Maternal malnutrition in developing countries is associated with adverse pregnancy and birth outcomes. Malnourished mothers are often faced with additional risk factors as a circumstance of poverty. Supplementary nutrition can improve the outcomes of both mother and infant. Identifying maternal nutritional and socioeconomic risk factors is critical for developing effective interventions.

Objective: A secondary analysis to evaluate maternal risk factors associated with poor birth outcomes including pregnancy loss, low birth weight, stunting, and preterm delivery among moderately malnourished pregnant women in Sierra Leone. Maternal risk factors in the analysis are age, education, parity, BMI, MUAC, gestational weight gain, and recent exposure to malaria infection.

Methods: Pregnant women were enrolled into a randomized controlled trial when presenting with a MUAC ≤ 23cm (N=1475). Demographic information was collected and women were randomly assigned two receive either a ready-to-use supplementary food (RUSF) or a corn-soy blended flour with an iron and folic acid supplement (CSB +IFA). Anthropometric measurements of height, weight, MUAC, and fundal height were measured every two weeks during pregnancy. Upon delivery the infant was measured for length, weight, MUAC, and head circumference and the mother was measured for MUAC. Infant outcomes of interest included stunting (length-for-age z-score < -2SD), preterm delivery (<37 weeks), and low birth weight (<2500g). Infant outcomes were compared by maternal age group (younger adolescent 13-16 years, older adolescent 17-19 years, adult 20-28 years, and older adult 29-42 years), educational level (none, 6 years, or 7+), parity (primiparous/multiparous), BMI at enrollment, MUAC at enrollment, adequate weekly gestational weight gain, and exposure to a recent malaria infection.

Results: The mean age of enrolled pregnant women was 21.2 years with a mean BMI of 19.78 kg/m². A total of 33.2% had never attended school. Controlling for weeks on treatment and BMI at enrollment, mothers receiving the RUSF treatment gained a mean 0.49 kg (p<0.000) more in total weight, a 0.28 cm larger MUAC at delivery (p=0.002), and a 0.16 cm greater increase in MUAC from enrollment to delivery (p=0.001) than the CSB +IFA group. Infants born to mothers receiving the RUSF were 0.29 cm longer on average than infants born to mothers who received CSB + IFA (p=0.027). Maternal outcomes by age revealed that mature adults had the highest rates of miscarriage and stillbirth. Infants born to younger adolescent mothers had significantly smaller anthropometric measurement of length (p<0.000), weight (p<0.000), MUAC (p<0.000), and head circumference (p<0.000) compared to their older counterparts. Infants of women with no education had a birth length 0.53 cm longer than women with primary education (p=0.012). Similarly, women with no education had infants that weighed 120 g
and 8 g more than women with 1-6 years of education and women with 7 or more years of, respectively (p=0.000). Giving birth for the first time produced significantly smaller infants and was a strong predictor for stunting, LBW, and preterm delivery. A maternal BMI <18.5 kg/cm² produced infants that were significantly smaller than women with a BMI ≥ 18.5 kg/cm². Similarly, infants born to women with a MUAC <21 cm weighed a mean 15 g less (p=0.004) and had a 0.26 cm smaller MUAC (p=0.008) compared to women with a MUAC ≥23. Additionally, for every one unit decrease in maternal MUAC, women has 1.2 greater odds of preterm delivery (p=0.022). Also, women with adequate weekly weight gain gave birth to infants with a 0.37 cm greater mean length (p=0.012), 7.0 g greater mean weight (p=0.030), and 0.08 cm greater mean MUAC (p=0.045) than women with inadequate weight gain. No association was found between recent exposure to malaria at enrollment and poor infant outcomes.

Conclusion: In resource poor settings like Sierra Leone with high rates of maternal malnutrition and a high burden of stunting, LBW, and preterm delivery, use of RUSF improved maternal nutritional status but did not impact infant outcomes. The youngest adolescents had the most adverse infant outcomes. Education did not have the expected outcome, indicating other risk factors in this population may play a greater role in infant outcomes. Maternal risk factors of malnutrition such as BMI <18.5 kg/cm² and MUAC <21 cm resulted in smaller infants. During pregnancy, women should be encouraged to gain adequate weight. Young primiparous adolescent are at the highest risk and interventions to postpone motherhood should be priority.
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LIST OF ABBREVIATIONS

ANOVA Analysis of variance
BMI Body mass index
CSB+ Fortified corn soy blend
cm Centimeter(s)
g Gram(s)
GWG Gestational weight gain
HC Head Circumference
IOM Institute of Medicine
IFA Iron and folic acid supplement
IFPRI International Food Policy Research Institute
IUGR Intrauterine growth restriction
kcal Kilocalorie(s)
kg Kilogram(s)
LBW Low birth weight
LMICs Low-middle income countries
MCH Maternal and Child Health
MDGs Millennium Development Goals
MSDR Maternal Death Surveillance and Response Report
MOHS Ministry of Health and Sanitation
MUAC Mid-upper arm circumference
RUSF Ready-to-use supplementary food
SD Standard deviation
SGA Small for gestational age
SSL Statistics Sierra Leone
UNFPA United Nations Population Fund
WHO World Health Organization
WFP World Food Programme
CHAPTER 1
INTRODUCTION

Maternal malnutrition in developing countries is a major public health problem. The cause of maternal malnutrition is a combination of increased nutrient requirements during pregnancy and inadequate intake of energy and/or micronutrients (Black et al, 2008). Maternal malnutrition is associated with several adverse pregnancy and birth outcomes. For the mother, maternal mortality and pregnancy loss may result (Alkema et al., 2016). For the infant, being born too early, low birth weight, and stunting are common (Abu-Saad & Fraser, 2010; Danaei et al., 2016). Additionally, women experiencing moderate to severe malnutrition during pregnancy are likely to be low income, exposing them to even more risk factors, with an increased effect when combined.

Low and middle-income countries continue to bear the largest burden of poor pregnancy and birth outcomes. About 98% of stillbirths and 94% of maternal deaths occur in developing countries (Blencowe et al., 2016; Goldenberg et al., 2018). For the infants that make it through a malnourished pregnancy, preterm delivery and low birth weight increase the risk of neonatal death (Cutland et al., 2017). Maternal malnutrition can also affect the infant’s body size and composition in the form of long-term deficits in fetal lean body mass (Victoria et al., 2008). Stunting, or a low length-for-age, is very common for these infants and manifests into lifelong consequences of impaired physical growth, cognitive development, and increased risk of non-communicable disease (Lartey, 2008).
Identification of at-risk women and their risk factors for poor birth outcomes is crucial for prevention and targeting services. Maternal anthropometrics indicating nutritional status such as BMI, MUAC, and gestational weight gain are strongly associated with growth and fetal development (Ay et al., 2009; Tang et al., 2016). However, environmental, economic, and sociopolitical circumstances are also important underlying causes for poor birth outcomes (Black et al., 2008). Low education, adolescent childbirth, and infections have been identified as important risk factors (Shah et al., 2014; Desai et al., 2007; Althabe et al., 2015). Understanding risk factors for malnourished women in developing countries may provide more insight, as well as inform best strategies in ameliorating adverse outcomes for the mother and child.

Numerous supplementation programs have targeted maternal malnutrition with varying success (Papathakis et al., 2016) Recommendations for treating malnourished pregnant women include a fortified corn-soy blend flour with an iron and folic acid supplement (World Health Organization, 2012). However, other treatments for maternal malnutrition, such as balanced protein energy supplementation and lipid-based nutrient supplements have also been successful (Imad, Aamer, and Bhutta, 2011; Adu-Afarwuah et al., 2010). These alternate treatments may have better acceptability and therefore may be more effective (Iuel-Brockdorph et al., 2015).

Sierra Leone is a small, densely populated country in sub-Saharan Africa and is one of the poorest countries in the world (Human Development Index, 2019). Fertility rates are high at 4.46 births per woman (The World Bank, 2019). Many of these births are among adolescents, as Sierra Leone has the 13th highest rate of teenage pregnancy globally (The World Bank, 2019). Worldwide, the maternal mortality rate is among the
highest at 1120 deaths per 100,000 live births (The World Bank, 2019). The national prevalence of stunting has improved but remains high at 31.3%, indicating persistent malnutrition (SSL, 2018). Additionally, women in Sierra Leone face low literacy rates (24.8%), limited reproductive rights, and exposure to infectious disease such as malaria (United Nations Education, Science, and Culture Organization, 2019; World Health Organization, 2018).

This analysis of baseline maternal characteristics of moderately malnourished pregnant women in Sierra Leone is intended to determine which are significant risk factors of poor birth outcomes such as low birth weight, stunting, and preterm delivery.
CHAPTER 2
REVIEW OF LITERATURE

Adverse pregnancy outcomes are a major public health problem in many developing countries and have significant economic, social, and health implications for families and society (Akombi et al., 2018). Sub-Saharan Africa has some of the highest maternal and infant mortality rates in the world (Akombi et al., 2018). The adverse health outcomes examined in this study—namely, low birth weight, preterm delivery, stunting, stillbirth, and miscarriage, persist in low and middle income countries. Compared to high income countries, the disparity in pregnancy outcomes in low income countries is multifactorial and often the result of malnutrition, disease, and inadequate health care (Symington et al., 2018) (Figure 2.1).

Figure 2.1 Conceptual framework of exposure and outcome variables of birth outcomes. (Adapted from Symington et al., 2018)
2.1 Poor Infant Outcomes

2.1.1 Low Birth Weight

Low birth weight (LBW) is a valuable public health indicator of both maternal and fetal health (Blencowe et al., 2019). The birth weight of an infant is ideally measured within the first hours of birth, before significant postnatal weight loss has occurred (Muchemi et al., 2015). LBW is defined as less than 2500 g (5.5 lbs.) at birth, regardless of gestational age (Mahumud, et al., 2017). Worldwide, it is estimated that 15.5% of all births are LBW (Muchemi et al., 2015). In 2015, 91% of LBW infants were from low middle income countries (LMICs) and 24% of those were from sub-Saharan Africa (Blencowe et al., 2019). LBW is one of the main predictors of infant mortality, stunting, and long-term consequences such as impaired neurodevelopmental problems and chronic disease (Cutland et al., 2017).

Maternal nutritional status is closely associated with infant birth weight (Thame et al., 1997; Jananthan et al., 2010; Ramakrishnan, 2004). An analysis of determinants of LBW in developing countries found a significant association between LBW and late maternal age (35-49 years), inadequate antenatal care (0 or 1 visits), low education level (<secondary education), and low body mass index (BMI)(≤18.5 kg/m²) (Mahumud et al., 2017). A young maternal age of less than 20 years has also been shown to have a greater risk of LBW (Oladeinde et al., 2016; Ngwira & Stanley 2015). In Ethiopia, an observational cohort study of pregnant women found LBW was significantly associated with poverty, mid upper arm circumference (MUAC) <23 cm, and not attending antenatal care (Assefa et. al, 2012). In Malawi, a community-based randomized controlled trial found a higher BMI and gestational weight gain had an independent protective effect.
against LBW (Van den Broek et al., 2014). Maternal malaria is also an important predictor of LBW (Wumba et al., 2015; Van den Broek, 2014). In a cohort of Congolese pregnant women, 94.5% of LBW infants were born to mothers with a detected malarial infection (Wumba et al., 2015).

_Intrauterine Growth Restriction_

LBW infants include those that did not grow fully in utero (intrauterine growth restriction-IUGR) and those that were born too early (preterm birth). IUGR is the predominant cause of LBW in developing countries (Black et al, 2008; Sharma, et al., 2016). It is defined as a rate of fetal growth that is less than normal in light of that specific infant’s growth potential (Sharma et al., 2016). The healthy neonate is the one whose birth weight is between the 10\textsuperscript{th} and 90\textsuperscript{th} percentile as per the gestational age, gender, and race with no feature of malnutrition and growth retardation (Sharma et al., 2016). The lifelong consequences of IUGR begin from fetal adaptations in utero. In the condition of an inadequate supply of nutrients, the fetus is forced to down-regulate growth and prioritize the development of essential tissues (Fall et al., 2003). This adaptation ensures short-term survival but at the cost of altered body composition and reduced secretion of and sensitivity to the fetal growth hormones (Fall et al., 2003). Asymmetrical IUGR is the most common type, and results from placental insufficiency later in the pregnancy, causing infants to have a reduced weight, but normal length and head circumference (Cutland et al., 2017).

The causes of IUGR may be maternal, fetal, or placental factors, with a commonality of insufficient uterine-placental perfusion and fetal nutrition (Cutland et al., 2017). IUGR has two strong predictors- poor maternal nutrition and maternal infection.
(de Onis, 2016). Both maternal energy and protein deficiency have been demonstrated to be causes of IUGR (Imdad & Bhutta, 2011). Strauss et al., examined the relationship between maternal weight gain in individual trimesters to IUGR in two large, prospective studies and found that low weight gain (<0.3kg/wk) in the second and third trimester of pregnancy increased the risk of IUGR. Maternal malaria has also been shown to increase the risk of IUGR (Landis et al., 2008). A study in Tanzania found IUGR was associated with younger age (<20 years) and maternal malaria (Watson-Jones, 2007). Additionally, the risk of IUGR associated with malaria was greatest after three or more cumulative infections, and was two-to-eight fold higher among women with evidence of undernutrition (Landis et al., 2008).

2.1.2 Preterm Birth

An estimated 15 million babies are born preterm, with the majority occurring in sub-Saharan Africa and South Asia (Figure 2.2)(Blencowe et al., 2013). Preterm birth is defined as birth before 37 weeks of gestation and can be further subdivided on the basis of gestational age: extremely preterm (<28 weeks), very preterm (28–<32 weeks), and moderate or late preterm (32–37 completed weeks of gestation) (World Health Organization (WHO), 2018).
Preterm birth complications are the leading cause of death among children under 5 years of age (Liu et al., 2016). Preterm infants risk having multiple immature organ systems resulting in intracranial hemorrhage, respiratory distress, sepsis, blindness, and gastrointestinal disorders (Cutland et al., 2017). Survival for preterm infants in developing countries is low, and half of the babies born at or below 32 weeks will die due to insufficient basic health care (WHO, 2018).

Multiple mechanisms may initiate a preterm delivery, and several maternal and fetal risk factors have been identified, but the exact etiology remains unknown. Micronutrient deficiencies such as folate, zinc, and iron have all been associated with preterm delivery (Black, 2001). In a meta-analysis and systematic review of 78 studies, the risk of preterm birth was increased in underweight women with a BMI <18.5 kg/m² (Han et. al., 2010). Salihu et al. (2009) found that the risk of preterm delivery among...
mothers increased with descending low BMI severity [BMI categorized as normal (19.5–24.9 kg/m²), mild thinness (17.0–18.5 kg/m²), moderate thinness (16.0–16.9 kg/m²) and severe thinness (≤15.9 kg/m²)]. Additionally, for each BMI category, extreme risk values for spontaneous preterm births were observed among women with low gestational weight gain of <0.12 kg/week. Shah et al., (2004) found the risk of preterm birth was lower among women with primary level of education and a higher risk of preterm birth among women with MUAC ≤25 cm. In Malawi, young age (<20 years) was associated with early preterm birth, and persistent malaria increased the risk of late preterm birth (Van den Broek et al., 2014).

2.1.3 Miscarriage

Miscarriage, or spontaneous abortion, is the premature loss of a fetus up to 28 weeks of pregnancy and weighing up to 500 g (WHO, 2019). In developing countries, the incidence of miscarriage is high in women from disadvantaged socioeconomic groups. Fetal causes of miscarriage, such as chromosomal anomalies, occur in the first trimester (Ahmadi et al., 2017). Although there are several reasons a miscarriage occurs, and often the pregnancy loss is unexplained, miscarriage is developing countries is frequently the result of infection and the poor nutritional status of the mother before and during pregnancy (Ahmadi et al., 2017).

Maternal nutritional deficiencies have been shown to cause cellular dysfunction and severe damage throughout fetal development (Abu-Saad & Fraser, 2010). The well-documented folate deficiency in early pregnancy has been associated with numerous pregnancy outcomes, including spontaneous abortion (George, 2002; Nelen et al., 2000; Ronnenburg et al., 2002). Poor status of vitamin B12, B6, and concurrent elevated
homocysteine levels are probable risk factors for placental diseases leading to spontaneous abortion (Ronnenberg et al., 2007; Hubner et al., 2008; Molloy et al., 2008). Additionally, many other micronutrients have been identified to have detrimental effects leading to spontaneous abortion including vitamin A and E, zinc, iron, and copper (Zare et al., 2013; Black et al., 2001).

Several other maternal risk factors have been associated with miscarriage. Among women exposed to malaria, McGready et al. (2012) found that the odds of miscarriage increased 2.7 times in women with asymptomatic malaria and 3.9 times with symptomatic malaria. Additionally, the odds of miscarriage doubled with maternal age ≥ 31 years (McGready et al., 2012). Maconochie et al. (2007) found a 72% increase in the odds associated with being underweight (BMI < 18.5 kg/m²) and a 75% increase in odds for women over 35 years for having a miscarriage. In a cross-sectional analysis of women aged 35-45 years old, women with higher educational attainment (high school and above) had a lower prevalence of miscarriage and women from rural areas had a 1.68 times greater risk than women from urban areas for miscarriage (Zheng et al., 2017). Similarly, Norsker et al. (2012) found maternal education inversely associated with the risk of miscarriage. Specifically, women with <10 years of education had an elevated risk of miscarriage compared to women with more than 12 years of education (Norsker et al., 2012).

2.1.4 Stillbirth

In 2015, the worldwide estimate of stillbirths was 2.6 million (Blencowe et al., 2016). Stillbirth is defined as a newborn having no signs of life at delivery (Ishaque et al., 2011). The highest burden, about 98%, both in terms of stillbirth rates and numbers of stillbirths
continues to be in sub-Saharan Africa and southern Asia (Figure 2.3) (Blencowe et al., 2016).

Figure 2.3 Worldwide stillbirth rates. (Adapted from Lawn et al., 2016)

In a systematic analysis of worldwide data, Blencowe et al. (2016) found that fetal growth restriction, preterm birth, and LBW were the top predictors of stillbirth. Placental dysfunction associated with fetal growth restriction and preterm birth can increase the risk of both antepartum stillbirth and intrapartum stillbirth for a compromised fetus during labor (Lawn et al., 2016). Nearly half of all stillbirths happen when the woman is in labor, with males having a 10% higher risk of stillbirth than female babies (Lawn et al., 2016). In developing countries, this poses an even greater risk, as many women give birth unattended at home and have limited access to intrapartum care (Blencowe et al., 2016).

Maternal risk factors associated with stillbirth include age, infection, and education. Worldwide, 6.7% of stillbirths are attributable to older maternal age (> 35 years) (Lawn et al., 2016; Saleem et al., 2018). However, adolescent pregnancy <16 years
Althabe et al., 2015) and < 20 years (Saleem et al., 2018) has also been associated with
an increased risk of stillbirth. In an African study including Burundi, Congo Democratic
Republic, Kenya, Rwanda, Tanzania and Uganda factors associated with stillbirth were:
no schooling (OR 1.85; CI 1.44-2.38), primary education level (OR 1.64; CI 1.32-2.05),
advanced maternal age (>35 years)(OR 2.39; CI 1.59-3.59), and drinking water from
unimproved sources (OR 1.18; CI 1.01-1.37) (Akombi et al., 2018). An infection during
pregnancy is also an important risk factor for stillbirth in LMICs (Goldenberg et al.,
2010). Specifically, malaria, due to the high prevalence of the disease and potential
extensive placental damage (Goldenberg et al., 2010). In a systematic review, van
Geertruyden et al. (2004) found placental malaria increased the risk of stillbirth over 2
times compared to women with no infection (OR 2.19; CI 1.49-3.22).

2.1.5 Stunting

Globally, 155 million children under the age of 5 have stunted growth, with 30%
of those from sub-Saharan Africa (Hawkes & Franzo, 2017). Factors that influence
stunting begin in utero, and even before if the mother’s health is compromised. The early
years of life, especially the first 1,000 days, are critical in determining a child’s growth
(Black et al. 2008; Victoria et al., 2008). Unfortunately, the development of stunting is a
slow and cumulative process that generally cannot be reversed, only prevented (WFP,
2012). Additionally, several generations are necessary to ‘wash out’ multigenerational
influences (Martorell & Zongrone, 2012). Stunting can have severe short-term and long-
term health and functional consequences, including poor cognition and educational
performance, low adult wages (Figure 2.4) and lost productivity (de Onis & Branca,
2016). The effects of stunting not only have a detrimental impact on personal potential
but in a population, stunting can have substantial adverse economic effects because of reduced human capital (Victoria et al., 2008).

Figure 2.4 Causes, correlates, and consequences of stunting. (Adapted from Galasso & Wagstaff et al., 2017)

Stunting is assessed by measuring an infant's length and interpreting the measurements by comparing them to an international standard (de Onis & Branca, 2016). Among the nutrition community, the use of length-for-age is increasingly the indicator of choice in monitoring the long-term impact of chronic nutritional deficiency (Lartey, 2012). Stunting is defined as having a length-for-age less than -2 standard deviations (SD) away from the WHO reference population median (WHO, 2014). The degree to which stunting is occurring is delineated by at risk (≥-1 SD), moderate (≤ -2 SD), and severe (≤ -3 SD) (de Onis & Branca, 2016) with the risk of death increasing with a descending z-score (Black et al, 2008).

Many times, the impaired growth and development of stunting is the result of several interacting factors; key among them are nutritional deprivation or an adverse fetal
environment during pregnancy (Lartey, 2012). Danaei et al. (2016) conducted a comparative risk analysis of risk factors for childhood stunting in 137 developing countries and found that the leading risks were fetal growth restriction and preterm birth. This highlights how maternal nutritional and health status before and during pregnancy is paramount in preventing stunting.

In a cross sectional study of singleton live births, Victoria et al. (2015) found younger maternal age (<20 years) and IUGR were strongly associated with stunting. Additionally, low education level (<8 years’ schooling) was associated with a 20% to 40% greater risk of stunting compared with higher educational levels (≥12 years), and low maternal BMI (<18.5 kg/m²) was associated with an approximately 2-fold increase in risk of stunting compared with a BMI of ≥ 25 kg/m² (Victoria et al., 2015). In Malawi, length-for-age in newborns was lowest in young adolescent mothers (< 18 years), greater in older adolescents (18-20 years), and greatest in adults (> 20 years) (Friebert et al., 2017). Maternal malaria at delivery and primiparity have also been associated with reduced length-for-age (Kalanda, 2005).

2.2 Maternal Risk Factors

2.2.1 Maternal Malnutrition

Nutritional status before and during pregnancy plays a significant role in determining early developmental processes in utero, as well as the outcome of the pregnancy for mother and child (Abu-Saad & Fraser, 2010). Maternal undernutrition has severe implications, including preterm delivery, LBW, maternal and infant mortality, and stunting (Tang, 2016). Causes of maternal malnutrition include nutrient deficiencies, both
macronutrient and micronutrient, inadequate food intake, frequent infections, and short inter-pregnancy intervals (Figure 2.5) (Lartey et al., 2008).

Figure 2.5 Effects of maternal malnutrition on maternal and infant health.
(Adapted from Lartey et al., 2008)

Nutrient deficiencies of vitamin A, zinc, iron, iodine, folic acid, and vitamin B12 have all been associated with poor pregnancy outcomes (Black et al, 2008). Global data indicates that 56% of pregnant women in LMICs have anemia (Black et al., 2013). The adverse effects of malnutrition persist into the next generation. This cyclical effect of maternal malnutrition is often seen when a woman who was malnourished in utero or early life tends to have underweight babies (Lutter & Lutter, 2012). Additionally, maternal nutritional status is complicated by several risk factors such as level of education, infection, and age.
2.2.2 Measuring Maternal Malnutrition

To understand the relationship between maternal nutrition and birth outcomes, an appropriate measurement of maternal nutritional status is needed (Fakier et al., 2017). Unfortunately, there is a lack of a single, universally accepted anthropometric measurement to diagnose acute malnutrition during pregnancy or which cutoff value to use (Ververs et al., 2013). Maternal anthropometry differs across global populations making a single measurement difficult. However, measuring maternal nutritional status is critical in developing nutritional interventions that improve birth outcomes and long-term quality of life (Ververs et al., 2013). In LMICs, BMI, MUAC, and gestational weight gain are predominantly used.

2.2.3 Body Mass Index

BMI is currently the gold standard for estimating body fat and mass (Fakier et al., 2017). BMI is an index of weight-for-height, and it is calculated by dividing a person’s weight in kilograms by the square of their height in meters (kg/m²). BMI before and at the beginning of pregnancy may be considered as a surrogate for the nutritional status of the mothers (Ay et al., 2009). Both a high and low pre-pregnancy BMI are associated with adverse pregnancy outcomes (Stang & Huffman, 2016; Liu et al., 2009). A pre-pregnancy BMI below 18.5 kg/m² is associated with an increased risk of LBW, preterm deliveries, and anemia (Stang & Huffman, 2016; Han et al., 2010; Liu et al., 2009). In a systematic review and meta-analysis of 78 studies, Han et al. (2010) compared pre-pregnancy BMI below 18.5 kg/m² and the risk of preterm birth and LBW. In women with pre-pregnancy BMI < 18.5 kg/m², the overall risk of preterm birth increased (RR 1.29; CI 1.15-1.46) and the risk of having a LBW infant increased (RR 1.64; CI 1.38-1.94) (Han et
There is also evidence that maternal BMI during pregnancy is positively associated with fetal growth (Ay et al., 2009). Researchers found that in addition to maternal height, pre-pregnancy BMI, and gestational weight gain, maternal BMI from mid-pregnancy onwards is associated with the risk of small and large for gestational age infants; the effects becoming larger with increasing gestational age (Ay et al., 2009).

Although BMI can be a very useful indicator of nutritional status, it has limitations, especially in a developing country (Papathakis et al., 2016; Fakier et al., 2017). BMI can vary substantially during pregnancy (Ververs et al., 2013). Pregnancy weight gain and edema coupled with late pregnancy antenatal visits limit the reliability of BMI for assessing maternal body fat or nutritional status (Fakier et al., 2017). Often, women in LMICs have no records of their weight, height, or BMI before antenatal care and often seek care later in the pregnancy (Kumar et al. 2018; Papathakis, et al., 2016). In a systematic analysis of regional and global level trends of early antenatal care (gestational age <12 weeks) from 1990 to 2013, researchers found the estimated coverage of early antenatal care visits in 2013 was only 24% (95% CI 21.7-26.5) in low-income countries compared to 82% (95% CI 81.6–87.7) in high-income countries (Moller et al., 2017). In clinics, an accurate scale and height measurement device is often not available (Kumar et al, 2018). Additionally, using the BMI chart or performing the calculations have proven to be difficult for some healthcare workers in these settings (Kumar et al., 2018).

2.2.4 Mid-Upper Arm Circumference

MUAC is a simple measurement and does not require expensive equipment or calculations (Fakier et al., 2017). MUAC is measured midway between the olecranon of
the elbow and the acromion process of the shoulder of the non-dominant arm, using a standard tape measure (Fakier et al., 2017). Since the arm contains both subcutaneous fat and muscle, MUAC is an indicator of change in muscle mass, a change in subcutaneous fat, or both (Kumar et al., 2018.) In low resource settings where pregnant women tend to have smaller amounts of subcutaneous fat, changes in MUAC are more likely to reflect changes in muscle mass (Tang, 2016). Additionally, changes in MUAC during pregnancy are minimal, making it a good indicator of pre-pregnancy body fat and maternal nutritional status (Fakier et al., 2017).

MUAC is an important measurement of chronic wasting and has been associated with maternal and infant mortality (Christian et al., 2008; Katz et al. 2003). For the mother, a low MUAC is associated with poor maternal outcomes such as anemia and mortality (Kumar et al., 2018; Christian et al., 2008). For the infant, low maternal MUAC is strongly associated with LBW (Tang et al., 2016; Begum et al., 2003). In Ethiopia, women with a low MUAC had an increased risk of a LBW infant (Assefa et al., 2012). The study found women with a MUAC <23 cm were 1.6 times more likely to have a LBW infant compared to women with a MUAC ≥ 23 cm (Assefa et al., 2012). Furthermore Katz et al. (2003) found Nepalese pregnant women with a larger MUAC in the second and third trimesters had a reduced risk of infant death during the first week of life (OR 0.88, 95% CI = 0.81–0.95).

Although a strong association between MUAC and birth weight has been established, there is still no consensus on global MUAC cutoffs for pregnant women (Tang, 2016). Additionally, because of the wide variability of settings where MUAC needs to be used, it may be difficult to recommend a universal cutoff (Tang, 2016).
Ververs et al. (2013) identified MUAC values less than <22 cm and <23 cm were associated with the most adverse birth outcomes in literature published between 1995 and 2012. Researchers conducted an analysis of studies from Bangladesh, Democratic Republic of Congo, Ethiopia, Malawi, Nepal, Pakistan, and South Africa to determine a global MUAC cutoff that would identify both malnutrition in pregnant women and pregnant women at risk of delivering a LBW infant (Tang, 2016). They found that measures of sensitivity and specificity for all MUAC cutoffs varied greatly between individual studies, but that MUAC was similarly nondiscriminatory in its ability to distinguish pregnant women at risk and not at risk of delivering an LBW baby (Tang, 2016).

MUAC may also be a surrogate for BMI (Fakier et al., 2017). In South African pregnant women, BMI and MUAC were shown to be strongly correlated (Figure 2.6) (Fakier et al., 2017). They found the correlation between BMI and MUAC for early gestation (<20 weeks) was 0.93 and for late gestation (>20 weeks) 0.92 (Fakier et al., 2017).

![Figure 2.6 Correlation between MUAC and BMI. (Adapted from Fakier et al., 2017)](image-url)
Taking a MUAC measurement is quick, easy to replicate, and cost-effective. Additionally, because of its relatively strong association with LBW, narrow range of cutoff values, simplicity of measurement, and no prior knowledge of gestational age, MUAC has been recommended as the preferential indicator for acutely malnourished pregnant women (Ververs et al., 2013; Christian et al., 2008).

2.2.5 Gestational Weight Gain

While BMI can reflect nutritional status, gestational weight gain (GWG) reflects both nutritional status and tissue expansion (Ay et al., 2009). GWG is positively related to fetal growth, development, and birth weight (Papathakis et al., 2016). GWG is the weight that occurs during pregnancy attributable to the growth of fetal and maternal tissues (placenta, uterus, breast, and fat stores) and fluids (blood, amniotic, and extracellular)(Arora & Aeri, 2019). This weight gain is essential, and irrespective of pre-pregnancy BMI, has a significant effect on fetal growth (Tela et al., 2019).

Gaining a desirable amount of weight is effective in supporting the growth and development of the fetus, and it may influence body composition later in life (Arora & Aeri, 2019). The Institute of Medicine (IOM) recommends a total weight gain of 12.5-18 kg in the 2nd and 3rd trimester or mean 0.51 (0.44 – 0.58) kg/week (Rasmussen & Yaktine, 2009). Women with lower pre-pregnancy BMI need to gain more weight during pregnancy to deliver infants with a higher BMI (Rasmussen & Yaktine, 2009) (Table 2.1). Specifically, the IOM recommends higher weight gain during pregnancy for women with a pre-pregnancy BMI < 18.5 kg/m² (Rasmussen & Yaktine, 2009).
Table 2.1 IOM recommendations for gestational weight gain according to pre-pregnancy BMI.

<table>
<thead>
<tr>
<th></th>
<th>Total weight gain recommended (kg)</th>
<th>Gain/week in the 2\textsuperscript{nd} and 3\textsuperscript{rd} trimesters (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&gt;18.5) kg/m(^2)</td>
<td>12.7-18.2</td>
<td>450-590</td>
</tr>
<tr>
<td>18.5-24.5 kg/m(^2)</td>
<td>11.4-15.9</td>
<td>365-420</td>
</tr>
<tr>
<td>25-24.5 kg/m(^2)</td>
<td>11.4-15.9</td>
<td>227-320</td>
</tr>
<tr>
<td>(&gt;30.0) kg</td>
<td>5.0-9.1</td>
<td>180-270</td>
</tr>
</tbody>
</table>

\(^1\)Adapted from Rasmussen & Yaktine, 2009.

Several studies have indicated GWG as a predictor of adverse pregnancy outcomes (Lima et al., 2018; Hasan et al., 2019; Gondwe et al., 2018). In a study examining over one million pregnancies worldwide, GWG below the IOM guidelines was associated with a higher risk for preterm birth (OR 1.70; CI 1.32- 2.20)(Goldstein et al., 2018). In rural Malawi, among a cohort of pregnant women, 71.8% had a low weekly GWG (below the IOM lower limit) (Gondwe et al., 2018). Researchers found a low weekly GWG increased the risk of having infants with LBW and small head circumference compared to those with normal weight gain (Gondwe et al., 2018). The study found weekly GWG was positively associated with birth weight and duration of gestation (Gondwe et al., 2018). Similarly, in a cross-sectional study of mother-infant dyads in Brazil, a 6 kg (1 SD) increase in GWG represented a 151.2 g (0.28 SD) increase in newborn weight (Lima et al., 2018). Additionally, the study found that GWG had a
more significant positive effect on birth weight than pre-pregnancy BMI (Lima et al., 2018).

The timing of GWG has also been shown to be an important factor. Sekiya et al. (2006) found that the most sensitive period of GWG for birth weight and length was the second trimester. Hasan et al. found that women with inadequate GWG in the third trimester had 1.8 times the odds of a LBW infant than those with adequate weight gain (Hasan et al., 2019). Similar to the difficulties of using pre-pregnancy BMI as an indicator of malnutrition in developing countries, GWG is challenging to monitor because pre-pregnancy weight is subject to recall bias, not documented, and antenatal visits are often late and few.

### 2.2.6 Gestational Age

In order to accurately measure fetal growth, gestational age is required. In resource-poor settings with limited access to ultrasound, fundal height and last menstrual period are traditionally used to establish the duration of gestation (Rosenburg et al., 2009; Rhondo, Filho, & Valverde, 2003). Last menstrual period may be potentially erroneous as it relies on the mother’s recall; complicated even more, as women often have their first antenatal clinic visit late into the pregnancy (Rosenburg et al., 2009; Unger et al., 2019). The fundal height measurement is simple to perform and routinely practiced in antenatal settings all around the world (Rhondo, Filho, & Valverde, 2003). Fundal height measures the distance between the pubic bone and the top of the uterus in centimeters with a non-elastic tape measure (Peter et al, 2015). The fundal height in centimeters is approximately equal to the gestational age in weeks between 20 and 36 weeks (Rhondo, Filho, & Valverde, 2003). Several studies have found this correlation and suggest fundal height
can be a valuable tool for determining gestational age in poor resource settings (Walraven et al., 1995; White, et al., 2011; Challis et al., 2002; Unger et al., 2019; Euans et al. 1995).

2.2.7 Parity

Parity refers to the number of previous pregnancies of > 20 weeks (Bai et al., 2002). In LMICs, high parity mothers are often of advanced maternal age and lower socioeconomic classes, while low parity mothers are adolescents (Ndiaye et al., 2018). Both nulliparity and high parity have been associated with poor pregnancy outcomes such as preterm delivery, LBW, and perinatal death (Ndiaye et al., 2018; Mombo-Ngoma, et al., 2016; Kemfang et al., 2013). Bai et al. (2002) found significant associations between parity and pregnancy outcomes. Researchers found that primiparous women have different labors and pregnancy complications than multiparous women (Bai et al., 2002). In this study, primiparous mothers had a 1.7 times greater risk of obstetric complications and an increased risk of perinatal death compared to women with low parity (1-2 pregnancies)(Bai et al., 2002). Researchers also showed an increasing risk for perinatal death with every additional pregnancy after the first (Bai et al., 2002). Figure 2.7 shows the increasing odds of perinatal death with every additional pregnancy up to 8 pregnancies (Bai et al., 2002).
2.2.8 Age

Several studies have shown a U-shaped relationship between maternal age and poor birth outcomes such as LBW, stillbirth, and preterm delivery (Reichman & Pagnini, 1997; Weng et al., 2014; Machado, 2005). In Taiwan, maternal age and adverse birth outcomes including still birth, preterm, LBW, neonatal death, and small for gestational (SGA) age were compared using age as a continuous variable. (Weng et al., 2014). The study found the highest risk for stillbirth, preterm birth, neonatal death, and LBW were in infants born to teenagers (< 20 years) and women with advanced maternal age (≥ 35 years) (Weng et al., 2014). Specifically, the risk for any of the measured adverse birth outcomes was highest among the youngest (< 14 years) and then gradually declined proportionally with an increase in age up to 26 years, but then steadily increased again to ages of 44 years or greater (Weng et al. 2014) In this population, the data suggests that the optimal maternal ages to minimize adverse birth outcomes are 22-28 years (Weng et al., 2014).
**Advanced Maternal Age**

In sub-Saharan African countries, advanced maternal age and high parity pregnancies are prevalent with childbearing continuing up until menopause (Lumbiganon et al., 2014). However, most of the literature on advanced maternal age and high parity is from high-income settings, with only a few studies from sub-Saharan Africa (Ndiaye et al., 2018). In Cameroon, Ngowa et al. (2013) found older multiparous women were at an increased risk of antepartum and intrapartum complications associated with adverse perinatal outcomes. Older (> 40 years) multiparous women had 1.3 times the risk of preterm delivery, 1.42 times the risk of LBW, and 3.5 times the risk for fetal death compared to their younger (20-29 years) counterparts (Kemfang et al., 2013). In South Africa, Hoque et al. (2012) found similar outcomes for women. Advanced maternal age of ≥ 34 years was 1.37 times more likely to have preterm delivery, and 1.67 times more likely to deliver LBW babies compared to adult women (20-34 years). In LMICs, however, young maternal age is more common (United Nations, 2015).

**Adolescence**

Adolescent pregnancy is a complex problem resulting from a combination of social, economic, and educational factors including lack of sexual and reproductive health knowledge and access to contraceptives (Loaiza & Liang, 2013). Adolescent girls between the ages of 15 and 19 years old give birth to 16 million babies each year, or 11% of global births (Althabe et al., 2015). Although global rates have declined, projections indicate that adolescent pregnancies will continue to increase the most in Africa (WHO, 2018). In West Africa, the rate is as high as 115 births per 1000 women compared to 7 births per 1000 women in East Asia (WHO, 2018). Additionally, in LMICs,
approximately a third of girls marry before they reach the age of 18 years (Christian & Smith 2018). Adolescent pregnancy is more likely to occur in impoverished, uneducated, or marginal communities (Christian & Smith 2018).

Pregnancy in adolescence occurs while the mother is still growing herself, leading to health consequences for both mother and child (Rah et al., 2008). Approximately 50% of adult body weight and 15% of final height is attained during adolescent years (Rah et al., 2008). This rapid growth makes adolescents particularly vulnerable to malnutrition because their nutritional needs are higher. The adolescent pregnancy usually begins in a nutritional deficit, and competition for dietary energy and nutrients can lead to emaciation and fat loss, as well as the halt of linear growth for the mother (Rah et al., 2008). Figure 2.8 illustrates the cyclical effect of malnutrition throughout the life cycle.

Figure 2.8 Nutrition throughout the life cycle. (Adapted from ACC/SCN-appointed Commission on the Nutrition Challenges of the 21st Century)
It is estimated that 70,000 adolescent deaths occur annually from complications from pregnancy and childbirth (United Nations Population Fund (UNFPA) 2013). Girls under the age of 15 years are twice as likely to die during labor as older females (UNFPA 2013). Adolescent mothers are exposed to a greater risk of maternal anemia, eclampsia, preeclampsia, emergency cesarean, postpartum depression, inadequate breastfeeding initiation, and systemic infections (Jeha et al., 2015; Black et al., 2013). Additionally, adolescent mothers may have a greater risk of low GWG and poor birth outcomes (Friebert et al., 2017). Among Malawian women, both young adolescents <18 years and older adolescents ≤ 20 years had lower GWG, compared to older women (>20 years) (Friebert et al., 2017). Among the younger adolescent mothers rates of newborn stunting and underweight were higher compared with those from older adolescents or adults (Freibert et al., 2017). Kozuki et al. (2015) found that nulliparous adolescent mothers have a 1.5-3 times greater risk for adverse birth outcomes such as SGA, preterm birth, and neonatal and infant mortality. Additionally, in a 2015 prospective study of LMICs, younger maternal age (≤ 19 years) was associated with LBW (OR 1.18; 95% CI 1.02-1.36), preterm birth (OR 1.26; 95% CI 1.03-1.53), 2-year stunting (OR 1.46; 95% CI 1.25-1.70), and failure to complete secondary schooling (OR 1.38; 95% CI 1.18–1.62) compared with mothers aged 20–24 years (Fall, 2015). The Global Health Network's Maternal Newborn Health Registry study found risk for preterm birth and LBW were significantly higher among both younger adolescents (<15 years) and older adolescents (15-19 years) compared to adults (20-24 years) (Althabe et al., 2015).
2.2.9 Maternal Education

Maternal education enhances the chance of survival for both the infant and mother (Karlsen et al., 2011). Education for many women in developing countries increases exposure and attendance to modern health facilities (Mehta et al., 2014). In a community-based study in western India of literate and illiterate women, literate women were significantly more likely to have healthcare-seeking behavior (Mehta et al., 2014). Literate compared to illiterate women were more likely to attend three or more antenatal checkups (93% vs. 67%), consume adequate iron and folic (51% vs. 27%), and deliver in an institution (91% vs. 68%) (Mehta et al., 2014). The WHO Global Survey on Maternal and Perinatal Health found that women with no education had a 2.7 times higher risk of maternal mortality than women with more than 12 years of education (Karlsen et al., 2011). In an Ethiopian study, primary education was associated with a 28% reduction in the odds of infant mortality compared to those who were illiterate, and a 45% reduction rate in those that attended secondary education (Kiross et al., 2019).

The association between maternal education level and LBW is also related to the low socioeconomic levels of the mother, which commonly results in a lower GWG and a late start to prenatal care (Silverstrin et al., 2013; Cantarutti et al., 2017). In a meta-analysis of maternal education level and LBW, education level was categorized into low, medium, and high (Silverstrin et al., 2013). Researchers found a protective effect of 33% for the risk of LBW in mothers with a higher education level when compared to women with low maternal education (Silverstrin et al., 2013). Similarly, studies have found low maternal education to be linked to appreciable risk of preterm birth and SGA (Cantarutti et al., 2017; Ruiz et al., 2015). Cantarutti et al. (2017), found that mothers with high
education (≥ 14 years) compared to those with low-level (≤ 8 years) education had reduced odds of preterm birth (OR 0.81; 95% CI 0.77–0.85), LBW (OR 0.78; 95% CI 0.70–0.81), SGA (OR 0.82; 95% CI 0.79–0.85). Similarly, in Rwanda, risk factors for stunting include a mother’s educational level of either only primary (OR 1.49; 95% CI 1.03–2.15) or never attended school (OR 1.83; 95% CI 1.18–1.61) (Nshimyiryo et al., 2019).

2.2.10 Malaria

There were an estimated 219 million malaria cases worldwide in 2017, with the greatest impact on pregnant women and children (WHO, 2018). In endemic regions, it is estimated that 25% of pregnant women are infected with malaria, accounting for more than 20% of all maternal deaths (Sharma & Shukla, 2017). Malaria infection can compromise the placenta, altering the exchange of nutrients between the mother and fetus (Sharma & Shukla, 2017). In sub-Saharan Africa where transmission is relatively high, adults have naturally acquired immunity, but infants and children do not and in pregnant women immunity is compromised (Doolan et al., 2009). The severity of malaria infection during pregnancy depends on the degree of acquired immunity, which in turn depends on the intensity of transmission (Takem & D’Alessandro, 2013). Often, malarial infections are asymptomatic and go untreated (Takem & D’Alessandro, 2013). Consequences for the mother include anemia, pulmonary edema, hypoglycemia, cerebral malaria, puerperal sepsis, and death (Sharma & Shukla, 2017).

Maternal factors associated with the risk of malaria during pregnancy include maternal age, parity, and gestational age (Takem & D’Alessandro, 2013). Studies have shown that adolescents have a higher risk of malarial infection than older women.
(Ayoola et al., 2012; Laloo et al., 2006; Orish et al., 2012). Similarly, in endemic regions, women in their first pregnancy are more susceptible to malarial infection, and 20-40% of babies born have a LBW (Sharma & Shukla, 2017; Ayoola et al., 2013). Schmiegelow et al. (2013) observed the effects of malaria in pregnant women in Tanzania. In this study, malaria infection only affected birth weight and fetal growth in primigravid and secundigravid women (Schmiegelow et al., 2017). Additionally, the effects of malaria on fetal growth were observed in the 3rd trimester, despite previous infections occurring much earlier in the pregnancy. It is unclear which gestational age is at the highest risk. Some research indicates that immune suppression early in pregnancy makes the first trimester the highest risk of infection (Sharma & Shukla, 2017; Coulibaly et al., 2007). However, other studies have shown that the highest risk of malarial infection during pregnancy is the second trimester (Schantz-Dunn & Nour, 2009; Desai et al., 2007). Figure 2.9 illustrates maternal and fetal outcomes of malaria during pregnancy (Schmiegelow et al., 2017).
For the fetus, miscarriage, stillbirth, IUGR, premature delivery, and LBW can result from a maternal malarial infection (Guyatt & Snow, 2004; Moore et al., 2017; Desai et al., 2007; Steketee et al., 2001, Goldenberg et al., 2010; Kalanda, 2005; Desai et al., 2007). Steketee et al., (2001) conducted a literature review from 1985 to 2000 on malaria and birth outcomes. The authors found malaria contributed to LBW by both IUGR and preterm delivery (Steketee et al., 2001). Among the studies reviewed, estimates of malaria’s contribution to LBW ranges from 8-14% (Steketee et al., 2001). Stillbirth is also associated with malaria during pregnancy (Moore et al., 2017). Malaria detected at delivery increased the odds of still birth (OR 1.81; CI 1.42-2.30) and malaria detected and treated during pregnancy was also associated with stillbirth (OR 1.47; CI 1.13-1.92)(Moore et al., 2017). In Thailand, women with malaria in their first trimester of pregnancy have an increased risk of miscarriage (McGready et al., 2012). Researchers
found in women with asymptomatic malaria, the odds of miscarriage increased (OR 2.70; CI 2.04-3.59) and did so even more with symptomatic malaria (OR 3.99; CI 3.10-5.13) (McGready et al., 2012).

2.3 Sierra Leone

Sierra Leone (Figure 2.10) is located on the West Coast of Africa, with a population of 7,396,000 people (WHO, 2019). It is one of the poorest countries in Sub-Saharan Africa and has some of the worst social and economic indicators in the world.

![Map of Sierra Leone by district](Adapted from www.vectorstck.com)

Figure 2.10 Map of Sierra Leone by district. (Adapted from www.vectorstck.com)

An estimated 59% of the population lives in rural areas, with 61% of the working population engaged in subsistence agriculture (Statistics Sierra Leone (SSL), 2018)). The life expectancy for Sierra Leonians is 52 and 54 years at birth for males and females, respectively (WHO, 2019). According to the International Food Policy Research Institute (IFPRI), Sierra Leone’s Global Hunger Index in 2018 was 114th out of 119 qualifying
countries, making it one of the highest in the world (IFPRI, 2019). Indicators for child malnutrition have improved but remain high (Figure 2.11).

![Trends in Malnutrition Prevalence 2008-2014, Sierra Leone](image)

Figure 2.11 Prevalence of child malnutrition in Sierra Leone, 2008-2014. (Adapted from Chauhan et al., 2018)

### 2.3.1 Access to Maternal Health Care

Since the late 1980s, Sierra Leone has experienced crippling hardships. In 2002, Sierra Leone saw the end of a ten-year civil war that displaced nearly a third of the population (Pasqualino et al., 2016). From 2008 to 2013, the country had been making some progress toward its Millennial Development Goals (MDGs). During this time, there was an increase in: coverage of antenatal care with at least four visits (from 56 % to 76%); use of modern contraception (from 7% to 16%); skilled birth attendance (from 42% to 62%); malaria bed net utilization (from 26% to 49%); malaria treatment (6% to 77%); diarrhea management (68% to 88%); and basic immunization (DPT3 from 54% to 78%) (Pesqualino et al., 2016).

However, Sierra Leone fell short of meeting its 2015 MDGs when progress came to a complete halt with the Ebola outbreak in 2014 (Quaglio et al., 2019). This public health disaster made an already under-resourced health system even weaker. Services
offered were disrupted, hundreds of health workers were infected, and women feared to seek antenatal care services (Ministry of Health and Sanitation (MoHSa), 2017)). Quaglio et al. (2019) found maternal perceptions of health care changed post-Ebola. Women in Sierra Leone perceived health care facilities as dangerous places where they could contract the Ebola virus (Quaglio et al., 2019). The impact of the Ebola virus resulted in a 18% decrease in the number of women attending antenatal care (Figure 2.12), 22% decrease in postnatal attendance visits, and 11% decrease in the number of women attending for birth at a healthcare facility (Jones et al., 2016). Additionally, for women who did access care there was a corresponding statistically significant 34% increase in the facility maternal mortality ratio and a 24% increase in the stillbirth rate (Jones et al., 2016).

Figure 2.12 Association between Ebola virus, number of women attending ANTENATAL CARE, PNC, and delivery at a healthcare facility: overall and by district disaggregated by level of healthcare. (Adapted from Jones et al., 2016)
Access to health care remains a significant public health issue (Figure 2.13). Sierra Leone’s health care system is comprised of two tiers: Peripheral Health Care Units (PHUs) with community health programs and secondary care, including district and referral hospitals (MoHSa, 2017). In 2010, Sierra Leone enacted free Maternal and Child Health (MCH) services. This program includes free health care for pregnant women, lactating mothers, and children under five years. The 2016 Maternal Death Surveillance and Response Report (MDSR) found that most pregnant women in Sierra Leone (97%) will make at least one visit for antenatal care, with much fewer (76%) making at least four visits (MoHSb, 2017). An estimated 44% of these women, however, will make their first antenatal care visit late into the pregnancy at 4-5 months (MoHSa, 2017). Currently, Sierra Leone has one of the highest maternal mortality, child mortality, and adolescent fertility rates in the world (MoHSa, 2017; MoHSb, 2017).

Figure 2.13 Percentage of those in need receiving coverage of key interventions across the continuum of care. (Adapted from Countdown Country Profile- Sierra Leone, 2018)
2.3.2 Maternal, Newborn, and Adolescent Health Risk Factors

*Maternal Health*

In 2015, the UN Maternal Mortality Estimation Inter-Agency Group estimated the maternal mortality rate in Sierra Leone as the highest in the world at 1,360 per 100,000 live births compared to 3 per 100,000 live births in Finland (Alkema et al., 2016). If this maternal rate persists, women of reproductive age face a 1 in 17 chance of maternal death (Alkema et al., 2016). The MDSR report found the estimated maternal deaths contributed to 36% of the total deaths in women aged 15-49 years (MoHSb, 2017). Additionally, the national prevalence of acute malnutrition using MUAC (<23 cm) was 5.7% and 5.1% using BMI (<18.5 kg/m²) among pregnant and lactating women (SSL, 2018).

*Infant Health*

The neonatal mortality rate is estimated to be 20 per 1000 live births, the infant mortality rate 56 per 1000 live births, the child mortality rate 40 per 1000 live births (SSL, 2018). The stillbirth rate in Sierra Leone is 24 per 1000 total births (Lawn, 2016) but varies by district (Figure 2.14). Mortality surveillance and vital registration are limited, however, as many are not reported (Sochas et al., 2017). The incidence of LBW in Sierra Leone is 14% of total births (Blencowe et al., 2019). The preterm birth rate in Sierra Leone is 10% of total births and is the leading cause of neonatal mortality (MoHSb, 2017). Identified risk factors for preterm birth in Sierra Leone include maternal malnutrition, infection, young maternal age, and pregnancies spaced too closely together (SSL, 2018).
Figure 2.14 Stillbirth rates in Sierra Leone by district. (Adapted from Maternal Death Surveillance and Response Report, 2016)

Stunting in Sierra Leone persists but has improved. The stunting rate in 2008 was 37.4% in children under 5 years (MoHSc, 2017). A more recent National Nutrition Survey found that stunting was 31.3% of children under 5 years, with more boys than girls reportedly stunted (MoHSc, 2017). Approximately 21.3% were moderately stunted, and 10.0% were severely stunted (MoHSc, 2017).

Adolescent Health

The rate of adolescent pregnancy is very high in Sierra Leone with 23.3% of adolescent females aged 15-19 already childbearing (SSL, 2018). The Pujehun District has the highest prevalence of adolescent birth rate in the country of 179 per 1,000 women (SSL, 2018). In 2013 about 25% of the total maternal deaths were teenage mothers (125.1 births per 1000 women aged 15-19 years) (SSL, 2013). The percentage of women married by age 15 years old is also high (SSL, 2018). A larger percentage of adolescent pregnancies happen in rural areas (34%) compared to urban (19%) (MoHSd, 2018). In the Pujehun District, the percentage is the highest in the country at 36.5% (SSL, 2018).
Additionally, the rate of female genital mutilation in women aged 15-19 years of age is estimated at an alarming 74.3% (SSL, 2013).

Early marriage and early sexual activity are major contributors to adolescent pregnancy (Denny et al., 2016). Although the legal age for marriage in Sierra Leone is 18 years, adolescents can marry with parental consent (Denny et al., 2016). Also, the widespread use of female genital mutilation is an initiation into adulthood, sometimes as young as 9 years old, and making the girls ready for marriage (Denny et al., 2016). Adolescent marriage and early sexual activity are higher in rural areas because of adherence to traditional norms, lower educational attainment, higher levels of poverty, and a narrower range of life options (MoHSd, 2018). Additionally, poverty contributes to early marriage by reducing the economic burden of a family; when an adolescent female becomes pregnant, they are sent to live with the father’s family (Denny et al., 2015). Bransky et al., (2017) found that early marriage is often the result of pregnancy. Additional reasons for early marriage and early sex reported by adolescents in Sierra Leone include the desire for material goods, coercion using physical pressure, coercion using violence, and family pressure (Bransky et al., 2017).

2.3.3 Education

Although the first nine years of education are compulsory, school enrollment continues to remain low in Sierra Leone (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2019). Sierra Leone’s education system is divided into four levels: primary (6 years), junior secondary (3 years), senior secondary (3 years), and tertiary (4 years). The civil war destroyed many of the school structures, leaving a shortage of facilities (Wright, 1997). By the end of the war, the majority of school-aged
children no longer attended school (UNESCO, 2019). The current literacy rate is estimated to be 51% for men and 34% for women over 15 years of age (UNESCO, 2019). Additionally, gross enrolment for primary education is low at 13% (UNESCO, 2019). For the children that do attend school, they face a shortage of school supplies and teachers who are unqualified (Global Partnership for Education, 2019). In Sierra Leone, 82% of mothers with higher education made at least four antenatal care visits compared to 74% with no education (UNICEF, 2016). Among mothers with no education, only 54% had a skilled birth attendant, compared to 63% of deliveries among mothers with primary education and 91% of deliveries among mothers with higher education (UNICEF, 2016). In Sierra Leone, adolescent pregnant Civil mothers are banned from attending school and abortion is illegal (Bransky et al., 2017).

2.3.4 Malaria

More than a quarter of the population in Sierra Leone is infected with malaria (WHO, 2019). Pregnant women and children under five constitute the most vulnerable population (SSL, 2018). The parasite causes about 14% of deaths among children under five (SSL, 2018). Sleeping under an insecticide-treated net the previous night was reported by 64% of pregnant women (SSL, 2018). Women who reported taking intermittent preventative treatment (IPTp) for malaria during pregnancy at least once was 95.5%, two or more times was 68.7%, and three or more times was only 26.8% (SSL, 2018). Sierra Leone’s National Malaria Control Program distributed over 4 million insecticide-treated nets reaching 95% of households (WHO, 2017). The national Malaria in Pregnancy guidelines and strategies have been revised to incorporate current
recommendations for delivery of three doses or more of IPTp during antenatal visits (WHO, 2017).

2.4 Summary Statement

The causes of adverse birth outcomes such as LBW, preterm birth, and stunting are multifactorial and compounding. Maternal malnutrition has important consequences for both the mother and child such as survival, incidence of diseases, healthy development, and the economic productivity of the individual and society collectively (Black et al., 2013). Identifying maternal malnutrition using BMI, MUAC, and gestational weight gain are important measures in resource poor settings, but have limitations in appropriate, evidenced based cut-points (Ververs et al., 2013). For mothers, results such as maternal mortality and morbidity, miscarriage, and stillbirth pose significant threats. For the infant, outcomes can be both short term- preterm birth and LBW, or long term- stunting and chronic diseases. Additionally, maternal risk factors that are likely to be particularly important in sub-Saharan Africa include exposure to infections like malaria, high and low parity, age, and social determinants such as low levels of education and poverty. In turn, all of these can exacerbate the intergenerational cycle of undernutrition. In Sierra Leone, poor reproductive, maternal, newborn, and adolescent health is a product of multiple interrelated factors that requires a collaborative
CHAPTER 3
MATERIALS AND METHODS

3.1 Objective

The main objective of this analysis was to determine the maternal risk factors at the time of enrollment into the study including BMI, MUAC, inadequate gestational weight gain, age, education level, recent infection with malaria, and bed net use associated with poor birth outcomes (LBW, preterm delivery, stunting, miscarriage, stillbirth, and perinatal death) in moderately malnourished pregnant women in Sierra Leone.

3.2 Participants

This sub-analysis of a randomized controlled clinical effectiveness trial in pregnant women with malnutrition comparing the impact of combined nutrition and infection control interventions with the standard of care in Sierra Leone. The trial assessed whether a combined intervention of a specialized nutritious food and anti-inflammatory interventions results in improved birth anthropometry compared with the standard of care. The study was approved by the Sierra Leone Ethics and Scientific Review Committee, the Human Research Protection Office at Washington University in St. Louis, and the Pujehun District Health Officer.

Pregnant women who met the following criteria were included in the study:

- ≥ 16 years old or if < 16 years old, with the consent of a parent
- MUAC ≤ 23 cm
- Fundal height ≤ 35 cm
- Intention to reside in the study area up to 6 months after delivery
- Intention to attend antenatal clinics every two weeks
Formal informed consent

Exclusion criteria included:

- < 16 years old without an adult community member willing to consent
- Known complications of pregnancy including gestational diabetes, pre-eclampsia, hypertension, or severe anemia

Sample Size

The sample size of enrollment was 1506 pregnant women with moderate malnutrition. The distribution of treatment was 761 women received the intervention and 745 women received the standard of care. False pregnancies (n=18) and women who gave birth to multiple infants (n=13) were not included; final eligible women for analysis of maternal characteristics at enrollment was 1,475 pregnant women. Additionally, maternal and infant outcome analyses did not include women with pregnancy outcomes miscarriage (n=23), still birth (n=33), perinatal death (n=25), maternal death (n=5) and lost to follow-up (n=110).

3.3 Randomization and Blinding

Subjects were randomized to receive either the ready-to-use-supplementary food (RUSF) with 5 anti-infective treatments or the standard of care- CSB +IFA (super cereal, oil, and iron and folic acid tablets) using a random number generator which assigns subjects to either study group. Participants chose a blank envelope which contained the randomly assigned study number and treatment. The research study team members and the participants were not blinded due to the distinct difference in appearance of the
treatments. However, the study managers remained blinded to treatment during data analysis.

### 3.4 Study Design

The main study was a prospective, randomized, controlled clinical effectiveness trial comparing the impact of an improved supplementary food and infection control interventions with the standard of care in moderately malnourished pregnant women in Sierra Leone.

**Intervention Group**

A ready-to-use supplementary food (RUSF), called Mama Dutasi, was made locally from millet, milk, palm oil, soybean oil, brown sugar, and groundnuts. The RUSF provided a total of 520 kcals, 18 g protein, and 200% of the RDA for most micronutrients required during pregnancy (Appendix A). The ratio of omega-6 to omega-3 fatty acids were optimized at 4.5% to 1.5%, respectively.

**Control Group**

In Sierra Leone, the standard of care for malnourished pregnant women includes 3.5 kg of super cereal (corn/soy blended flour) with 350 mL vegetable oil every two weeks. This ration provides 250 mg of super cereal and 20 mL of oil per day, equating to 1177 kcals and 35 g of protein. Additionally, supplementation of folic acid (440mcg) and iron (60 mg) is given via oral tablets.

**Medical Interventions**

In addition to the RUSF, women in this group received a package of five anti-infective treatments to address infection and inflammation. The treatment included:

- Insecticide-treated mosquito net at the time of enrollment
• Albendazole- anti-helminthic given at enrollment
• Testing and treatment for bacterial vaginosis at enrollment and again in the third trimester
• Sulfadoxine-pyrimethamine- chemoprophylaxis for preventative treatment of malaria given every 4 weeks beginning at 13 weeks’ gestation
• Azithromycin- broad spectrum antibiotic given at the time of enrollment and at 28–34 weeks of gestation

The control group receiving the standard of care protocol received the current recommendation of the government of Sierra Leone which included:
• Insecticide-treated mosquito net at the time of enrollment
• 60 mg of iron as a daily supplement
• 400 mg of folic acid as a daily supplement
• Sulfadoxine-pyrimethamine, three does given during the second and third trimester
• Albendazole- anti-helminthic given at enrollment

Maternal Data Collection

Women attending antenatal clinic were informed of the study and entry criteria. Participation in the study required participants to return to clinic bi-weekly throughout pregnancy and continue with follow-up until the infant was 6 months old. Women willing to participate were screened and assessed for eligibility by measurement of MUAC. Women who met eligibility requirements and were older than 16 years were required to give informed consent. If participants were younger than 16 years, consent from a parent or guardian was required. Women who were unable to sign their names used their
thumbprint instead. Nurses reviewed medical records to screen for previous pregnancy complications and medications.

Upon enrollment, participants were interviewed, and demographic and health information were collected. Anthropometric measurements taken included height, weight, MUAC, and previous weight history. Additionally, time of last menses, blood pressure, fundal height, and estimated time of delivery were recorded. A background demographic form was used to assess baseline characteristics (Appendix B) including age, educational level, household information, pregnancy history, and previous illnesses. Participants returned every two-weeks and maternal weight, height, MUAC, and blood pressure was measured and recorded. MUAC was measured in cm using a non-elastic tape measurer. A MUAC of less than 23 cm was required to participate in the study and classified as moderate malnutrition. A trained Sierra Leonian nurse interviewed the patient for antenatal health bi-weekly and took fundal height measurements to be used as an estimation for gestational age.

*Infant Data Collection*

Upon delivery, participants were instructed to call the birth team in order for timely measurements of the infant. A trained birth measurer took anthropometric measurements of the infant including length, weight, MUAC, and head circumference (HC). MUAC and HC were taken using a non-elastic tape measurer. The mother’s MUAC was also recorded. Infant weight was measured using a digital scale. A length board was used to take three measurements of the infant’s length and recorded to the nearest millimeter. After delivery, the mother infant dyad returned for postpartum visits at 6 weeks, 3 months, and 6 months.
3.5 Statistical Analysis Methods

Data was analyzed using IBM SPSS Statistics Version 26.0 and R Core Team (2020). To calculate the anthropometric z-scores, The World Health Organization (WHO) Survey Analyzer (WHO Anthro (https://whonutrition.shinyapps.io/anthro/) was used.

The demographic variables were summarized using descriptive summary measures: expressed as mean (standard deviation) for continuous variables, and percent for categorical variables. To compare means between two groups, students’ t-test was used. Analysis of variance was used to compare multiple groups and Tukey Honestly Significance test was used to indicate which groups were different. The chi-square test for independence was used to find any association between categorical variables. Least square means are reported with standard error adjusted for weeks of treatment and maternal BMI at enrollment. Binary logistic regression was carried out to determine which maternal risk factors were predictors of poor birth outcomes. Independent variables as covariates used for regression modeling included: age, education, MUAC and BMI at enrollment, parity, weekly gestational weight gain, malaria, and bed net use. Poor birth outcomes included LBW, stunting, preterm delivery, and pregnancy loss (miscarriage, stillbirth, and perinatal death). P values less than 0.05 were considered significant.

Maternal Variables

Age was categorized as young adolescent (13-16), older adolescent as (17-20), adult (20-28), and older adult (29 or older). Parity was classified as primiparous if the participant had never had a pervious birth and multiparous if the participant had one or more live births. Education category was categorized as none if the participant had never
attended school, 1-6 if the participant had only attended primary school, and 7+ is the participant had attended junior secondary, senior secondary, or tertiary. MUAC was converted into a categorical variable of severe malnutrition of <21 cm and moderate malnutrition of 21.1-23 cm. BMI at enrollment was calculated using the equation: Weight (kg) / Height (m)^2. A BMI of less than 18.5 was classified as underweight. BMI was converted into a categorical variable of underweight < 18.5 kg/m^2 and normal ≥ 18.5 kg/m^2.

**Infant Variables**

Gestational age for determining weekly gestational weight gain was calculated for women who received ≥ 4 weeks of treatment using weight records from the second and third trimester. A mean maternal weight gain of less than 454g/week indicated inadequate weekly gestational weight gain. A fundal height of less than 37 weeks was classified as preterm delivery. This was determined using the fundal height of the last clinic visit before delivery. Determination of LBW was calculated for infants measured within 48 hours of delivery (n= 852). Infants born with a birth weight less than 2500g were classified as LBW. Stunting was defined as a length-for-age (LFA) z-score of -2 SD, wasting as weight-for-length (WFL) < -2 SD, and underweight as a weight-for-age (WFA) < -2 SD according to gender.
CHAPTER 4

RESULTS

4.1 Baseline Characteristics

The 1475 participants ranged in age from 13 to 42 years old, with a mean age of 21.20 years (Table 4.1). The women on average were not short in stature with a mean height of 155.7 cm. Upon enrollment the mean BMI was 19.78 kg/m², with 22.7% of the population being underweight (BMI <18.5 kg/cm²). All women were considered moderately malnourished at enrollment (MUAC <23 cm) with only 7.9% severely malnourished with a MUAC <21 cm. Education was grouped into three categories (none, 1-6 years, and 7 or more years) with 33.2% of the participants never attending school and 45.8 % attaining at least 7 years. Only 14.4% of the women reported a recent malarial infection in the previous 2 months and 66.4% of the women reported sleeping under a bed net every night.

Overall participants did not differ in baseline characteristics between treatment groups. The RUSF and the CSB +IFA groups were not significantly different in age, with the CSB +IFA group being 0.50 years older (p=0.050). Anthropometrics of height, weight, BMI, and MUAC were all similar between groups. Although none reached significance, all were greater in the RUSF group. The number of pregnancies was different between the groups, with the CSB + IFA having an mean 1.47 pregnancies compared to 1.27 pregnancies in the RUSF (p=0.036). Although not significant, the CSB +IFA group had a larger fundal height of 23.61 cm compared to 23.24 cm in the RUSF, indicating a later start on treatment in the pregnancy.
Table 4.1 Baseline nutritional and demographic characteristics at enrollment of pregnant women, by treatment group

<table>
<thead>
<tr>
<th>Baseline Characteristic</th>
<th>Overall</th>
<th>CSB+IFA</th>
<th>RUSF</th>
<th>(P^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=1475)</td>
<td>(n=729)</td>
<td>(n=746)</td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>21.20 ±4.81</td>
<td>21.45 ±4.89</td>
<td>20.95 ±4.72</td>
<td>0.050</td>
</tr>
<tr>
<td>Height, cm</td>
<td>155.69 ±6.60</td>
<td>155.56 ±6.37</td>
<td>155.83 ±6.82</td>
<td>0.415</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>47.96 ±4.94</td>
<td>47.82 ±4.90</td>
<td>48.08 ±5.00</td>
<td>0.319</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>19.78 ±1.86</td>
<td>19.76 ±1.76</td>
<td>19.81 ±1.95</td>
<td>0.668</td>
</tr>
<tr>
<td>MUAC, cm</td>
<td>22.29 ±0.76</td>
<td>22.28 ±0.79</td>
<td>22.30 ±0.73</td>
<td>0.541</td>
</tr>
<tr>
<td>Malnutrition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe (MUAC &lt;21 cm)</td>
<td>116 (7.9)</td>
<td>60 (4.1)</td>
<td>56 (3.8)</td>
<td></td>
</tr>
<tr>
<td>Moderate (MUAC &lt;23 cm)</td>
<td>1359 (92.1)</td>
<td>669 (45.4)</td>
<td>690 (46.7)</td>
<td>0.675</td>
</tr>
<tr>
<td>Underweight-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(BMI&lt;18.5 kg/m²)</td>
<td>331 (22.7)</td>
<td>167 (50.5)</td>
<td>164 (49.5)</td>
<td>0.742</td>
</tr>
<tr>
<td>Fundal Height, cm</td>
<td>23.42 ±6.48</td>
<td>23.61 ±6.30</td>
<td>23.24 ±6.65</td>
<td>0.293</td>
</tr>
<tr>
<td>Number of Previous Pregnancies</td>
<td>1.37 ±1.77</td>
<td>1.47 ±1.82</td>
<td>1.27 ±1.72</td>
<td>0.036</td>
</tr>
<tr>
<td>Number of Live Births</td>
<td>1.21 ±1.66</td>
<td>1.28 ±1.71</td>
<td>1.14 ±1.60</td>
<td>0.096</td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primiparous</td>
<td>692 (46.9)</td>
<td>329 (22.3)</td>
<td>363 (24.6)</td>
<td></td>
</tr>
<tr>
<td>Multiparous</td>
<td>783 (53.1)</td>
<td>400 (27.1)</td>
<td>383 (26.0)</td>
<td>0.192</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>489 (33.2)</td>
<td>249 (16.9)</td>
<td>249 (16.3)</td>
<td></td>
</tr>
<tr>
<td>1-6 years</td>
<td>311 (21.1)</td>
<td>160 (10.8)</td>
<td>151 (10.2)</td>
<td></td>
</tr>
<tr>
<td>7+ years</td>
<td>675 (45.8)</td>
<td>320 (21.7)</td>
<td>355 (24.1)</td>
<td>0.360</td>
</tr>
<tr>
<td>Malaria Infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Previous 2 Months)</td>
<td>212 (14.4)</td>
<td>116 (54.7)</td>
<td>96 (45.3)</td>
<td>0.116</td>
</tr>
<tr>
<td>Does Not Use Bed Net</td>
<td>495 (33.6)</td>
<td>257 (51.9)</td>
<td>238 (48.1)</td>
<td>0.191</td>
</tr>
</tbody>
</table>

1Values expressed as unadjusted mean ± SD or \(n\) (%)
2\(P\) values calculated using students t-test (continuous measures) and Chi-square (categorical measures)
3Twin pregnancies \((n=13)\) and false pregnancies \((n=18)\) excluded
4BMI-Body Mass Index
5MUAC-Mid-Upper Arm Circumference

In a pooled treatment analysis stratified by age, participants varied in baseline characteristics by several characteristics (Table 4.2). Age was compared by four categories: younger adolescent (13-16 years), older adolescent (17-19 years), adult (20-29 years), and older adult (29-42 years). The mean age among the groups was 17.3 years.
(young adolescents), 19 years (older adolescents), 22.4 years (adults), and 31.5 years (mature adults). There was no association between age grouping and treatment group. Older adolescents were significantly taller than all other age groups, with young adolescents being the shortest (p=0.005). The mean weight of the mature adults (46.93 kg) was significantly lower than younger adolescents (48.15 kg) and older adolescents (48.77 kg)(p=0.008). Additionally, the BMI of younger adolescents was significantly greater than both adults and mature adults by 0.34 kg/m² and 0.23 kg/m², respectively (p=0.002). Also, mature adults also had significantly higher rates of mothers who were underweight (BMI <18.5 kg/m²) (p=0.001).

At enrollment, the mature adults had a significantly larger fundal height than both the younger adolescents and the older adolescent (p=0.017). The majority (83.4%) of young adolescents were primiparous compared to 96.5% of mature adults being multiparous (p<0.000). Accordingly, the mean difference in number of previous pregnancies (p<0.000) and number of live births (<0.000) was statistically significant between all adolescents and both adults and mature adults. As expected, the older adult women had 4.15 births compared to 1.76 (adults), 0.52 (older adolescents), and 0.27 (young adolescents). The mature adults had the highest rates of no education (74.1%) while the older adolescents had the highest rates of education equal to seven years or more (63.4%). Adolescents had significantly higher rates of not sleeping under a bed net every night compared to their adult and older adult counterparts (p=0.045).
Table 4.2 Baseline nutritional and demographic characteristics at enrollment of pregnant women, by age category

<table>
<thead>
<tr>
<th>Baseline Characteristic</th>
<th>Younger Adolescent 13-16 YO</th>
<th>Older Adolescent 17-19 YO</th>
<th>Adult 20-28 YO</th>
<th>Mature Adult 29-42 YO</th>
<th>n=537</th>
<th>n=153</th>
<th>n=572</th>
<th>n=170</th>
<th>P²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard of Care</td>
<td>243 (45.3)</td>
<td>76 (49.7)</td>
<td>296 (51.7)</td>
<td>90 (52.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>29 (54.7)</td>
<td>77 (50.3)</td>
<td>276 (48.3)</td>
<td>80 (47.1)</td>
<td>0.121</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>17.29 ±0.98</td>
<td>19.00 ±0.00</td>
<td>22.38 ±2.26</td>
<td>31.54 ±3.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, cm</td>
<td>155.13 ±6.3a</td>
<td>157.19 ±6.9b</td>
<td>156.03 ±6.8a</td>
<td>155.74 ±6.6a</td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>48.15 ±4.71a</td>
<td>48.77 ±5.32a</td>
<td>47.90 ±5.05c,b</td>
<td>46.93 ±4.97b</td>
<td>0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>19.99 ±1.91a</td>
<td>19.75 ±1.80a</td>
<td>19.65 ±1.81b</td>
<td>19.76 ±1.86b</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUAC, cm</td>
<td>22.29 ±0.72</td>
<td>22.21 ±0.85</td>
<td>22.34 ±0.75</td>
<td>22.23 ±0.82</td>
<td>0.159</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malnutrition (MUAC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe (&lt;21cm)</td>
<td>38 (7.1)</td>
<td>18 (11.8)</td>
<td>42 (7.3)</td>
<td>13 (7.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate (&lt;23 cm)</td>
<td>499 (92.9)</td>
<td>135 (88.2)</td>
<td>530 (92.7)</td>
<td>157 (92.4)</td>
<td>0.270</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underweight-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(BMI &lt;18.5 kg/m²)</td>
<td>92 (17.3)a</td>
<td>36 (23.7)a</td>
<td>140 (24.7)a</td>
<td>52 (31.1)b</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fundal Height, cm</td>
<td>23.07 ±6.41a</td>
<td>22.69 ±6.40a</td>
<td>23.40 ±6.59a,b</td>
<td>24.78 ±6.37b</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pregnancies</td>
<td>0.27 ±0.536a</td>
<td>0.52 ±0.689a</td>
<td>1.76 ±1.48b</td>
<td>4.15 ±2.11c</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primiparous</td>
<td>448 (83.4)a</td>
<td>98 (64.1)b</td>
<td>125 (21.9)c</td>
<td>6 (3.50)d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiparous</td>
<td>89 (16.6)a</td>
<td>55 (35.9)b</td>
<td>447 (78.1)c</td>
<td>164 (96.5)d</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>105 (19.6)a</td>
<td>26 (17.0)a</td>
<td>209 (36.5)b</td>
<td>126 (74.1)c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-6 years</td>
<td>147 (27.4)a</td>
<td>30 (19.6)a,b</td>
<td>98 (17.1)b</td>
<td>25 (14.7)b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7+ years</td>
<td>285 (53.1)a,b,b</td>
<td>97 (63.4)b</td>
<td>265 (46.3)a</td>
<td>19 (11.2)c</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaria Infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Previous 2 Months)</td>
<td>83 (15.5)</td>
<td>25 (16.4)</td>
<td>87 (15.2)</td>
<td>16 (9.4)</td>
<td>0.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does Not Use Bed Net</td>
<td>194 (36.1)a</td>
<td>56 (36.6)a</td>
<td>183 (32.0)a,b</td>
<td>43 (25.3)b</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Values expressed as unadjusted mean ±SD or n (%)
2P values calculated using ANOVA (continuous measures) and Chi-square (categorical measures)
3Tukey’s Honest Significance Test results indicated for means significantly different
4Twin pregnancies (n=13) and false pregnancies (n=18) excluded
5Age data not collected (n=43)
6BMI-Body Mass Index
7MUAC-Mid-Upper Arm Circumference
4.2 Maternal Outcomes

4.2.1 Maternal Outcomes by Treatment Group

While maternal outcomes for weekly weight gain, MUAC at delivery, change in MUAC from enrollment to delivery, and final fundal height were greater among the RUSF group compared to the CSB +IFA group, there was no effect of treatment on these measures. When controlling for weeks on treatment and maternal BMI at enrollment, total weight gain from enrollment to final measure was significantly greater in the RUSF group with an average gain of 0.49 kg more than the CSB +IFA group (p=0.000)(Table 4.3). Although not reaching significance (p=0.191), the time on treatment was also greater in the RUSF group by approximately 3 days.

Mean weekly weight gain measured from the second trimester until the final visit before delivery was 6.5% greater in the RUSF group (p=0.022). Additionally, the RUSF mothers had both a greater MUAC at delivery (p=0.002) and a greater change in MUAC from the time of enrollment to delivery (p=0.001). Although not significant (p=0.131) the RUSF group also delivered with a larger mean fundal height of 0.23 cm more than the CSB +IFA. Accordingly, the CSB +IFA group had a higher percentage of adverse pregnancy outcomes including miscarriage, stillbirth, and perinatal death (not significant). An analysis of power for poor pregnancy outcomes (miscarriage, stillbirth, perinatal death, and maternal death) indicates inadequate power (<0.80) to detect the effect of interest.
Table 4.3 Maternal outcomes, by treatment group

<table>
<thead>
<tr>
<th>Maternal Outcomes</th>
<th>Overall</th>
<th>CSB ± IFA</th>
<th>RUSF</th>
<th>p^3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Total Weight Gain, kg</td>
<td>1279</td>
<td>622</td>
<td>657</td>
<td>5.61 (0.068)</td>
</tr>
<tr>
<td>(Enrollment to Final Measure)</td>
<td></td>
<td>5.35 (0.10)</td>
<td>5.84 (0.09)</td>
<td>0.000</td>
</tr>
<tr>
<td>Time on Treatment (weeks)</td>
<td>1279</td>
<td>622</td>
<td>657</td>
<td>14.27 (0.177)</td>
</tr>
<tr>
<td>Weekly Weight Gain, kg</td>
<td>1279</td>
<td>622</td>
<td>657</td>
<td>377.21 (5.01)</td>
</tr>
<tr>
<td>Weekly Weight Gain, g</td>
<td></td>
<td>365.01 (0.23)</td>
<td>389.47 (7.42)</td>
<td>0.022</td>
</tr>
<tr>
<td>(Adequate≥ 454 g/week)^7</td>
<td>1279</td>
<td>622</td>
<td>657</td>
<td>345 (26.97)</td>
</tr>
<tr>
<td>MUAC at Delivery, cm^6</td>
<td>1270</td>
<td>619</td>
<td>651</td>
<td>22.39 (0.03)</td>
</tr>
<tr>
<td>Change in MUAC, cm^6</td>
<td></td>
<td>22.25 (0.04)</td>
<td>22.53 (0.03)</td>
<td>0.002</td>
</tr>
<tr>
<td>(Enrollment to Delivery)</td>
<td>1270</td>
<td>619</td>
<td>651</td>
<td>0.082 (0.03)</td>
</tr>
<tr>
<td>Final Fundal Height, cm</td>
<td>1279</td>
<td>622</td>
<td>657</td>
<td>35.86 (0.07)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35.74 (0.98)</td>
<td>35.97 (0.07)</td>
<td>0.131</td>
</tr>
</tbody>
</table>

Poor Pregnancy Outcome

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>CSB ± IFA</th>
<th>RUSF</th>
<th>p^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscarriage</td>
<td>1475</td>
<td>729</td>
<td>746</td>
<td>13 (1.78)</td>
</tr>
<tr>
<td>Stillbirth</td>
<td>1475</td>
<td>729</td>
<td>746</td>
<td>18 (2.47)</td>
</tr>
<tr>
<td>Perinatal Death</td>
<td>1475</td>
<td>729</td>
<td>746</td>
<td>14 (1.92)</td>
</tr>
<tr>
<td>Maternal Death</td>
<td>1475</td>
<td>729</td>
<td>746</td>
<td>5 (0.34)</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment and BMI at enrollment
2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
3P values for treatment group (Effects test), Chi-square (categorical measures)
4Fisher Exact Test
5Lost to Follow Up (n=110)
6MUAC (Mid-Upper Arm Circumference) not measured at delivery (n=9)
7Weekly weight gain (Adequate≥ 454g/week) calculated for women on treatment > 4 weeks during 2nd and 3rd trimester
4.2.2 Maternal Outcomes by Age

Overall, maternal outcomes by age were similar across all age groups (Table 4.4). Although not significant, younger adolescents had the lowest total weight gain (p=0.175), lowest change in MUAC from time of enrollment to delivery (p=0.157), and MUAC (p=0.133) at delivery. Mature adults had the lowest time on treatment (p=0.544) and lowest weekly weight gain (p=0.078), however, neither reached significance. Mature adults had significantly lower rates of adequate weekly weight gain (≥454 g/week) than older adolescents (p=0.035).

Maternal outcomes across age groups were not statistically significant after controlling for weeks on treatment and BMI at enrollment except for final fundal height measurement. The mean final fundal height of mature adults was significantly greater at 1.27 cm and 0.97 cm than younger adolescents and older adolescents, respectively (p<0.000). An analysis of power for poor pregnancy outcomes (miscarriage, stillbirth, perinatal death, and maternal death) indicates inadequate power (<0.80) to detect the effect of interest.
Table 4.4 Maternal outcomes, by age category

<table>
<thead>
<tr>
<th>Maternal Outcomes</th>
<th>Younger Adolescent</th>
<th>Older Adolescent</th>
<th>Adult</th>
<th>Mature Adult</th>
<th>P³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n 13-16 years</td>
<td>n 17-19 years</td>
<td>n 20-28 years</td>
<td>n 29-42 years</td>
<td></td>
</tr>
<tr>
<td>Total Weight Gain, kg (Enrollment to Final Measure)</td>
<td>470 5.68 (0.13)</td>
<td>133 5.83 (0.22)</td>
<td>484 5.58 (0.11)</td>
<td>150 5.19 (0.24)</td>
<td>0.175</td>
</tr>
<tr>
<td>Time on Treatment (weeks)</td>
<td>470 14.08 (0.28)</td>
<td>133 14.88 (0.60)</td>
<td>484 14.52 (0.26)</td>
<td>150 14.01 (0.62)</td>
<td>0.544</td>
</tr>
<tr>
<td>Weekly Weight Gain, kg</td>
<td>470 383.52 (8.02)</td>
<td>133 394.43 (15.76)</td>
<td>484 372.78 (9.21)</td>
<td>150 347.34 (14.82)</td>
<td>0.078</td>
</tr>
<tr>
<td>Weekly Weight Gain, g (Adequate≥ 454g/week)</td>
<td>470 125 (26.59)ab</td>
<td>133 47 (35.34)b</td>
<td>484 144 (29.75)ab</td>
<td>150 29 (19.33)a</td>
<td>0.035</td>
</tr>
<tr>
<td>MUAC at Delivery, cm</td>
<td>468 22.31 (0.06)</td>
<td>132 22.45 (0.09)</td>
<td>483 22.46 (0.05)</td>
<td>146 22.40 (0.09)</td>
<td>0.133</td>
</tr>
<tr>
<td>Change in MUAC, cm</td>
<td>468 0.04 (0.04)</td>
<td>132 0.24 (0.08)</td>
<td>483 0.09 (0.03)</td>
<td>146 0.12 (0.06)</td>
<td>0.157</td>
</tr>
<tr>
<td>Final Fundal Height, cm</td>
<td>470 35.48 (0.11)a</td>
<td>133 35.78 (0.20)ab</td>
<td>484 36.08 (0.12)b</td>
<td>150 36.75 (0.19)b</td>
<td>0.000</td>
</tr>
<tr>
<td>Poor Pregnancy Outcome</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscarriage</td>
<td>5 (1.06)</td>
<td>1 (0.75)</td>
<td>11 (2.27)</td>
<td>4 (2.66)</td>
<td>0.341</td>
</tr>
<tr>
<td>Stillbirth</td>
<td>13 (2.76)</td>
<td>3 (2.25)</td>
<td>11 (2.27)</td>
<td>3 (2.0)</td>
<td>0.878</td>
</tr>
<tr>
<td>Perinatal Death</td>
<td>9 (1.91)</td>
<td>4 (3.00)</td>
<td>9 (1.85)</td>
<td>4 (2.66)</td>
<td>0.744</td>
</tr>
<tr>
<td>Maternal Death</td>
<td>0</td>
<td>0</td>
<td>4 (0.83)</td>
<td>1 (0.66)</td>
<td>0.196</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment and BMI at enrollment
2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
3P values for age group (Effects test), Chi-square (categorical measures)
4Tukey’s Honest Significance Test results indicated for means significantly different
5Age data not collected (n=43)
6Lost to Follow Up (n=110)
7Weekly weight gain (Adequate≥ 454g/week) calculated for women on treatment > 4 weeks during 2nd and 3rd trimester
8MUAC (Mid-Upper Arm Circumference) not measured at delivery (n=9)
9Fundal Height measurement taken from last clinic visit
4.2.3 Maternal Outcomes by Education

Maternal outcomes by education were inconsistent. Women with the highest education had significantly higher mean weekly weight gain than women with no education (p=0.029)(Table 4.5). Interestingly, this group also had the shortest mean weeks of treatment but highest mean total weight gain (both not significant). Additionally, the group with the highest education (7 or more years) had significantly higher rates of adequate weekly weight gain compared to women with 1-6 years of education (p=0.001). However, women with no education had significantly larger fundal heights at the last visit (p<0.000).

When comparing poor pregnancy outcomes by education category, there were no significant differences between the groups. Women with no education had the highest rates of miscarriage (not significant) while women with 7 or more years of education had the highest rates of stillbirth (not significant). An analysis of power for poor pregnancy outcomes (miscarriage, stillbirth, perinatal death, and maternal death) indicates inadequate power (<0.80) to detect the effect of interest.
Table 4.5 Maternal outcomes, by education category

<table>
<thead>
<tr>
<th>Maternal Outcomes</th>
<th>None</th>
<th>1-6 years</th>
<th>7 + years</th>
<th>p²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Total Weight Gain, kg</td>
<td>422 (5.62 (0.17)</td>
<td>278 (5.25 (0.18)</td>
<td>579 (5.72 (0.15)</td>
<td>0.178</td>
</tr>
<tr>
<td>(Enrollment to Final Measure)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time on Treatment (weeks)</td>
<td>422 (14.44 (0.32)</td>
<td>278 (14.54 (0.37)</td>
<td>579 (13.97 (0.26)</td>
<td>0.342</td>
</tr>
<tr>
<td>Weekly Weight Gain, kg</td>
<td>422 (376.18 (11.02)ab</td>
<td>278 (354.86 (10.07)a</td>
<td>579 (394.08 (8.48)b</td>
<td>0.029</td>
</tr>
<tr>
<td>Weekly Weight Gain, g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Adequate≥ 454 g/week)⁶</td>
<td>422 (110 (26.06)ab</td>
<td>278 (56 (20.14)⁶</td>
<td>579 (170 (29.36)⁶</td>
<td>0.001</td>
</tr>
<tr>
<td>MUAC at Delivery, cm⁷</td>
<td>417 (22.42 (0.05)</td>
<td>276 (22.32 (0.06)</td>
<td>577 (22.39 (0.05)</td>
<td>0.484</td>
</tr>
<tr>
<td>Change in MUAC, cm⁷</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Enrollment to Delivery)</td>
<td>417 (0.11 (0.04)</td>
<td>276 (0.02 (0.05)</td>
<td>577 (0.11 (0.04)</td>
<td>0.093</td>
</tr>
<tr>
<td>Final Fundal Height, cm⁸</td>
<td>422 (36.33 (0.12)a</td>
<td>278 (35.77 (0.16)b</td>
<td>579 (35.61 (0.17)b</td>
<td>0.000</td>
</tr>
<tr>
<td>Poor Pregnancy Outcome</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscarriage</td>
<td>422 (9 (2.13)</td>
<td>278 (3 (1.08)</td>
<td>579 (11 (1.90)</td>
<td>0.546</td>
</tr>
<tr>
<td>Stillbirth</td>
<td>422 (10 (2.37)</td>
<td>278 (9 (3.24)</td>
<td>579 (14 (2.41)</td>
<td>0.481</td>
</tr>
<tr>
<td>Perinatal Death</td>
<td>422 (7 (1.66)</td>
<td>278 (2 (0.72)</td>
<td>579 (16 (2.76)</td>
<td>0.453</td>
</tr>
<tr>
<td>Maternal Death</td>
<td>422 (3 (0.71)</td>
<td>278 (0 (0.00)</td>
<td>579 (2 (0.36)</td>
<td>0.521</td>
</tr>
</tbody>
</table>

¹Adjusted for weeks on treatment and BMI at enrollment
²Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
³P values for age group (Effects test), Chi-square (categorical measures)
⁴Tukey’s Honest Significance Test results indicated for means significantly different
⁵Lost to Follow Up (n=110)
⁶Weekly weight gain (Adequate≥ 454g/week) calculated for women on treatment > 4 weeks during 2nd and 3rd trimester
⁷MUAC (Mid-Upper Arm Circumference) not measured at delivery (n=9)
⁸Fundal Height measurement taken from last clinic visit
4.3 Infant Outcomes

At birth, infants were approximately 47.1 cm in length, weighed 2.80 kg, had a MUAC of 9.82 cm, and head circumference of 33.9 cm (Table 4.6). The mean length-for-age z-score was -1.12, weight-for-age z-score was 1.13, and the weight-for-length z-score was 0.085. Infants measured after 48 hours were excluded from weight analyses (n=427). Overall, 25.4% of the infants born were stunted, 20.4% were LBW, and 57.6% were born preterm.

4.3.1 Infant Outcomes by Treatment Group

Analysis of infant outcomes by treatment group showed that the infants born to mothers in the RUSF group had a significant outcome for length only (Table 4.6). The RUSF group gave birth to infants 0.29 cm longer on average than the CSB + IFA group (p=0.027). After adjusting weight-related infant outcomes to include only infants measured within 48 hours, infants in the RUSF group weighed 0.05 kg (p=0.055) more than the CSB + IFA group. Additionally, rates for preterm delivery among the RUSF group were significantly lower than the CSB + IFA group (p=0.032). Although not significant, rates of stunting (p=0.119) and LBW (p=0.546) were lower among the RUSF group. Z-scores for infants between treatment groups showed the RUSF group had higher mean z-scores for all three indicators, length-for-age, weight-for-age, and weight-for-length, although, none reached significance.
Table 4.6 Infant outcomes, by treatment group

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Overall</th>
<th>CSB ± IFA</th>
<th>RUSF</th>
<th>P^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, cm</td>
<td>1279</td>
<td>47.11 (0.06)</td>
<td>622</td>
<td>46.97 (0.094)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>852</td>
<td>2.80 (0.013)</td>
<td>422</td>
<td>2.78 (0.019)</td>
</tr>
<tr>
<td>MUAC, cm</td>
<td>852</td>
<td>33.90 (0.042)</td>
<td>622</td>
<td>33.84 (0.061)</td>
</tr>
<tr>
<td>Stunted</td>
<td>329</td>
<td>25.33</td>
<td>172</td>
<td>27.39</td>
</tr>
<tr>
<td>LBW</td>
<td>176</td>
<td>20.35</td>
<td>91</td>
<td>21.26</td>
</tr>
<tr>
<td>Preterm delivery</td>
<td>747</td>
<td>57.64</td>
<td>381</td>
<td>60.77</td>
</tr>
</tbody>
</table>

### Z-scores

<table>
<thead>
<tr>
<th>Z-scores</th>
<th>Overall</th>
<th>CSB ± IFA</th>
<th>RUSF</th>
<th>P^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length-for-Age</td>
<td>1279</td>
<td>-1.12 (0.032)</td>
<td>622</td>
<td>-1.31 (0.048)</td>
</tr>
<tr>
<td>Weight-for-Age</td>
<td>852</td>
<td>-1.13 (0.045)</td>
<td>422</td>
<td>-1.17 (0.045)</td>
</tr>
<tr>
<td>Weight-for-Length</td>
<td>852</td>
<td>0.085 (0.031)</td>
<td>422</td>
<td>-0.029 (0.044)</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment and BMI at enrollment
2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
3P values for treatment group (Effects test), Chi-square (categorical measures)
4Infants not measured within 48 hours after birth excluded (n=427)
5MUAC- Mid-upper Arm Circumference
6HC- Head Circumference
7Stunted defined as length-for-age z-score < -2 standard deviation from the WHO mean
8LBW (low birth weight) defined as <2500g
9Preterm delivery defined as birth before 38 weeks of gestation

### 4.3.2 Infant Outcomes by Maternal Age

In a pooled treatment analysis of infant outcomes stratified by age, younger adolescents had infants with smaller anthropometric measurements than their older counterparts (Table 4.7). Younger adolescents gave birth to infants with a mean length that was 0.63 cm and 0.8 cm less than adults and mature adults, respectively (p=0.000).

Younger adolescents also gave birth to infants with a birth weight that was 3.9% and 7.1% less than adults and mature adults, respectively (p=0.000). Additionally, the MUAC of infants born to younger adolescents was 0.23 cm and 0.34 cm smaller than adults and mature adults, respectively (p=0.000). Head circumference was also smallest in the younger adolescent group when compared to both adults and mature adults (p=0.000).
Both younger and older adolescents had significantly higher rates of stunting compared to adults and mature adults (p=0.001). In addition, younger adolescent had significantly higher rates of LBW compared to all other groups (p=0.000). Preterm delivery was also found to be significantly higher in younger adolescents than all other age groups (p=0.000) Likewise, mean z-scores for length-for-age, weight-for-age, and weight-for-length were smallest among the younger adolescents. The mean z-score for length-for-age among younger adults was 0.28 and 0.39 smaller than adults and mature adults, respectively (p=0.000). The result was similar for weight-for-age z-score in young adolescents, with a significantly smaller z-score than all adults (p=0.000). Finally, mean weight-for-age z-scores among adults and mature adults was significantly greater than all adolescents, with mean negative z-scores of -0.045 (younger adolescents) and -0.123 (older adolescents) versus positive mean z-scores in both adults and mature adults (p=0.045).
Table 4.7 Infant outcomes by age category

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Younger Adolescent</th>
<th>Older Adolescent</th>
<th>Adult</th>
<th>Older Adult</th>
<th>$P^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>13-16 years</td>
<td>$n$</td>
<td>17-19 years</td>
<td>$n$</td>
</tr>
<tr>
<td>Length, cm</td>
<td>470</td>
<td>46.74 (0.107)$^a$</td>
<td>134</td>
<td>47.01 (0.201)$^{a,b}$</td>
<td>492</td>
</tr>
<tr>
<td>Weight, kg$^4$</td>
<td>311</td>
<td>2.73 (0.022)$^a$</td>
<td>91</td>
<td>2.81 (0.040)$^{a,b}$</td>
<td>325</td>
</tr>
<tr>
<td>MUAC, cm$^4,5$</td>
<td>311</td>
<td>9.69 (0.041)$^a$</td>
<td>91</td>
<td>9.78 (0.077)$^{a,b}$</td>
<td>325</td>
</tr>
<tr>
<td>HC, cm$^6$</td>
<td>470</td>
<td>33.60 (0.068)$^a$</td>
<td>134</td>
<td>33.99 (0.128)$^{a,b}$</td>
<td>492</td>
</tr>
<tr>
<td>Stunted$^7$</td>
<td>149 (31.37)$^a$</td>
<td>38 (28.15)$^a$</td>
<td>110 (22.04)$^b$</td>
<td>28 (18.06)$^b$</td>
<td>0.001</td>
</tr>
<tr>
<td>LBW$^8$</td>
<td>82 (26.03)$^a$</td>
<td>19 (20.88)$^b$</td>
<td>58 (17.58)$^b$</td>
<td>8 (7.77)$^c$</td>
<td>0.000</td>
</tr>
<tr>
<td>Preterm delivery$^9$</td>
<td>311 (65.47)$^a$</td>
<td>79 (58.52)$^b$</td>
<td>269 (53.91)$^b$</td>
<td>67 (43.51)$^c$</td>
<td>0.000</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>467</td>
<td>-1.43 (0.055)$^a$</td>
<td>134</td>
<td>-1.34 (0.102)$^{a,b}$</td>
<td>492</td>
</tr>
<tr>
<td>Weight-for-Age$^4$</td>
<td>311</td>
<td>-1.23 (0.047)$^a$</td>
<td>91</td>
<td>-1.09 (0.088)$^{a,b}$</td>
<td>325</td>
</tr>
<tr>
<td>Weight-for-Length$^4$</td>
<td>311</td>
<td>-0.045 (0.045)$^a$</td>
<td>91</td>
<td>-0.123 (0.085)$^a$</td>
<td>325</td>
</tr>
</tbody>
</table>

$^1$Adjusted for weeks on treatment and BMI at enrollment  
$^2$Values expressed as least square means (LSM) (SE) or $n$ (%) for categorical measures  
$^3$P values for age group (Effects test), Chi-square (categorical measures)  
$^4$Infants not measured within 48 hours after birth excluded (n=427)  
$^5$MUAC- Mid-upper Arm Circumference  
$^6$HC -Head Circumference  
$^7$Stunted defined as length-for-age z-score < -2 standard deviation from the WHO mean  
$^8$LBW (low birth weight) defined as <2500g  
$^9$Preterm delivery defined as birth before 38 weeks of gestation
4.3.3 Infant Outcomes by Maternal Education

Education did not have the expected impact on birth outcomes (Table 4.8). Surprisingly, all anthropometric measurements were superior among the women with no education. Infants of women with no education and 7+ years had a birth length 0.53 cm and 0.35 cm longer, respectively, than women with primary education (p=0.012). Similarly, women with no education had infants with a significantly larger weight than both women with 1-6 years of education (120 g more) and women with 7 or more years of education (7 g more)(p=0.000). This same trend was observed in both a significantly larger MUAC (=0.005) and head circumference (p=0.000).

Rates of stunting were 28% and 15% higher in women with 1-6 years and 7 or more years of education, respectively (p=0.028). Rates of LBW were 39% and 35% higher in women with 1-6 years and 7 or more years of education, respectively, compared to women with no education (p=0.012). Additionally, rates of preterm delivery were 14.5% and 14.6% higher in women with 1-6 years and 7 or more years of education, respectively (p=0.010). The corresponding z-scores also indicated that education did not improve birth outcomes. In fact, women with no education had significantly bigger mean z-scores for length-for-age (p=0.006), weight-for-age (p=Women 0.000), and a weight-for-length (p=0.018).
### Table 4.8 Infant outcomes, by education category

<table>
<thead>
<tr>
<th>Infant Outcome</th>
<th>None</th>
<th>1-6 years</th>
<th>7+ years</th>
<th>( P^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n )</td>
<td>( n )</td>
<td>( n )</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>425</td>
<td>278</td>
<td>576</td>
<td>0.012</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>286</td>
<td>196</td>
<td>370</td>
<td>0.003</td>
</tr>
<tr>
<td>MUAC, cm</td>
<td>286</td>
<td>196</td>
<td>370</td>
<td>0.054</td>
</tr>
<tr>
<td>HC, cm</td>
<td>425</td>
<td>278</td>
<td>576</td>
<td>0.000</td>
</tr>
<tr>
<td>Stunted( ^8 )</td>
<td>94</td>
<td>86 (30.30)</td>
<td>149 (25.56)</td>
<td>0.028</td>
</tr>
<tr>
<td>LBW( ^9 )</td>
<td>43</td>
<td>48 (24.24)</td>
<td>176 (22.67)</td>
<td>0.012</td>
</tr>
<tr>
<td>Preterm Delivery( ^{10} )</td>
<td>223</td>
<td>170 (60.50)</td>
<td>354 (60.62)</td>
<td>0.010</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>425</td>
<td>278</td>
<td>576</td>
<td>0.006</td>
</tr>
<tr>
<td>Weight-for-Age( ^5 )</td>
<td>286</td>
<td>196</td>
<td>370</td>
<td>0.004</td>
</tr>
<tr>
<td>Weight-for-Length( ^5 )</td>
<td>286</td>
<td>196</td>
<td>370</td>
<td>0.041</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment and BMI at enrollment
2Values expressed as least square means (LSM) (SE) or \( n \) (%) for categorical measures
3\( P \) values for education group (Effects test), Chi-square (categorical measures)
4Tukey’s Honest Significance Test results indicated for means significantly different
5Infants not measured within 48 hours after birth excluded (n=427)
6MUAC - Mid-upper Arm Circumference
7HC - Head Circumference
8Stunted defined as length-for-age z-score < -2 standard deviation from the WHO mean
9LBW (low birth weight) defined as <2500g
10Preterm delivery defined as birth before 38 weeks of gestation

### 4.3.4 Infant Outcomes by Maternal BMI at Enrollment

Maternal BMI at enrollment revealed that women with a BMI \( \geq 18.5 \) kg/cm\(^2\) had significantly larger infant outcomes than women with a underweight BMI (\(<18.5 \) kg/cm\(^2\)) (Table 4.9). Women with a BMI \( \geq 18.5 \) kg/m\(^2\) gave birth to infants that were 0.38 cm longer than underweight women (\( p=0.029 \)). Women with normal BMI also gave birth to infants with a birthweight 150 g more than underweight women (\( p=0.000 \)). Similarly, women with a BMI \( \geq 18.5 \) kg/m\(^2\) gave birth to infants with a larger MUAC (\( p=0.027 \)) and head circumference (0.021).
The rates of stunting were similar between the groups and not significant. There was, however, a significant difference in LBW by maternal BMI at enrollment. Women with an underweight BMI had rates of LBW 184% higher than women with a normal BMI (p=0.031). These results were reflected by greater negative mean z-scores for weight and weight-for-length. Women with a underweight BMI had a 0.35 smaller weight-for-age z-score (p<0.000), and a 0.19 smaller weight-for-length z-score (p=0.022).

Table 4.9 Infant outcomes, by maternal BMI

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>BMI&lt; 18.5 kg/m²</th>
<th>BMI ≥ 18.5 kg/m²</th>
<th>p^3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>271</td>
<td>1008</td>
<td>0.029</td>
</tr>
<tr>
<td>Weight, kg(^4)</td>
<td>188</td>
<td>664</td>
<td>0.000</td>
</tr>
<tr>
<td>MUAC, cm(^4,5)</td>
<td>188</td>
<td>664</td>
<td>0.027</td>
</tr>
<tr>
<td>HC, cm(^6)</td>
<td>271</td>
<td>1008</td>
<td>0.021</td>
</tr>
<tr>
<td>Stunted(^7)</td>
<td>71 (26.20)</td>
<td>255 (25.20)</td>
<td>0.797</td>
</tr>
<tr>
<td>LBW(^8)</td>
<td>49 (52.77)</td>
<td>124 (18.56)</td>
<td>0.031</td>
</tr>
<tr>
<td>Preterm delivery(^9)</td>
<td>143 (19.4)</td>
<td>595 (58.86)</td>
<td>0.084</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment
2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
3P values for BMI group (Effects test), Chi-square (categorical measures)
4Infants not measured within 48 hours after birth excluded (n=427)
5MUAC- Mid-upper Arm Circumference
6HC -Head Circumference
7Stunted defined as length-for-age z-score < -2 standard deviation from the WHO mean
8LBW (low birth weight) defined as <2500g
9Preterm delivery defined as birth before 38 weeks of gestation

4.3.5 Infant Outcomes by Maternal MUAC at Enrollment

Maternal MUAC at enrollment also revealed significant differences between women with severe and moderate malnutrition (Table 4.10). Severe maternal malnutrition
(MUAC<21 cm) produced infants with statistically lower birth weight (p=0.004) and MUAC (p=0.008). Although not reaching significance, birth length (p=0.664) and head circumference (p=0.682) was smaller in women with severe malnutrition. There were, however, significantly higher rates of LBW (p=0.008) and preterm (p=0.010) among women with severe malnutrition compared to women with moderate malnutrition. This was also reflected in the z-scores for wasting and underweight. Women with severe malnutrition had infants with a mean weight-for-age z-score 0.35 smaller than moderately malnourished mothers (p=0.005). Finally, women with severe malnutrition gave birth to infants with a mean weight-for-age z-score significantly less than moderately malnourished women (p=0.016).

Table 4.10 Infant outcomes, by maternal MUAC

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Severe Malnutrition MUAC&lt; 21 cm</th>
<th>Moderate Malnutrition MUAC&lt;23 cm</th>
<th>p^2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>100</td>
<td>1179</td>
<td>0.664</td>
</tr>
<tr>
<td>Weight, kg^4</td>
<td>64</td>
<td>788</td>
<td>0.004</td>
</tr>
<tr>
<td>MUAC, cm^4,5</td>
<td>64</td>
<td>788</td>
<td>0.008</td>
</tr>
<tr>
<td>HC, cm^6</td>
<td>100</td>
<td>1179</td>
<td>0.682</td>
</tr>
<tr>
<td>Stunted ^7</td>
<td>23 (22.77)</td>
<td>306 (22.59)</td>
<td>0.614</td>
</tr>
<tr>
<td>LBW^8</td>
<td>22 (33.85)</td>
<td>154 (19.25)</td>
<td>0.008</td>
</tr>
<tr>
<td>Preterm delivery^9</td>
<td>71 (70.30)</td>
<td>676 (56.57)</td>
<td>0.010</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>100</td>
<td>1179</td>
<td>0.693</td>
</tr>
<tr>
<td>Weight-for-Age^4</td>
<td>64</td>
<td>788</td>
<td>0.005</td>
</tr>
<tr>
<td>Weight-for-Length^4</td>
<td>64</td>
<td>788</td>
<td>0.016</td>
</tr>
</tbody>
</table>

^1Adjusted for weeks on treatment and BMI at enrollment
^2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
^3P values for MUAC group (Effects test), Chi-square (categorical measures)
^4Infants not measured within 48 hours after birth excluded (n=427)
^5MUAC- Mid-upper Arm Circumference
^6HC -Head Circumference
^7Stunted infants were born with a length-for-age z-score <-2 standard deviation from the WHO mean
^8LBW (low birth weight) defined as <2500g
^9Preterm delivery defined as birth before 38 weeks of gestation
4.3.6 Infant Outcomes by Maternal Weight Gain

Women with an adequate mean weekly weight gain (≥ 454 g/week) was found in 27.8% of women who were treated for 4 weeks or more (n=345). Adequate weight gain in mothers during the 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester resulted in a greater mean birth length and birth weight (Table 4.11). Women gave birth to infants with a mean birth length of 0.37 cm more than women with inadequate weight gain (p=0.012). In women with adequate weight gain infants had a mean weight 7.0 g more than women with inadequate weight gain (p=0.030). Also, women with adequate weight gain gave birth to infants with a 0.08 cm greater mean MUAC than women with inadequate weight gain (p=0.045). Although not significant, women with adequate weight gain also gave birth to infants with a head circumference 0.10 cm larger (p=0.291).

Statistical significance was not found for stunting, LBW, and preterm delivery being associated with weight gain. However, in accordance with the difference in birth length and weight, z-scores for length-for-age and weight-for-age were statistically different between women with adequate weight gain and inadequate weight gain. Women with adequate weight gain had a z-score 0.21 smaller than women with adequate weight gain (p=0.004). Similarly, women with inadequate weight gain had a weight-for-age z-score 0.17 smaller than women with adequate weight gain (p= 0.043).
Table 4.11 Infant outcomes, by adequate weight gain

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Adequate Weekly Weight Gain</th>
<th>Inadequate Weekly Weight Gain</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>345 47.41 (0.127)</td>
<td>894 47.04 (0.078)</td>
<td>0.012</td>
</tr>
<tr>
<td>Weight, kg5</td>
<td>216 2.86 (0.027)</td>
<td>614 2.79 (0.016)</td>
<td>0.030</td>
</tr>
<tr>
<td>MUAC, cm5,6</td>
<td>216 9.92 (0.051)</td>
<td>614 9.80 (0.030)</td>
<td>0.045</td>
</tr>
<tr>
<td>HC, cm7</td>
<td>345 33.99 (0.081)</td>
<td>894 33.89 (0.050)</td>
<td>0.291</td>
</tr>
<tr>
<td>Stunted8</td>
<td>82 (23.43)</td>
<td>227 (25.14)</td>
<td>0.578</td>
</tr>
<tr>
<td>LBW9</td>
<td>40 (18.35)</td>
<td>126 (20.29)</td>
<td>0.603</td>
</tr>
<tr>
<td>Preterm delivery</td>
<td>195 (55.56)</td>
<td>512 (56.70)</td>
<td>0.762</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>345 -1.09 (0.64)</td>
<td>894 -1.30 (0.039)</td>
<td>0.004</td>
</tr>
<tr>
<td>Weight-for-Age5</td>
<td>216 -0.98 (0.037)</td>
<td>216 -1.15 (0.037)</td>
<td>0.043</td>
</tr>
<tr>
<td>Weight-for-Length5</td>
<td>216 0.110 (0.063)</td>
<td>216 0.84 (0.037)</td>
<td>0.716</td>
</tr>
</tbody>
</table>

1Adjusted for weeks on treatment and BMI at enrollment
2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
3P values for adequate weight gain group (Effects test), Chi-square (categorical measures)
4Adequate weight gain (≥454g/week) calculated for women on treatment >4 weeks during 2nd and 3rd trimester
5Infants not measured within 48 hours after birth excluded (n=427)
6MUAC- Mid-upper Arm Circumference
7HC -Head Circumference
8Stunted defined as length-for-age z-score < -2 standard deviation from the WHO mean
9LBW (low birth weight) defined as <2500g
10Preterm delivery defined as birth before 38 weeks of gestation

4.3.7 Infant Outcomes by Maternal Parity

Parity was statistically significant for all infant outcome measures (Table 4.12).

Women who were experiencing their first pregnancy gave birth to infants with a 0.87 cm smaller birth length (p=0.000), a 6.6% smaller birth weight (p=0.000), a 0.3 cm smaller MUAC (p=0.000), and a 0.6 cm smaller head circumference (p=0.000). Primiparous women also gave birth to higher rates of stunted, LBW, and preterm infants (p=0.000 for all). Accordingly, the infant z-scores were all significantly lower for primiparous mothers. Length-for-age z-score was 0.44 smaller than multiparous women (p=0.000).
Weight-for-age z-score was 0.44 smaller (p=0.000) and weight-for-length z-score was 0.149 smaller in primiparous women than multiparous women (P=0.000)

Table 4.12 Infant outcomes, by parity

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Primiparous</th>
<th>Multiparous</th>
<th>p^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>587 (46.64, 0.095)</td>
<td>691 (47.52, 0.088)</td>
<td>0.000</td>
</tr>
<tr>
<td>Weight, kg^4</td>
<td>379 (2.70, 0.020)</td>
<td>473 (2.89, 0.018)</td>
<td>0.000</td>
</tr>
<tr>
<td>MUAC, cm^4,5</td>
<td>379 (9.66, 0.038)</td>
<td>473 (9.96, 0.034)</td>
<td>0.000</td>
</tr>
<tr>
<td>HC, cm^6</td>
<td>587 (33.57, 0.061)</td>
<td>691 (34.17, 0.056)</td>
<td>0.000</td>
</tr>
<tr>
<td>Stunted^7</td>
<td>194 (32.7)</td>
<td>135 (19.2)</td>
<td>0.000</td>
</tr>
<tr>
<td>LBW^8</td>
<td>113 (29.43)</td>
<td>63 (13.10)</td>
<td>0.000</td>
</tr>
<tr>
<td>Preterm delivery^9</td>
<td>396 (66.67)</td>
<td>351 (50.0)</td>
<td>0.000</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>587 (-1.49, 0.048)</td>
<td>691 (-1.05, 0.048)</td>
<td>0.000</td>
</tr>
<tr>
<td>Weight-for-Age^4</td>
<td>379 (-1.36, 0.046)</td>
<td>473 (-0.92, 0.041)</td>
<td>0.000</td>
</tr>
<tr>
<td>Weight-for-Length^4</td>
<td>379 (-0.003, 0.047)</td>
<td>473 (0.152, 0.042)</td>
<td>0.000</td>
</tr>
</tbody>
</table>

^1 Adjusted for weeks on treatment and BMI at enrollment
^2 Values expressed as least square means (LSM) (SE) or n (%) for categorical measures
^3 P values for Parity group (Effects test), Chi-square (categorical measures)
^4 Infants not measured within 48 hours after birth excluded (n=427)
^5 MUAC - Mid-upper Arm Circumference
^6 HC - Head Circumference
^7 Stunted defined as length-for-age z-score <-2 standard deviation from the WHO mean
^8 LBW (low birth weight) defined as <2500g
^9 Preterm delivery defined as birth before 38 weeks of gestation

Logistic regression was performed to assess the impact of the previous maternal risk factors on the likelihood of stunting to occur (Table 4.13). The model contained maternal BMI and MUAC at enrollment, education category, age category, parity, malaria infection, and bed net usage. Only two of the variables made a statistically significant contribution to the model (parity and maternal BMI). Low parity was a stronger predictor of stunting; primiparous women had 2.0 times greater odds of having a stunted child than multiparous women. Maternal BMI was used on a continuous scale and indicated that for every unit decrease in BMI, women had 1.1 times greater odds of having a stunted infant.
Table 4.13 Logistic regression predicting likelihood of stunting

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primiparity</td>
<td>2.082</td>
<td>1.49-2.98</td>
<td>0.000</td>
</tr>
<tr>
<td>Maternal BMI</td>
<td>1.103</td>
<td>1.10-1.20</td>
<td>0.033</td>
</tr>
</tbody>
</table>

1Primiparity is categorized as having no previous births
2Stunting defined as -2 SD below the WHO reference mean

Similarly, logistic regression was performed to assess the impact of the previous maternal risk factors on the likelihood of LBW to occur (Table 4.14). Only two of the variables made a statistically significant contribution to the model (parity and maternal BMI). Low parity was a stronger predictor of LBW; primiparous women had 2.5 greater odds of having a LBW infant than multiparous women. Maternal BMI was used on a continuous scale and indicated that for every unit decrease in BMI, women had 1.2 times greater odds of having a LBW infant.

Table 4.14 Logistic regression predicting likelihood of LBW

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Odds Ratio</th>
<th>(95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primiparity</td>
<td>2.495</td>
<td>1.55-4.00</td>
<td>0.000</td>
</tr>
<tr>
<td>Maternal BMI at Enrollment</td>
<td>1.209</td>
<td>1.06-1.37</td>
<td>0.004</td>
</tr>
</tbody>
</table>

1Primiparity is categorized as having no previous births
2LBW defined as birthweight less than 2500g and measured within 48 hour

Finally, logistic regression was performed to assess the impact of the previous maternal risk factors on the likelihood of preterm delivery to occur (Table 4.15). Only two of the variables made a statistically significant contribution to the model (parity and maternal MUAC). Low parity was a stronger predictor of preterm delivery; primiparous women had 1.6 times greater odds of having a preterm infant than multiparous women. Maternal MUAC was used on a continuous scale and indicated that for every unit decrease in MUAC, women had 1.2 greater odds of having a preterm infant.
Table 4.15 Logistic regression predicting likelihood of preterm delivery

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Odds Ratio</th>
<th>(95% CI)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primiparity</td>
<td>1.568</td>
<td>1.18-2.08</td>
<td>0.002</td>
</tr>
<tr>
<td>Maternal MUAC at Enrollment</td>
<td>1.223</td>
<td>1.03-1.45</td>
<td>0.022</td>
</tr>
</tbody>
</table>

1Primiparity is categorized as having no previous births
2Preterm delivery defines as birth before 37 weeks of gestation

### 4.3.8 Infant Outcomes by Gender

Infant outcomes were compared by gender (Appendix C). Statistical significance was found between the sexes for all anthropometric measurement. Not surprisingly, male infants were bigger. Additionally, females had higher rates of LBW ($p=0.000$). There was no statistical difference in stunting and preterm delivery rates between the sexes.

### 4.3.9 Infant Outcomes by Recent Malaria Infection and Bed Net Usage at Enrollment

Anthropometric measurements of infants born to women with a malaria infection in the previous 2 months did not differ between women who reported an infection and those who reported no infection (Appendix D). Between the groups, anthropometric measurements for length, weight, MUAC, and head circumference as well as rates of stunting, LBW, and preterm birth were not statistically significant. This analysis also investigated infant outcomes between women at enrollment who reported using a bed net every night and those who did not (Appendix E). There was no statistical difference between infants outcomes by bed net usage.
CHAPTER 5
DISCUSSION

In this analysis, several maternal risk factors were identified for adverse infant outcomes among moderately malnourished pregnant women. Mothers delivering their first child and the youngest adolescents experienced significantly more and severe poor birth outcomes including stunting, LBW, and preterm delivery. Descending maternal BMI increased the odds of LBW and stunting while low maternal MUAC increased the odds of preterm delivery. Additionally, women with inadequate weight gain had significantly more LBW and stunted infants.

Results from this analysis showed that 25.3% of the infants were born stunted. This is slightly lower than the country stunting rate of 31.3% (SSL, 2017). Of all infants measured within 48 hours 20.4% had LBW. Analysis of LBW could not include 427 infants that were measured beyond 48 hours because significant weight loss may have occurred (Muchemi et al., 2015). The rate of preterm delivery was very high at 57.6%. This could be an overestimation due to the use of fundal height as an estimation of gestational age. The use of fundal height to estimate gestational age has been criticized in developing countries where IUGR is common because fundal height can misclassify a growth-restricted infant as having an earlier week of gestation (Smith et al., 1998).

The RUSF treatment group produced superior maternal and infant outcomes. Upon enrollment the two treatment groups (RUSF and CSB +IFA) were very similar in baseline demographic and anthropometric characteristics. Height, BMI and MUAC were all very similar between groups. Women were slightly older, by 0.50 years in the CSB +IFA group and the weight of the RUSF group was slightly greater than the CSB +IFA
group at enrollment. Although women were randomized into their treatment group, women who were assigned to the CSB +IFA group enrolled with a larger fundal height. Mothers who were assigned the RUSF group had an average 8.4% greater total weight gain from enrollment to final measurement than the CSB +IFA group after adjusting for weeks on treatment. The RUSF group also achieved a higher mean weekly weight gain. This weight gain was reflected in a greater change in MUAC from enrollment to delivery and a larger MUAC at delivery. These results are similar to a comparable study of moderately malnourished pregnant women in Malawi (Callaghan-Gillespie et al., 2017). In this study, researchers compared three treatment foods: RUSF, CSB +IFA and CSB+ a daily multiple micronutrient antenatal supplement (UNIMMAP). Women receiving the RUSF gained significantly more weight from the initiation of treatment until their final clinic visit than women given the CSB+ UNIMMMAP. However, unlike the present analysis, infant outcomes remained similar across all interventions (Callaghan-Gillespie et al., 2017).

Mothers receiving the RUSF treatment had infants that were both greater in length and weight. Accordingly, these mothers also delivered significantly less often prematurely than mothers in the CSB +IFA group. These improved infant outcomes of length and weight could be the results of a combination of the greater weekly weight gain, greater total weight gain, and longer duration of pregnancy observed in the RUSF group. In comparable studies using lipid-based supplementation or balanced protein-energy supplements to treat malnutrition in pregnant women, infants had improved outcomes (Mridha et al., 2015; Ashorn et al., 2015, Imdad & Bhutta, 2011). In Ghana, undernourished pregnant women treated with a lipid-based supplement also reported a
higher mean infant birth weight compared to women treated with the standard of care (Adu-Afarwuah et al., 2010). Additionally, and consistent to this study, infant birth length, length-for-age z-score, and head circumference did not differ between groups (Adu-Afarwuah et al, 2010).

Although there were improvements in anthropometric outcomes in the RUSF group, neither treatment was able to produce a significant effect on rates of stunting or LBW. The literature is mixed. Mridha et al. (2016) found a significant 17% reduction in the prevalence of stunting with a lipid-based treatment given to malnourished pregnant women in Bangladesh. Imdad & Bhutta (2012) found balanced protein-energy supplementation in malnourished pregnant women reduced the risk of LBW by 32% compared with the control group. However, Callaghan-Gillespie et al. (2017) did not see a significant reduction in stunting and concluded that stunting in utero in women with malnutrition during pregnancy is unlikely to be reduced by supplemental food alone.

Maternal Age

Adolescent mothers had more adverse infant outcomes than adults. However, the age of the mother did not contribute significantly to maternal outcome differences between women grouped into young adolescent (13-16 years), older adolescent (17-19 years), adult (20-28 years) and mature adults (29-42 years). At enrollment, mothers differed in anthropometric measurements, parity, and level of education. Younger adolescents had significantly larger BMI, weight, and MUAC than adults and mature adults. However, this advantage in maternal size did not translate into improved outcomes for the mother or infant. The results of maternal outcomes by age group were inconsistent. Older adolescents had significantly higher rates of adequate weight gain
compared to mature adults. However, adults and mature adults delivered with a significantly larger fundal height than their younger counterparts. This inconsistency may be due in part to the differences in access to financial support and food. The adolescents may still be receiving support and improved access to food from their families, while the more mature mothers most likely no longer have family financial support and have other children to feed.

Maternal age did, however, have a significant impact on adverse infant outcomes. Although the older mothers had lower weight, BMI, and MUAC at enrollment, they delivered bigger infants. Compared to both adults and mature adults, younger adolescents had infants with smaller anthropometric measurements including length, weight, MUAC, and head circumference. Corresponding z-scores confirmed younger adolescents had infants with smaller z-scores for stunting, wasting, and underweight. Additionally, these younger adolescents had higher rates of LBW and preterm delivery compared to their older counterparts. These findings are consistent with a large body of evidence showing adolescent pregnancy can be detrimental for the infant (Paranjothy et al., 2009; Borja & Adair, 2003; Fall et al., 2015, Friebert et al., 2017). Friebert et al. (2017) found that young adolescents (≤18 years) delivered with a 1.3 cm mean fundal height smaller than adults (> 20 years) and for their infants, a length-for-age z-score significantly smaller than their older counterparts. Fall et al. (2015) found younger mothers (≤19 years) to have increased odds of LBW (OR 1.18; CI 1.02-1.36) preterm birth (OR 1.26; CI 1.03-1.53), and 2-year stunting (OR 1.46; CI 1.25-1.70). Additionally, these disadvantages were independent of socioeconomic status, height, poor schooling, and parity (Fall et al., 2015).
The most understood mechanisms for these adverse outcomes are biological. The young adolescents (13-16 years) in this study may have just recently began menstruation. Height and pelvic dimensions typically take 2 years post menarche to fully develop (Gibbs et al., 2012). Additionally, chronic malnutrition leads to later age of menarche (Scholl et al., 1994). This gynecological immaturity may prevent adolescent mothers from delivering safely (Johnson & Moore, 2015). The well documented theory of maternal and infant competition for nutrients most likely played a significant role (Naeye, 1981; Scholl et al., 1994). The competition for nutrients between a still growing mothers and the rapidly growing fetus results in ‘nutrient partitioning’, compromising both mother and fetus (Johnson & Moore, 2015). Also, in adolescents leptin surges in the third trimester may increase the use of glucose over fat breakdown, making less energy available for the fetus (Gibbs et al., 2012). Moreover, maternal nutritional status at conception influences how nutrients are partitioned between mother and fetus (King, 2003). In severe nutrient deficiencies, the mother is given preference (King, 2003). Despite adolescent mothers in this study beginning with superior anthropometrics than the older mothers, it is likely that both their underdeveloped bodies and competition for nutrients with their growing fetus resulted in the significant adverse infant outcomes.

Maternal Education

Maternal education did not have the expected affect on maternal outcomes or infant outcomes. While the women with the most education (7 or more years) had greater mean weekly weight gain and higher rates of adequate weekly weight gain than women with only 1-6 years of education, they did not differ significantly from women with no education. Also, women with the least education measured with the largest mean final
fundal height. A significantly larger mean final fundal height was also observed in the mature adult age group. Explained in further detail below, this is most likely due to the least educated women also being the mature adults. In this analysis, women with no education gave birth to infants with superior outcomes compared to women with 1-6 years and 7 or more years of education. These findings are inconsistent with the literature. For instance, Shah et al. (2014) found a reduction in preterm births among women with primary or higher level of education (RR 0.86; 95% CI: 0.83-0.90). In Malawi, women with no education were 29% more likely to bear children who had a LBW (Muula et al., 2010) and in Bangladesh, women with primary education or higher had lower risk of preterm birth (Shah et al., 2014).

An explanation for this inverse relationship could be specific to this population. The majority of women with no education were both adults and mature adults. These women born in Sierra Leone from the 1980’s throughout the late 1990’s experienced a civil war that disrupted the education system (Wright, 1997). During this time, school attendance dropped dramatically, and by the end of the war most children did not attend school (UNESCO, 2019). Accordingly, in the present study, these older women who experienced the war contributed the largest numbers to the group with no education. Additionally, adults and mature adults experienced significant better infant outcomes. Therefore, it is likely that the explanation for poorer infant outcomes among women with no education is due to this large cohort of older, uneducated women with higher parity and not the lack of education itself. Also, after the civil war ended, Sierra Leone experienced an unprecedented increase in school enrollments (Moyi, 2013). These more
educated women were most likely primiparous younger and older adolescents, explaining the poorer outcomes among more educated women.

**Maternal Anthropometrics**

A low maternal BMI <18.5 kg/m$^2$ was a significant risk factor for poor infant outcomes. Underweight women (BMI <18.5 kg/m$^2$) gave birth to infants with lower anthropometrics including length, weight, MUAC, and head circumference. These finding are similar with several other studies, however most measure pre-pregnancy BMI (Landau, 2019; Ay et al., 2009; Han et al., 2010). Additionally, maternal BMI was a significant risk factor for LBW. For every 1 unit decrease in maternal BMI at enrollment, the odds of LBW increased 1.20 times. Maternal BMI also increased the risk of stunting. For every 1 unit decrease in maternal BMI at enrollment, the odds of stunting increased 1.10 times. The association between low BMI, LBW, and stunting is most likely explained by a lack of adequate nutrients prior to and during pregnancy resulting in diminished fetal growth (Han et al., 2010). Interestingly, older women had the highest rates of underweight women at enrollment, but as previously discussed, had the best infant outcomes. This may be partially explained by the previously mentioned difference in body composition and nutrient requirements of the adolescent mother. Although these finding highlight the importance of a healthy pre-pregnancy and pregnancy BMI, it is important to note that a BMI cutoff of ≤18.5 cm/kg$^2$ during pregnancy may not be adequate to identify women at risk of adverse infant outcomes.

In this analysis maternal MUAC at enrollment was a risk factor for preterm delivery. For every 1 unit decrease in maternal MUAC, the odds of delivering prematurity increased 1.22 times. Analysis of women by severity of malnutrition
revealed that a MUAC <21 cm resulted in significantly lower infant birth weight and MUAC compared to women with moderate malnutrition. The significant difference in infant weight was also reflected in smaller z-scores for weight-for-age and weight-for-length in women with severe malnutrition at enrollment. These results were congruent with other studies that found a low maternal MUAC associated with low birth weight and preterm delivery (Ververs et al., 2013; Ramlal et al., 2012; Shah et al., 2014). Although all women in the study were determined to be malnourished (MUAC ≤23 cm), the present analysis confirmed that a descending MUAC, and especially women with a MUAC <21 cm, only worsened the consequences for the infant. These findings support the usefulness of a MUAC measurement as a screening tool in LMICs to identify pregnant women with higher risks of LBW and possible preterm delivery. However, it is limited in that all women were malnourished, and may falsely suggest MUAC of 23 cm is less risky. On the contrary, other studies have found that MUAC < 25 cm (Shah et al., 2014) and < 26 cm (Petraro et al., 2018) significantly increased the risk of preterm birth and low birth weight.

Not surprisingly, women who gained adequate weight (≥ 454g per week past the 2nd trimester) produced significantly better infant anthropometric measurements than women who did not gain adequately. In this population, 72% of the mothers did not have adequate weekly weight gain. While this is a very high rate of inadequate weight gain, this rate is lower than 97% in Nigeria and 75% in Malawi reported among pregnant women (Esimai et al., 2014; Callaghan-Gillespie et al., 2017). In general, it is recognized that adequate gestational weight gain has significant influence on fetal growth (IOM, 1990). Among the women who did meet adequate weekly weight gain recommendations,
infant length, weight, and MUAC were all significantly larger. Additionally, women with inadequate weight gain gave birth to infants with lower mean z-score for length-for-age. The association with inadequate weight gain and birthweight has been shown in other studies (Wen & Lv, 2015; Siega-Riz et al., 2009). A large systematic review found consistent evidence of an association between LBW and weekly gestational weight gain below IOM recommendations among underweight women (Siega-Riz et al., 2009). Although this analysis did not find an association with preterm delivery, Han et al. (2011) found the overall risk of preterm birth was significantly increased in women who had a low weekly gestational weight gain (<400g/week). Findings from this analysis underline the importance of meeting minimum adequate weekly weight gain in malnourished pregnant women.

Maternal Parity

The most significant risk factor contributing to poor birth outcomes was being a first time mother. Women who were childbearing for the first time were 2.08 times more likely to deliver stunted infants than multiparous women. These primiparous women were also 2.50 times more likely to deliver infants that were LBW than multiparous women. Childbearing for the first time also increased the odds of delivering prematurely 1.57 times compared to women who had multiple previous pregnancies. All infant birth anthropometric infant outcomes were larger for women who were multiparous including length, weight, MUAC, and head circumference. Corresponding z-scores for stunting, wasting, and underweight confirmed that primiparous women had significantly adverse infant outcomes compared to multiparous women. These finding are due in part to the majority of primiparous women being in the younger adolescent group. As discussed
earlier, the youngest adolescents had the most adverse birth outcomes among all age groups.

Poor birth outcomes related to primiparity found in the present analysis are consistent with other studies (Mombo-Ngoma et al., 2016; Kemfang, 2013; Shah 2010). Maternal parity has been identified as a predictor of infant birthweight, with first time mothers delivering infants with the lowest birthweights (Shah et al., 2010). A common theory is that the first pregnancy primes the body and with each subsequent pregnancy the body is more efficient (Prefumo et al., 2006; Khong et al., 2003). However, some evidence suggests that this relationship between poor birth outcomes and party is a j-shaped curve (Aliyu et al., 2005; Desyibelew et al., 2019). Although malnourished primiparous women face greater adverse infant outcomes than multiparous women in this analysis, multiple pregnancies spaced to close together are also very dangerous (Ramakrishnan et al., 2012). In Sierra Leone, 37% of women have four or more children (SSL, 2013). This high parity may be especially dangerous for malnourished women, as pregnancies are often spaced too closely, depleting the mothers nutrient stores and increasing her risk of malnutrition (Smits et al., 2001).

Malaria and Bed Net Usage

Although malaria is a major public health problem in Sierra Leone, mothers who reported a malarial illness within the previous 2 months at enrollment did not have significantly different infant outcomes than mothers who did not report malaria. The same was found for mothers who reported not using a bed net every night compared to those that used a bed net. Both malarial infection at enrollment and delivery have been associated with a reduction of infant birth weight around 55 grams (Cates et al., 2017).
Significance was most likely not found because the incidence of a malarial infection in the previous 2 months may have been too far before the pregnancy started to have impact.

The behavior of not using a bed net every night at enrollment increases the risk of malaria transmission. Although there was no association between this behavior and increased adverse infant outcomes, several factors may explain the results. Firstly, women were all given a bed net at enrollment. Although there was no follow-up on whether it was being used throughout pregnancy, this most likely would have increased coverage. Additionally, intermittent preventive treatment sulfadoxine-pyrimethamine (IPTp-SP) was given throughout the pregnancy to both treatment groups. The CSB +IFA group received 3 treatments total during the 2nd and 3rd trimester while the RUSF group received treatment every 4 weeks starting after 13 weeks of gestation. Kayenato et al. (2013) evaluated IPTp-SP to control malaria during pregnancy in 37 countries in sub-Saharan Africa. Researchers found three or more doses associated with fewer LBW infants (RR, 0.80; 95% CI 0.69-0.94).

Although this analysis could not find any significant findings related to previous malaria illness reported at enrollment or bed net use behavior, malaria is an important maternal risk factor in Sierra Leone (Buh et al., 2019). Use of bed nets and IPTp-SP treatment are crucial components of preventing gestational malaria in this population.

5.1 Strengths and Limitations

The greatest strength of this analysis is that it was based on a large randomized controlled trial with a sample size of 1506. The data collected in the main study provided a rich data set with several variables to analyze. Additionally, data collection was from several districts throughout Sierra Leone and succeeded in collecting infant birth data
despite many barriers. For this analysis, data used was from enrollment until birth. This was the time frame that participants were most likely to continue in the program, reducing the loss to follow-up seen during the infant 6 week, 3 month, and 6 month follow-up.

There were also several limitations to main study and this analysis. There was a lack of blinding of the nutritional and anti-infective treatments between the two groups. This was because the packaging of the two treatments was very different in size and shape. In the main study, there was no true way of knowing how well the women followed the treatment. Food rations given to a malnourished mother are likely to be shared with her family. Also, there was no control group. Due to the severe consequences of malnutrition, it would have been unethical to not provide treatment if a participant qualified. The control group therefore received the standard of care for Sierra Leone.

Another limitation was in the collection of data. Anthropometric measurements, such as MUAC and head circumference are subject to variability among the different study team members. Additionally, women interviewed at enrollment may not have given accurate data. For instance, many women did not know their birthdate, so age is estimated. Finally, collection of infant data in a timely manner was difficult. To get a measurement within 48 hours relied on the mother to contact the study team when she had delivered. Unfortunately, 33% of these calls came too late or not at all. Without the use of a ultrasound, gestational age was predicted by both maternal reporting of last menstrual period and the use of fundal height. These measurements are subject to maternal recall and variability in measurement by the study team member. Additionally, the determination of a preterm delivery was determined from the last fundal height
measured. This allowed for up to a two week variability from the time that measurement was taken and the actual delivery date.
CHAPTER 6

CONCLUSION

The findings of this literature review and analysis support a strong association between maternal malnutrition and adverse birth outcomes such as inadequate gestational weight gain, preterm birth, LBW, and stunting in spite of providing approximately 1200 kcals and 35 grams of protein per day. Additionally, maternal risk factors such parity and age were shown to have significant implications on infant outcomes. Maternal MUAC and BMI at enrollment were predictors of preterm delivery and LBW, respectively. This highlights the importance of maternal nutrition and the consequences when women begin a pregnancy already in deficit. In this analysis most of the women experienced inadequate weight gain, underlining the lack of antenatal care resources and services in Sierra Leone to sufficiently address maternal weight gain during pregnancy. With nearly half of participants being adolescents and bearing the most severe consequences, it is evident that further implementation of pregnancy prevention strategies and healthcare interventions for pregnant adolescents should be priority.

Maternal malnutrition is a critical determinant of the short and long-term health of offspring. As malnutrition before and during pregnancy continues to restrict the progress of developing countries, future treatment and research must target prevention and amelioration of maternal malnutrition. Additionally, with only modest improvements observed from nutritional supplementation, the multitude of other risk factors that affect growth in utero must be integrated. In order to improve birth outcomes, future research should include the environmental, biological, and emotional stressors such as infection, inflammation, gender inequality, poverty, violence, and exclusion experienced by
pregnant women in Africa. A combination of nutrition education and nutritional supplementation could provide more beneficial effects than supplementation alone. Developing population-based measurements for diagnosing malnutrition such as BMI, MUAC, and appropriate gestational weight gain cutoff points will also be imperative in targeting those most at risk in developing countries. Programs targeting the recovery of women from malnutrition before they enter into a pregnancy could have significant improvement in pregnancy and birth outcome.
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c. Maternal Mortality Ratio: Sierra Leone. Retrieved from:


## Appendix A: Nutrient Profile of Study Foods

<table>
<thead>
<tr>
<th>Nutrient (units)</th>
<th>RUSF</th>
<th>CSB+ with sugar, oil. Iron/folic acid</th>
<th>RDA for pregnancy, 19–30 yr</th>
<th>UL (Tolerable Upper Limit Intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, Kcal</td>
<td>520</td>
<td>1177</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein, g</td>
<td>18</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-6 (% from energy)</td>
<td>4.5</td>
<td>7.3c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-3 (% from energy)</td>
<td>1.5</td>
<td>.7c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vit A (mcg)</td>
<td>770</td>
<td>2621</td>
<td>770</td>
<td>3000</td>
</tr>
<tr>
<td>Vit B1/Thiamine (mg)</td>
<td>2.8</td>
<td>0.5</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Vit B2/Riboflavin (mg)</td>
<td>2.8</td>
<td>3.5</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Vit B3/Niacin (mg)</td>
<td>32</td>
<td>20</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>Vit B6 (mg)</td>
<td>3.8</td>
<td>2.5</td>
<td>1.9</td>
<td>100</td>
</tr>
<tr>
<td>Vit B12 (mcg)</td>
<td>5.2</td>
<td>5.0</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Folic acid (mcg)(^a)</td>
<td>500</td>
<td>275</td>
<td>400</td>
<td>1000</td>
</tr>
<tr>
<td>Vit C (mg)</td>
<td>170</td>
<td>225</td>
<td>85</td>
<td>2000</td>
</tr>
<tr>
<td>Vit D (IU)</td>
<td>1200</td>
<td>1104</td>
<td>600</td>
<td>4000</td>
</tr>
<tr>
<td>Vit E (mg)</td>
<td>30</td>
<td>20.8</td>
<td>15</td>
<td>1000</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>30</td>
<td>66.5</td>
<td>27</td>
<td>45</td>
</tr>
<tr>
<td>Zinc (mg)</td>
<td>22</td>
<td>12.5</td>
<td>11</td>
<td>40</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>1600</td>
<td>905</td>
<td>1000</td>
<td>2500</td>
</tr>
<tr>
<td>Chromium (mcg)</td>
<td>60</td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Copper (mcg)</td>
<td>2000</td>
<td></td>
<td>1000</td>
<td>10,000</td>
</tr>
<tr>
<td>Iodine (mcg)</td>
<td>300</td>
<td>100</td>
<td>220</td>
<td>1100</td>
</tr>
<tr>
<td>Magnesium (mg)</td>
<td>300</td>
<td>350</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>Selenium (mcg)</td>
<td>120</td>
<td>60</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Amount recommended for supplementation, with 200 mcg to come from dietary sources for total RDA of 600 mg/d  
\(^b\) Daily ration: 250 g supercereal (CSB+) with sugar, 20 ml oil, 60 mg Fe supplement with 400 mcg folic acid  
\(^c\) Calculated based on a WFP supercereal product containing ~ 64% corn, ~ 24% soybean, ~ 20 ml vegetable oil  
Appendix B: Enrollment Demographic Form

Belumman Welbodi

Background Demographic Form

ID Number:_________________
Participants Name:_________________ Village Name:_________________
Phone Number:_________________
Name of CHW who works in participant’s village:_________________
Home Village:_________________
Directions (to home from study site):_________________

Participant Identification Information
1. What is the participant’s date of birth? ____/____/___ Participant’s Age: __Years
   dd mm yyyy
2. Has this woman participated in the research study before? Yes No

Social and Demographic Information – Circle response
3. Your highest level of education completed:
   Primary      Junior Secondary      Senior Secondary       Tertiary     None

Household Information – Circle response
4. How many children live in your household? 1   2   3   4   5   6   7   8   9   Other:
5. Including you, how many adults live in the household?   1   2   3   4   5   6   7 Other: _
6. Does the father of your unborn baby live with you? Yes No
7. How many people slept in the same room with you last night?
   0   1   2   3   4   5   6 Other:_____  
8. What material is the household roof made from?
   Thatch     Metal Sheet    Other:_____  
9. How many radios are in the household? 0   1   2   3 Other:_____  
10. How many bicycles are in the household?    0   1   2   3 Other:_____  
11. Does the household have electricity?   Yes    No
12. What is the household’s water source?
   Borehole    River    Stream    Well    Public Tap
13. How many times per day do you collect water?
   0   1   2   3   4   5 Other:_______
14. Did any animals sleep in the same house as you last night?       Yes     No
   IF YES, what kind? 
   Chicken    Dog    Goat    Pig    Duck    Sheep    Cat    Other____
15. What do you use as a toileting facility?
   Field/Bush    Open Pit    Pit with Slab    Ventilated Improved Pit (VIP) Other ___
Health Information
16. During the last 2 months, what illnesses have you had (not including antenatal illnesses)?

   None      Diarrhea      Pneumonia      TB      Malaria     Other_____

   For how long? _____days or months _____ days or months _____

   How long ago did the illness begin?

   _____days or months _____ days or months _____ days or months _____

17. During the last 6 months, has anything happened to reduce your normal food intake? Yes    No

   If yes, what were the reasons?

   Own illness   Child’s Illness   Husband’s illness   Left village   Other

18. Have you been diagnosed with TB? Yes    No

   IF YES, are you currently taking TB Treatment? Yes    No

   If no, why not?________________________________________

19. Is there any other person in the house that has been diagnosed with TB?

   Yes    No

   IF YES, are they currently taking TB Treatment? Yes    No

   If no, why not?________________________________________

20. Do you sleep beneath a bed net every night? Yes    No

21. Do you currently chew, sniff, or smoke tobacco? Yes    No

   IF YES, how often? 1x/wk 2-3x/wk 4-7x/wk

22. Do you currently chew kola nut? Yes    No

   IF YES, how often? 1x/wk 2-3x/wk 4-7x/wk

23. Do you currently drink alcohol? Yes    No

   IF YES: Palm Wine/Poyo   Beer   Spirits   Other:_______

   IF YES, how often? 1x/wk 2-3x/wk 4-7x/wk

Pregnancy History
24. Number of previous pregnancies? 0 1 2 3 4 5 6 Other:_______

25. Number of live births? 0 1 2 3 4 5 6 Other:_____

26. What is the age of your youngest child? ________ months/years (circle month or year)

27. Number of miscarriages? 0 1 2 3 4 5 6 Other:_____

28. Number of stillborns? 0 1 2 3 4 5 6 Other:_____

29. Number of living children? 0 1 2 3 4 5 6 Other:_____

30. Are you currently breastfeeding? Yes    No

Symptoms/Illness
31. Have you taken any medications in the last 14 days? Yes    No

   IF YES If you have taken medications, please list them:

   Malarial tx Amoxicillin ARV ORS TB Tx PCM (paracetamol)

   Other __________________________________________

32. Are you currently taking any supplements?
Yes  No
  IF YES  Which ones?  Iron  Folic Acid  Other:
____________________________________

33. Has any family member been prescribed therapeutic food in the past month?  Yes  No
  IF YES  Who?______________________________

34. Does the family currently receive Super Cereal/CSB?  Yes  No
  IF YES  How often?  1x/wk  Every 2 wks  1x/month

35. Does the family currently receive cooking oil?  Yes  No
  IF YES  How often?  1x/wk  Every 2 wks  1x/month

36. Do you have a known peanut, milk, or antibiotic allergy?  Peanut  Milk  Antibiotic  None
  If Antibiotic, which ones? _________________________
Appendix C: Infant Outcomes by Gender

| Infant Outcomes     | Female | Male | P
|---------------------|--------|------|---
|                     | n      |      | n  |      |      | <br><br>| **Female** | **Male** |<br>**P**<br> |<br>**Length, cm** | 646 | 46.80 (0.092) | 633 | 47.44 (0.093) | 0.000 |<br>**Weight, kg** | 424 | 2.73 (0.019) | 428 | 2.88 (0.019) | 0.000 |<br>**MUAC, cm** | 424 | 9.75 (0.036) | 428 | 9.90 (0.036) | 0.003 |<br>**HC, cm** | 646 | 33.62 (0.058) | 633 | 34.18 (0.059) | 0.000 |<br>**Stunted** | 161 (24.51) | 168 (26.25) | 0.510 |<br>**LBW** | 112 (25.93) | 64 (14.78) | 0.000 |<br>**Preterm delivery** | 395 (60.12) | 352 (55.10) | 0.075 |<br>**Z-scores** |<br>**Length-for-Age** | 646 | -1.24 (0.047) | 633 | -1.27 (0.047) | 0.592 |<br>**Weight-for-Age** | 424 | -1.19 (0.045) | 428 | -1.27 (0.047) | 0.020 |<br>**Weight-for-Length** | 424 | -0.005 (0.044) | 428 | 0.175 (0.089) | 0.004 |

1Adjusted for weeks on treatment and BMI at enrollment<br>2Values expressed as least square means (LSM) (SE) or n (%) for categorical measures<br>3P values for MUAC group (Effects test), Chi-square (categorical measures)<br>4Infants not measured within 48 hours after birth excluded (n=427)<br>5MUAC- Mid-upper Arm Circumference<br>6HC -Head Circumference<br>7Stunted infants were born with a length-for-age z-score < -2 standard deviation from the WHO mean<br>8LBW (low birth weight) defined as <2500g<br>9Preterm delivery defined as birth before 38 weeks of gestation
### Appendix D: Infant Outcomes by Previous Malaria Infections

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>Malaria Infection</th>
<th>No Malaria Infection</th>
<th>(P^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n)</td>
<td>(n)</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>1100</td>
<td>178</td>
<td>0.768</td>
</tr>
<tr>
<td>Weight, kg(^4)</td>
<td>730</td>
<td>122</td>
<td>0.198</td>
</tr>
<tr>
<td>MUAC, cm(^4,5)</td>
<td>730</td>
<td>122</td>
<td>0.173</td>
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<tr>
<td>HC, cm(^6)</td>
<td>1100</td>
<td>178</td>
<td>0.605</td>
</tr>
<tr>
<td>Stunted (^7)</td>
<td>280 (25.11)</td>
<td>49 (27.07)</td>
<td>0.638</td>
</tr>
<tr>
<td>LBW(^8)</td>
<td>146 (83.0)</td>
<td>30 (24.19)</td>
<td>0.303</td>
</tr>
<tr>
<td>Preterm delivery(^9)</td>
<td>643 (57.72)</td>
<td>103 (56.91)</td>
<td>0.901</td>
</tr>
<tr>
<td>Z-scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length-for-Age</td>
<td>1100</td>
<td>178</td>
<td>0.951</td>
</tr>
<tr>
<td>Weight-for-Age</td>
<td>730</td>
<td>122</td>
<td>0.856</td>
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<tr>
<td>Weight-for-Length(^4)</td>
<td>730</td>
<td>122</td>
<td>0.825</td>
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</tbody>
</table>

\(^1\)Adjusted for weeks on treatment and BMI at enrollment

\(^2\)Values expressed as least square means (LSM) (SE) or \(n\) (%) for categorical measures

\(^3\)\(P\) values for MUAC group (Effects test), Chi-square (categorical measures)

\(^4\)Infants not measured within 48 hours after birth excluded (\(n=427\))

\(^5\)MUAC - Mid-upper Arm Circumference

\(^6\)HC - Head Circumference

\(^7\)Stunted infants were born with a length-for-age \(z\)-score < -2 standard deviation from the WHO mean

\(^8\)LBW (low birth weight) defined as <2500g

\(^9\)Preterm delivery defined as birth before 38 weeks of gestation
## Appendix E: Infant Outcomes by Bed Net Use

<table>
<thead>
<tr>
<th>Infant Outcomes</th>
<th>No Bed Net</th>
<th>Bed Net</th>
<th>$P^3$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>$n$</td>
<td></td>
</tr>
<tr>
<td>Length, cm</td>
<td>407 47.13 (0.117)</td>
<td>872 47.11 (0.080)</td>
<td>0.914</td>
</tr>
<tr>
<td>Weight, kg$^4$</td>
<td>268 2.81 (0.024)</td>
<td>584 2.80 (0.016)</td>
<td>0.905</td>
</tr>
<tr>
<td>MUAC, cm$^{4,5}$</td>
<td>268 9.77 (0.046)</td>
<td>584 9.85 (0.31)</td>
<td>0.184</td>
</tr>
<tr>
<td>HC, cm$^6$</td>
<td>407 33.88 (0.075)</td>
<td>871 33.81 (0.051)</td>
<td>0.749</td>
</tr>
<tr>
<td>Stunted$^7$</td>
<td>114 (27.80)</td>
<td>871 215 (24.24)</td>
<td>0.170</td>
</tr>
<tr>
<td>LBW $^8$</td>
<td>56 (20.80)</td>
<td>872 120 (20.10)</td>
<td>0.817</td>
</tr>
<tr>
<td>Preterm delivery$^9$</td>
<td>239 (58.30)</td>
<td>872 508 (57.30)</td>
<td>0.746</td>
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</tbody>
</table>

Z-scores

<table>
<thead>
<tr>
<th></th>
<th>$n$</th>
<th>$n$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length-for-Age</td>
<td>406 -1.25 (0.059)</td>
<td>869 -1.26 (0.040)</td>
<td>0.937</td>
</tr>
<tr>
<td>Weight-for-Age$^4$</td>
<td>268 -1.12 (0.057)</td>
<td>584 -1.11 (0.038)</td>
<td>0.959</td>
</tr>
<tr>
<td>Weight-for-Length$^4$</td>
<td>268 0.142 (0.056)</td>
<td>584 0.060 (0.038)</td>
<td>0.231</td>
</tr>
</tbody>
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---

1 Adjusted for weeks on treatment and BMI at enrollment
2 Values expressed as least square means (LSM) (SE) or $n$ (%) for categorical measures
3 $P$ values for MUAC group (Effects test), Chi-square (categorical measures)
4 Infants not measured within 48 hours after birth excluded (n=427)
5 MUAC - Mid-upper Arm Circumference
6 HC - Head Circumference
7 Stunted infants were born with a length-for-age $z$-score $<-2$ standard deviation from the WHO mean
8 LBW (low birth weight) defined as <2500g
9 Preterm delivery defined as birth before 38 weeks of gestation

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