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The association between environmental exposures and the physical growth status, bone growth status, and metabolic risk factors of children of Sudanese immigrant families living in the USA

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THE ASSOCIATION BETWEEN ENVIRONMENTAL EXPOSURES AND THE PHYSICAL GROWTH STATUS, BONE GROWTH STATUS, AND METABOLIC RISK FACTORS OF CHILDREN OF SUDANESE IMMIGRANT FAMILIES LIVING IN THE USA

by

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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To Amanda, my most brilliant companion whom I was my able to persuade to marry me, I dedicate this work. We all have dreams, but in order to make dreams become reality, it takes determination, dedication, self-discipline, effort, and support. This work could not be achieved without the great help, support, dedication, patience, advice, and encouragement of my wife

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ABSTRACT

Objectives

The purpose of this research was to describe the physical growth status, bone mineral content, areal bone mineral density, body composition, and metabolic risk level of children of Sudanese immigrant families, and to determine the relationship between these outcome measures and exposure to an adverse environment. Exposure was defined as the time spent in Sudan or neighboring countries and timing was defined as the age a child arrived in the USA. Two major modifying factors were considered; current nutritional status (food quality and food security) and current physical activity levels.

Study Design and Methods

This is a cross-sectional study conducted between July 2011 and April 2012. Subjects were recruited from the Iowa City, Iowa metropolitan area. The sample included 64 children between the ages of five and eighteen; 33 females and 31 males. Physical growth measures included weight, height, and BMI. Bone growth measures (body bone mineral content and areal bone mass density at the hip and spine) and body composition measures (lean mass, fat mass, and body fat percent) were measured using DXA. Metabolic risk factors included fasting blood glucose, low density lipoprotein (LDL), high density lipoprotein (HDL), total cholesterol, triglyceride, and C Reactive Protein (CRP) levels, and Homeostasis Model of Assessment Insulin Resistance (HOMA-IR). Physical activity was measured by self-report physical activity questionnaire for children and adolescents (modified PAQ-A and PAQ-C) and by direct measure using Omron Pedometers (HJ-720 IT). Other collected data included food quality, food security, food frequency, and pubertal development using a puberty developmental scale.

Results

The mean age for all children was 10.1 ± 3.3 years. More than half of the children (n=33, 51.6%) were born in the USA, 14 children (21.9%) were born in Sudan, and the other children were born in other countries. The majority of the children (63.6%) lived in low income households reporting annual income less than USD $19,000.

Over one quarter (26.5%) of the children were overweight or obese as defined by BMI percentile and when categorized by BF%, 35.5% of the girls and 27.3% of the boys were identified as obese. Height stunting was noted with 4.7% severely stunted (more than 2 sd below the mean) and 9.4% moderately stunted (more than 1 sd below the mean).

The mean Z score for FMI and LMI were -0.57 ± 1.51 and 0.49 ± 0.75, respectively, and neither was normally distributed. Around half of the children had FMIZ (53.1%) and LMIZ (47%) scores more than 1 SD below the mean. Median Z scores for all bone measures were negative; BMC, -0.71, hip aBMD, -0.53, and Spine aBMD, -0.13. Around one-third of the children fell more than 1sd below the mean for BMC (38%) and hip aBMD (33%). Metabolic risk factors were elevated in some subjects; high total cholesterol, 23.4%; high triglycerides, 32.8%; low HDL, 19%; high HOMA-IR and CRP levels, 15.6 %.

Forty percent of participating families reported some level of food insecurity, and 31% reported skipping or cutting the size of meals due to inadequate food supplies. Both self-reported questionnaires and data collected from pedometers showed that the majority of study participants were inactive, Wednesday & Thursday were identified as the most active days with activity levels of 52.6% and 50.9%, respectively, and 40% of the study subjects were inactive on weekends. More than half (56.9%) of the subjects reported watching TV more than two hours per day. Children born in the USA had higher rates of height and weight stunting and obesity as compared to children born outside the USA (24%, 37.5%, 32.26%; 3.12%, 25%, 21.21%, respectively). Children born in the USA had lower Z scores in all bone and body composition measures.

Using GEE analysis, longer residence in Sudan was associated with lower WAZ scores (β= -0.16, p= 0.07), and lower LMIZ scores (β= -0.05, p= 0.06). Children with longer residence in Sudan or neighboring countries had higher LDL and HOMA-IR levels (β= 2.997, p= 0.0005), and (β= 0.03, p= 0.08). Adjusting for gender, girls who spent more time in Sudan had higher triglyceride and CRP levels (β= 11.9, p=0.027) and (β=0.5, p=0.03), respectively.

Children who were older when they entered the USA had higher HAZ scores (β= 0.06, p=0.05). Adjusting for gender, Girls who arrived in the USA at a younger age had lower WAZ scores (β=-0.42, p=0.01), while girls who entered the USA at an older age had higher HOMA-IR, triglyceride, and CRP levels (β= 0.29, p=0.005), (β= 0.14, p= 0.05) and (β=0.5, p=0.05), respectively.

Adjusting for number of years spent in the USA and physical activity levels, longer residence in Sudan was associated with poorer LMIZ (β= -0.06, p=0.001) and hip aBMD Z scores (β=0.11, p= 0.01). In addition, children who arrived in the USA at a younger age had higher height for age Z scores β=0.094, p=0.005) and lower LMIZ scores (β =-0.09, p=0.04), respectively.

Conclusion

Sudanese children in the Iowa City metropolitan area, particularly those born in the USA, have low Z scores for physical growth, bone growth, and body composition measures. A significant percent of the children had high triglycerides and total cholesterol levels. The majority of Sudanese children were physically inactive and food insecurity was common.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND SPECIFIC AIMS

Immigrants from the developing countries of Sudan, Somalia, and Ethiopia are among the fastest growing population subgroups in the USA (Passel, 2011; Van Hook, Zhang, Bean, & Passel, 2006). Children emigrating from these countries often experience malnutrition and diarrheal disease due to poor environmental conditions, potentially leading to adverse effects on their long term growth and health. In Sudan, reports show that only 56% of the population has sustained access to an improved water source, 31% have access to improved sanitation, 37.9% of children under age five are stunted, and the prevalence of moderate and severe underweight is 31.7 % (World Health Organization (WHO), 2009). Children who transition through refugee camps often receive less than half the recommended daily calorie intake, compounding environmental effects on health (Mason, 2002; WHO, 2009; Allotey, 2003).

A child's growth and development is dependent on biology (e.g. genes and hormones) and environment (Roche & Sun, 2003; Adair, 2008). During important growth periods, poor environmental conditions (including inadequate nutrition) can permanently adversely affect growth. The acute effects of adverse environmental exposures on the growth and health of children can include malnutrition, anemia, growth delay, and increased incidence of infectious disease (Tiong, Patel, Gardiner, Ryan, Linton, Walker, & Biggs, 2006; Zeidan, Hashim, Muhit, & Gilbert, 2007; Wishart, Reeve, & Grant, 2007; Woodruff, Blanck, Slutsker, Cookson, Larson, Duffield, & Bhatia, 2006; Umoh, 2003; Hjeron & Bouvier, 2004). These acute effects have been extensively studied. However, poor environmental conditions have also been linked to chronic health problems including permanent short stature, low bone mass, and paradoxically, obesity, metabolic syndrome and cardiovascular disease in adulthood (Duerr, Posner, & Gilbert, 2003; De Onis, 2003; Chopra, 2003; Walker, Chang, Powell, & McGregor, 2005).These long term effects are not fully understood. Growth delay is primarily caused by inadequate nutrition during early life and critical periods of growth throughout childhood and adolescence. If adequate nutrition is restored, children can experience a period of "catch up growth" where linear growth exceeds the normal rate for age. Whether growth delays or stunting are reversed may depend on the timing of the catch up growth period (Sawaya et al., 2009). Permanent stunting may occur if linear growth is completed prior to improvement of the nutritional environment. Undernourished children have lower muscle and fat mass accumulation than adequately nourished child (De Onis, 2006). When adequate nutrition is restored, there can be a rapid gain in fat mass. Generally, increase in fat mass outpaces the increase of lean mass by as much as 2:1, resulting in a relatively greater fat to lean mass by the time a child reaches an appropriate height for age. This phenomena is referred to as "catch up fat", and has been linked to obesity, increased metabolic risk (e.g. higher fasting glucose, cholesterol, and triglyceride levels), metabolic syndrome, diabetes, and heart disease in adulthood (Horta, Sibbritt, Lima, & Victora, 2009; Eriksson, Forsn, Tuomilehto, Osmond, & Barker, 2001).

Childhood and adolescence are critical times for skeletal development with the most rapid increase of physical growth occurring in the year preceding and following onset of puberty. Exposure to a poor environment during childhood and adolescence that impacts nutritional status could affect bone development and predispose a child to osteoporosis and increased risk of bone fracture in later years. By age 17, boys have attained approximately 86%, and girls have attained approximately 93% of their adult bone density. Total bone mass accrual is generally completed by age 25 (Baroncelli & Saggese, 2000; Barr, 1998; Fewtrell, Williams, Singhal, Murgatroyd, Fuller, & Lucas, 2009). Therefore, poor environmental conditions that affect nutritional status, particularly calcium and vitamin D deficiency, could permanently affect the attainment of peak bone mass, a major predictor of fractures in later life (Clark, Bond, & Hecker, 2006; Borges & Brandao, 2006).

Studies describing the physical growth, body composition, bone mineral content, and metabolic risk of children immigrating from developing countries are limited. There is some evidence that Sudanese child refugees have higher cholesterol levels than other immigrants, and lower than expected total bone mineral content and serum vitamin D levels (Nisbet, 2011; Sheikh, Wang, Pal, MacIntyre, Wood, & Gunesekera , 2011). However, none of the existing literature has comprehensively studied multiple growth parameters, and most fail to consider other factors that could compromise physical growth and metabolic risks, like the amount of time spent living in a suboptimal environment or current diet quality and level of physical activity. Immigrants and refugees are unique groups that often have higher rates of illness and suffer poor health outcomes. Child immigrants and refugees are particularly vulnerable. Understanding growth in this context is important in order to fully comprehend existing deficiencies and to develop appropriate interventions where required.

Purpose

The purpose of this research is to describe the physical growth status, bone mineral content, areal bone mineral density, body composition, and metabolic risk level of Sudanese immigrant children, and to determine the relationship between these measures and exposure to an adverse environment. Timing and duration of adverse environmental exposures may influence growth and health effects. This research will determine whether associations between environmental exposures and growth and health effects are modified by physical activity and current nutritional status. This study has the potential to identify unique long term health risks of Sudanese immigrant children and will provide knowledge important to the planning and implementing of future interventions on immigrant children.

Specific Aims

The specific aims of this study are:

1) To describe the physical growth status and selected metabolic risk factors of Sudanese children living in the Iowa City metropolitan area. Physical growth variables include weight, height, body mass index (BMI), BMI percentile, weight for age Z score (WAZ), and height for age Z score (HAZ). Body composition variables include fat mass, lean mass, fat mass index (FMI) $\left(\frac{fat\ mass\ (g)}{ht\ (cm)^2}\right)$, lean mass index (LMI)$\left(\frac{lean\ mass(g)}{ht\ (cm)^2}\right)$, and body fat percent (BF%). Bone growth variables include bone mineral content (BMC), and areal bone mineral density (aBMD) at the femoral neck and lumbar spine. The metabolic profile includes fasting blood glucose (FBS), insulin, high density lipoprotein (HDL), low density lipoprotein (LDL), total cholesterol, triglyceride, C-reactive protein (CRP) levels, and Homeostatic Model Assessment Insulin Resistance (HOMA-IR) calculated by $\left(\frac{fasting\ Glucose(mg/dL)\ x\ fasting\ Insulin(\mu U/mL)}{405}\right)$

2) To determine the association between environmental exposures, as defined by the

duration and timing of residence in Sudan and neighboring countries, and children's a) physical growth b) total bone mineral content and aBMD at the hip and spine c) body composition and d) metabolic risk factors.

i.) *Hypothesis 1*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI, and LMI, and higher FMI Z scores.

ii.) *Hypothesis 2*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for total body BMC and aBMD at the hip and spine.

iii.) *Hypothesis 3*: Longer residence in Sudan or in neighboring developing countries will be associated with poorer metabolic risk indicators.

iv.) *Hypothesis 4*: Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and BMC of the femoral neck and spine.

v.) *Hypothesis 5*: Age at arrival to the USA will be positively associated with FMI and metabolic risks.

3) To determine if the relationship between environmental exposures, as defined by the duration and timing of residence in Sudan and neighboring countries, and children's a) physical growth b) bone mineral content and bone density at the hip and spine c) body composition and d) metabolic risk factors are modified by the number of years spent in the United States, current physical activity, and current nutritional status as measured by food quality, calcium intake, and food security.

i.) *Hypothesis 1*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI, and LMI, and higher FMI Z scores, independent of number of years spent in the USA, current physical activity, and current nutritional status.

ii.) *Hypothesis 2*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for total body bone mineral content and aBMD at the hip and spine, independent of number of years spent in the USA, current physical activity, and current nutritional status.

iii.) *Hypothesis 3*: Longer residence in Sudan or in neighboring developing countries will be associated with poorer metabolic risk indicators, independent of years spent in the USA, current physical activity, and current nutritional status.

iv.) *Hypothesis 4*: Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and BMC of the femoral neck and spine, independent of number of years spent in the USA, current physical activity, and current nutritional status.

v.) *Hypothesis 5*: Age at arrival to the USA will be positively associated with FMI and metabolic risks, independent of number of years spent in the USA, current physical activity, and current nutritional status.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

This chapter presents a literature review of the physical health of children immigrating from developing countries, specifically, children emigrating to the United States of America from Sudan. The chapter gives an overview of the extent and nature of emigration from Sudan, as well as the environmental and nutritional challenges Sudanese children encounter in Sudan, or in refugee camps. A conceptual model that illustrates the relationship between exposure to environmental challenges and adverse effects on selected health outcomes is presented. The literature is reviewed for each of the key concepts used in the model including environmental exposures (inadequate nutrition, sanitation, potable water), potential acute and long term effects of these exposures (malnutrition, infectious disease, growth delay, short stature, chronic disease, and low bone mineral content), and factors which may modify the relationship between exposure and outcome (nutrition and physical activity).

Sudanese Immigrants and Refugees

Immigrants are the fastest growing population subgroup in the USA, accounting for more than 37 million people, or twelve percent of the total population. The immigrant subgroup is projected to reach over 42 million people, or 11.7 percent of the total projected population by 2025 (U.S. Census Bureau, 2010). Almost twenty percent of all children under the age of 18 residing in the USA are either first or second generation immigrants (Passel, 2011). African countries generate relatively large numbers of emigrants, accounting for more than 19.3 million emigrants, and approximately 2.3 million refugees worldwide United Nations High Commissioner for Refugees (UNHCR, 2008). A refugee is a person who is forced to leave their country of origin or habitual residence due to fear of persecution based on their race, religion, nationality, and/or political opinions. Such a person is referred to as an asylum seeker until his/her claim for refugee status has been approved (UNHRC, 2010). The United States of America is currently the largest single recipient of new asylum claims of all industrialized countries, receiving thirteen percent of all claims (UNHRC, 2010). The USA granted more than 294,000 refugees and asylums legal residence between 1990 and 2010 (Department of Homeland Security, 2010). Immigrant concepts include refugees, asylum seekers, and legal immigrants.

In 2010, Sudanese refugees living in UN registered refugee camps numbered more than 635,000, accounting for more than thirteen percent of all asylum applicants worldwide (U.S. Census Bureau, 2012; UNHRC, 2010). The 2008 census estimates that approximately 41,000 Sudanese immigrants live in the USA, with 1,400 in the state of Iowa (Iowa Department of Human Services, 2010). There has been significant growth in the Sudanese population in Iowa since the 2008 census. In Iowa City alone, Sudanese Community Services, Inc., a group that maintains records on the local Sudanese population, estimates there are more than 2,000 members from 180 families.

Sudan is one of the poorest countries in the world with a gross domestic product (GDP) per capita of USD $2,210 (WHO, 2009). Sudan has a long history of civil wars, military conflicts, political instability, and natural disasters (e.g. famine and droughts) that have caused human losses, disrupted infrastructure (including the health care system) and hampered progress in social and economic development. These human and natural disasters have created environmental challenges that include impoverished living conditions (substandard housing, poor sanitation, and unclean water), food shortages, family separations, absence of support systems, and minimal health care services (Temapny, M. 2009; Laban, Komproe, Gernaat, de Jong & Joop, 2008; Allotey, 2003). A mere 56% of the Sudanese population has sustained access to an improved water source, and 31% have no access to improved sanitation. The proportion of people below the minimal level of dietary energy consumption is 39.4%, and the Global Hunger Index in Sudan is as high as 21.5% (WHO, 2011). As a result, the total life expectancy at birth is 59 years for both men and women, and the mortality rate for children under five is 112 per 1,000 live births. In addition, many Sudanese emigrants are refugees who may spend several years in refugee camps (Willis & Ntchowka, 2006), increasing the risk of environmental or nutritional adversity.

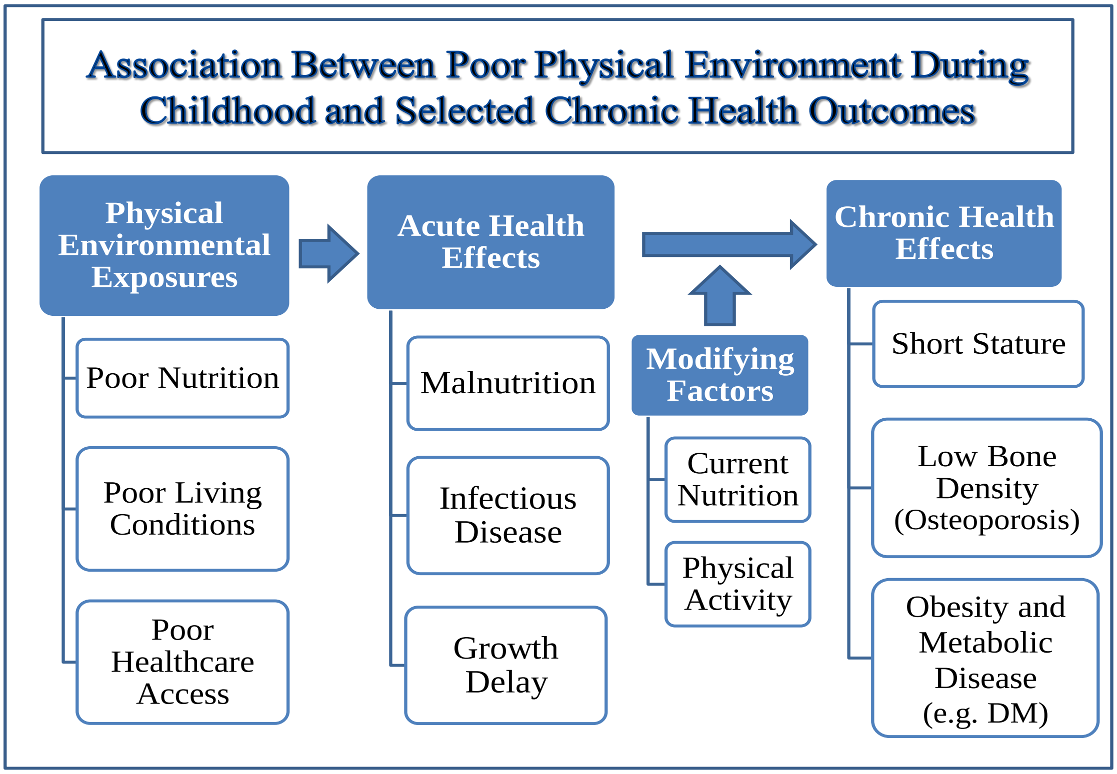
Children are perhaps most vulnerable to environmental challenges due to important developmental processes which begin prenatally and continue into early adulthood (Sun & Roche, 2003). Early childhood is a critical time in human development due to rapid physical growth (bone, muscle, and fat) and cognitive development. Additionally, major cellular structures of the brain and immune system are developing rapidly (Sun & Roche 2003). Interrupting or stunting any process at any point can have long-term repercussions.

Conceptual Framework

Conceptual Model

The conceptual model below depicts the relationship between physical environmental exposures during childhood and the potential acute and chronic health effects resulting from exposures. The major exposures of interest for this research relate to the physical environment and include inadequate nutrition, poor living conditions, and minimal access to quality health care.

Figure 2.1 Conceptual Model



The epidemiological model describes environmental factors that impact human health (Peters, Hoek, & Katsouyanni, 2011). Environmental exposure is characterized by the duration, timing, and recency of exposure. These factors may attenuate or intensify the effect of the exposure. In this study, duration of exposure is defined as the number of years spent living in Sudan and/or refugee camps. Timing refers to when the exposure occurred relative to age and key developmental events in childhood (e.g. growth spurts and puberty). Recency is the amount of time that has passed since exposure and for this study is defined as the number of years living in the United States.

Environmental exposures can contribute to acute health effects such as malnutrition, growth delay, and infectious disease. These acute effects may lead to chronic health effects such as permanent short stature, low bone mineral content, obesity, and metabolic abnormalities. While duration, timing, and recency of exposure contribute to the presence of chronic health effects, a child's post-exposure nutritional quality and physical activity can modify the effects.

Physical Environmental Exposures

Physical environmental exposures including general living conditions (general poverty related conditions such as crowding, and reduced access to clean water, sanitation, and adequate housing), inadequate nutrition, and minimal and/or low quality health care services are the focus of this research and are detailed in this section.

Overview: As noted earlier, Sudan is one of the poorest countries in the world with a gross domestic product (GDP) per capita of USD $2,210 (WHO 2009) with approximately 47% of the total population living below the poverty line (World Bank, 2012). Eighty percent of the workforce is employed in the agricultural industry, which contributes 39% of the GDP (The World Bank, 2013). Sudan has a lower than expected economic growth rate, in spite of recent increases in oil production (World Bank, 2013).

Nutritional Environment: Many factors including food scarcity, low food quality, and deficient food distribution in Sudan and refugee camps contribute to a poor nutritional environment, leading to insufficient total energy and nutrient intake (Banjong et al., 2003; Renzaho & Burns 2003; Stellinga-Boelen, Wiegersma, Bijleveld, 2007). Data from a national survey conducted in Sudan showed that nearly one-third of Sudanese people, or more than thirteen million, suffered from food deprivation, while undernourishment ranged from 31 to 34 percent. The average Sudanese person consumed 1,370 Kcal daily, while recommended daily caloric intake is 2,000-2,600 Kcal for an average adult and

1,400 to 2,300 Kcal for children, depending on age and gender (NCDS 2009, USDA 2009).

The prevalence of anemia is a significant indicator of nutritional deficiency in any population. Although iron deficiency is the commonest cause of anemia, other causes include acute and chronic infections, vitamin and mineral deficiencies (especially folate, vitamin $B_{12,}$ and vitamin A), and genetically inherited traits, such as thalassemia (WHO, 2009). In a cross-sectional study of 250 pregnant women in Sudan, the prevalence of severe anemia (HB < 7 g/dL) was 6.8%, and the prevalence of mild anemia (defined as hemoglobin (HB <11 g/dL) was 58.4% (Mohammad, Ali, Abusalama, Elbashir, Adam, 2011). In a second cross-sectional study of adolescent schoolgirls, 96.8% were anemic (Hb <12 g/dL), 66.8% had moderate anemia (Hb 8.0–10.9 g/dL), and 12.1% had severe anemia (Hb <8 g/dl) (Abdelrahim et al., 2009). One recent study in eastern Sudan found that severe malnutrition was reported in 16.3% of children admitted to one hospital between 2007 and 2009. The majority of these children were under the age of two years old (Mahgoub & Adam, 2012).

Nutritional deficiencies may be more severe for refugees. The WHO recommends all refugees receive at least 2,400 Kcal per day, however, the majority receive fewer than 1,000 Kcal per day (Mason, 2002; WHO, 2003). Zeidan and colleagues (2007) examined the prevalence and causes of visual impairment and blindness in 29,048 children less than 16 years of age in five refugee camps in Khartoum, Sudan. The WHO criteria of visual quality was used in this cross sectional study and results showed that 2.7% of children were blind, 1.6% were severely visually impaired, and 5.5% were visually impaired. The overall prevalence of blindness in children in the camps was estimated as 1.4 per 1000 children, primarily due to vitamin A deficiency (Zeidan et al., 2007). In another cross-sectional study of Sudanese refugees displaced by the civil war in Kenya, Woodruff and colleagues concluded that iron deficiency anemia and vitamin A deficiency was common among Sudanese adolescent refugees. In the study of 455 adolescents (ages 10–19 years) with an average length of stay in the camp of three years, the prevalence of iron deficiency anemia and Vitamin A deficiency was 46% and 43%, respectively (Woodruff et al., 2006).

A more detailed study conducted between March 2000 and September 2002 including 289,000 refugees living in five African refugee camps aimed to assess the effectiveness of international aid in preventing micronutrient deficiencies. The prevalence of anemia in children (defined as hemoglobin (Hb) <110 g/L) was high, with more than 60% affected in three of the five camps. Iron deficiency (defined as serum transferrin receptor more than 8.5 mg/L) was also high, ranging from 23 to 75% (Seal et al., 2005). Clearly, there is an alarming micronutrient deficiency among refugees leading to serious consequences to refugees' health. The highest rates of child malnutrition in selected refugee camps were reported among the Sudanese population (20.7%) (Seal et al., 2005). Approximately 46% of Sudanese refugee children living in Kenyan refugee camps were vitamin D deficient (seal al., 2006), while the rate of vitamin A deficiency ranged from 20.5 to 61.7% (Zeidan et al., 2007; Seal et al., 2005).

<u>Living Conditions:</u> Access to adequate sanitation and clean water in Sudan is limited. In 2009, the WHO reported that 42% of Sudanese people had no access to improved (least likely to be contaminated) drinking water (WHO, 2009). Per capita daily water consumption is less than six liters per day, far below the recommended standard of

twenty liters per day (World Bank, 2010). Water supplies are routinely polluted by flooding during the rainy season (April-November) (UN, 2011). Nearly three-quarters of Sudanese people have no access to improved sanitation (defined as sanitation which separates waste from human/animal/insect contact) (WHO, 2009).

Refugees experience similar water and sanitation inadequacies. The United Nations High Commissioner for Refugees (UNHCR) estimates that more than half of refugee camps worldwide are unable to provide recommended minimum daily water requirements, while 30% of camps do not have adequate waste disposal and sanitation facilities (UNHCR, 2009). Additionally, refugees face compounding factors of poverty, malnutrition, inadequate housing, and poor hygiene, precipitating rapid transmission of infectious diseases (Bruijn, 2009; Groenewold & Schoorl, 2006).

<u>Health Care Services:</u> The physical environment includes access to health care and the quality of health care services, which are both necessary for treatment and prevention of health problems. Health services in Sudan are generally underdeveloped, underfunded, and have deteriorated to such a degree that most are now supported by international humanitarian agencies (World Bank, 2010). The 2009 budget for the Sudanese Ministry of Health is less than 4% of the total government budget, or about USD $2.50 per capita (WHO, 2009). A 2008 WHO report stated that there were 2.8 physicians, 0.2 dentists, 8.4 nurses and midwives, and 7.3 hospital beds per 10,000 people. Health care workers and functional facilities are concentrated in the capital, Khartoum, and other more prosperous states and people in urban areas have access to more and better health care than people in rural areas (Ministry of Health, Sudan).

A 2010 UNHCR review acknowledges that there are major deficiencies in all levels of health care services in most refugee camps worldwide. Health care services are classified in four levels: community level with outreach services; health centers with basic facilities for outpatient departments, dressings, injections, and a pharmacy; a central health facility with inpatient and outpatient departments; and a referral hospital for laboratory tests, emergency obstetric care, surgery, management of complex cases, etc. In addition, there are shortages in support services such as rehabilitation, child psychology, and other specialized services (UNHCR, 2010).

The impact of clinical health services in refugee camps is largely determined by the adequacy and effectiveness of health care services. Health care services in refugee camps are both limited and of poor quality. Medical care is limited to treatment of acute conditions and disease outbreaks, while chronic conditions (e.g. diabetes and hypertension) receive no attention. Increasing numbers of refugees mean health care providers typically exceed the recommended number of visits set by the UNHCR (<50 visits/day/clinician), especially in pediatrics. Medication availability and distribution is also limited, and reports show that a 24 hour delay in the dispensation of medication can result in the deterioration of a refugee’s health and increase mortality rates. Refugees with previously undiagnosed or untreated chronic health problems, disabilities, or congenital abnormalities also put an extra burden on the health care available in a refugee camp.

In addition, refugee camp locations and conditions present significant barriers to health care. Camps are typically remote and difficult to access. Electricity is limited, making it especially difficult to provide specialized services such as ophthalmology, dentistry, gynecology, and orthopedic surgery, and as previously described, adequate sanitation and clean water are limited (Mateen et al., 2012).

In conclusion, Sudanese emigrants and refugees face many physical environment challenges in their home country and in refugee camps. Physical environment challenges include inadequate nutrition, substandard living conditions, and minimal access to quality health care services. All of these exposures can contribute to and cause acute and chronic physical health problems.

Acute Effects of Environmental Exposures

The acute effects of exposure to challenging environments have been well documented. Three major and inter-related problems are malnutrition, growth delay, and infectious (particularly diarrheal) diseases (WHO, 2005).

Malnutrition: Malnutrition is a significant public health problem in developing countries. More than half of the 10 million childhood deaths worldwide each year are attributed either directly or indirectly to malnutrition (WHO, 2011), and these children often had diarrhea (71.1%), or malaria (10.2%) (Mahgoub & Adam, 2012).

The World Health Organization (WHO) defines malnutrition as “the cellular imbalance between supply of nutrients and energy and the body's demand for them to ensure growth, maintenance, and specific functions” (WHO, 2011). Among other etiologies, malnutrition can be caused by poor nutrient and energy intake, or poor nutrient and energy absorption, which occurs with diarrheal diseases. Common and well-studied nutrient deficiency diseases found in developing countries and refugee camps include anemia (iron), pellagra (vitamin B3), scurvy (vitamin C), ariboflavinosis (B2), beriberi (B1), rickets (vitamin D), and generalized protein and energy malnutrition (Printzo, 2002; Ziedan, 2007, Seal et al., 2005). Children are at especially high risk of developing vitamins A and C deficiency (scurvy) (Ziedan et al., 2001). A study of vitamin A levels (critical for vision and immune function) among Sudanese children residing in the capital, Khartoum, showed that 2.7% of the children were blind and 5.5% were visually impaired, likely due to vitamin A deficiency (Ziedan et al., 2007). Vitamin D is essential for skeletal health, and severe deficiency is associated with defective mineralization, resulting in rickets in children and osteomyelitis in adults (Pasco et al., 2001). One study reported the prevalence of vitamin D deficiency to be as high as 80% among new immigrants and refugees to New Zealand and Australia (Grover & Morley, 2001).

Inadequate nutrition and the attendant short and long term health related consequences of malnutrition in refugee camps is a significant problem facing refugees. In a study of refugee camps, rates of vitamin A deficiency ranged from 20.5 to 61.7%, and the prevalence of blindness in children was estimated as 1.4 per 1000 (Zeidan et al., 2007; Seal et al., 2005). In a longitudinal study of five African refugee camps, the prevalence of anemia in children ranged from 12.8 to 72.9% (Seal et al., 2007). The same study also reported that the prevalence of anemia and micronutrient deficiency disease was associated with the size of the refugee camp and the quality of health care provided. Malnutrition and related diseases may continue even after resettlement. African children immigrating to Europe have a higher than expected prevalence of iron deficiency anemia, rickets, and vitamin D deficiency, and are susceptible to infectious diseases like kwashiorkor, marasmus, hepatomegaly, and diarrhea (Tiong et al., 2006, Woodruff et al., 2006; Wishart, Reeve, & Grant, 2007; Ziedan et al., 2001; Hjeron & Bouvier, 2004).

<u>Infectious Disease:</u> There is strong evidence that poor living conditions, particularly inadequate water and sanitation, play a major role in diarrheal disease and contribute to

nutrient deficiency diseases in Sudan and in refugee camps. A recent study of children from seventy low and middle income countries found that children living in a household with no toilet facility have a mortality risk 15–23% higher than children living in households with a high quality toilet infrastructure. Children in households with access to only low quality water sources have nearly 10% greater odds of diarrheal episodes than those with access to high quality water. Furthermore, children in households with access to high quality sanitation have 13% lower odds of suffering from diarrhea (Fink, Gunther & Hill, 2011).

Introducing an improved water supply or improved sanitation can reduce diarrhea morbidity risk by 25% and 32%, respectively, while a combined intervention can reduce diarrhea morbidity by 33% (Fewtrell & Claford, 2005). A meta-analysis of 46 studies conducted in different countries found that a water supply and water quality intervention was very effective in reducing the cases of illness with overall relative risk of 0.89 (95% CI 0.62-0.91), while suitable sanitation interventions were found to reduce illness with relative risk of 0.68 (CI, 0.53-0.87) (Fewtrell et al., 2005). In refugee camp settings, households consuming less than 10 to 15 liters of water per day experienced 2.5 times the rate of diarrhea than those consuming at least 30 liters of water per day (Clasen & Basteblar 2003).

<u>Growth Delay:</u> Growth delay refers to children who are small for their age and growing at a slower than normal rate. Delayed growth can lead to stunting or lower attainment of peak height if not reversed prior to the closure of the epiphyseal plates.

Environmental factors including poor nutrition and exposure to infectious disease during childhood, especially at the time of fast growth periods, have been shown to detrimentally affect a child's growth. It is well documented that malnutrition during the early years of life can inhibit physical growth. Studies have consistently found that the growth status of malnourished children is significantly below that of other healthy children matched for age and sex (Hammami, Hammad, & Koo, 2006; Geltman, Radin, Zhang, Cochran, & Meyers, 2001). Children's growth can be affected directly through multiple nutrient deficiencies (e.g., Vitamin A, Zinc), which are consistently associated with growth stunting and short stature, and indirectly with increased risk of disease (e.g., anemia), which inhibits normal child growth and development. Growth delays, growth stunting, childhood diseases, and short adulthood stature are disproportionately prevalent among emigrant and refugee children (Das Neves, Martins, Sesso, & Sawaya, 2006; Jayatissa, Bekele, Piyasena, & Mahamithawa, 2006; Sawaya et al., 2009). A longitudinal study of 28,100 Northern Sudanese children aged 6 months to 6 years found that childhood infections were significantly and inversely associated with attained height and weight and gain in height and weight. Attained height was, on average, 17 mm lower for children with diarrheal diseases, and the risk of being stunted was 1.38 times greater among children with diarrheal diseases (Tiong et al., 2006, Nestel et al., 2000).

Long-Term Effects of Challenging Environments

<u>Overview:</u> While the acute health effects of a challenging physical environment are well documented, the potential long-term effects of childhood environmental exposures have not been adequately studied. The extent and timing of exposure can lead to permanent stunting and short stature, lowered bone mineral content (increasing risk for osteoporosis), and paradoxically, to obesity and related metabolic health problems. This section presents an overview of normal physical growth and explains how disruptions

may lead to long-term health problems.

Overview of Children's Growth: Physical growth is defined as an increase in size and development (maturity), and an increase in function and ability (Karaolis, Buyken, Bolzenius, Lentze, & Kroke, 2006; Nicklas & Hayes, 2008). Human growth is not uniform, it occurs in patterns that vary in magnitude at different ages. Linear growth velocity decreases from birth onwards, interrupted by short periods of growth acceleration (growth spurts) (De Onis, 2009: Griffiths, Rousham, Norris, Pettifor, & Cameron, 2008). There are several periods in a child's life where his/her growth is faster than other times, referred to as mini-spurts. During the first two years of life, growth is characterized by a faster rate than at any other time in postnatal life (weight increases by 200% and body length increases by 55%) (Brook et al., 2000). Healthy children grow at a consistent rate from six years of age until the onset of puberty, though small growth spurts occur in stature at about age seven in males and six in females (the rate of growth in stature increased by 0.5 cm a year for males and 0.3 cm for females) (Guo et al., 1997).

Pubescence is recognized as a period of rapid increase in weight and stature for both genders, body fat for females, and muscle mass for males (Geithner et al., 1999). At puberty there is a rapid change in body size and shape, and height velocity approximately doubles for a year or more. Puberty and the pubertal growth spurt begin earlier in girls than in boys, and vary among normal individuals and between ethnic populations (Monteiro et al., 2003; Proos, 2009). On average, girls begin puberty between ages ten and eleven and usually complete puberty between ages fifteen and seventeen. The major feature of puberty for females is menarche (onset of menstruation), which occurs on average between ages twelve and thirteen. Puberty begins for boys at age eleven to twelve and is completed by age sixteen to seventeen. The main feature is the first episode of ejaculation, occurring at an average age of thirteen. In a systematic review of more than 13 studies comparing pubertal age between the 19^{th} and 21^{st} centuries, using breast maturation as the biologic landmark of pubertal maturation in girls, Biro and colleagues concluded that the average age when girls reach puberty is lower now than in the 19^{th} century, this decline might be due to genetic and environmental factors (Biro, Greenspan & Galvez, 2012) .

Variations in onset of puberty between ethnic groups exist, with African-American boys' mean age for genital development at 9.14 years, a full six months to two years earlier than previously recorded, and earlier than Hispanic (10.04 years) and white (10.14) boys (Herman-Giddens et al., 2012). The results of another study showed that 23.4% of black girls had begun puberty by age seven, as compared to white girls (10.4%) and Hispanic girls (14.9%) (Biro,Greenspan, & Galvez, 2012).

Catch-up Growth: Stunting refers to a failure to achieve one's genetic potential for height (Golden, 2009). A child is considered ‘stunted’ if his or her height is more than two standard deviations below the World Health Organization length or height-for-age standards median, or if the child falls below the fifth percentile of the reference population in height-for-age (De Onis, Blossner, & Borghi, 2011). There is a high rate of recovery (rapid growth) from stunting if treatment and appropriate nutrition are provided at the right developmental stage (Sawaya et al., 2009; Das Neves, Martins, Sesso, & Sawaya , 2006). This rapid growth phenomenon is well described in literature as catch-up growth, and refers to the acceleration of growth in both height and weight, beyond the normal rate for age (Van den Brande, J. L. 1986). When malnutrition or illness causing stunting resolve, linear growth does not just normalize but actually exceeds the normal rate for age (Gafni & Baron, 2000; Dulloo, 2009; WI & Boersma, 2002). The catch-up growth phenomenon is more common in infants and young children than in older children (Dullo, 2009). Children may show spontaneous catch up growth during recovery from illnesses such as celiac or Crohn's disease (Adair, 2008; Horta, Sibbritt, Lima, & Victora, 2009), or as a response to improved living conditions and/or nutritional intervention (das Neves, Martins, Sesso, & Sawaya 2006).

<u>Short Stature and Permanent Stunting:</u> Stunting and growth delay are significant issues affecting childhood development, and both can lead to permanent negative consequences. The main causes of stunting include intrauterine growth retardation, inadequate nutrition, and frequent infections during early life (Milman, Frongillo, de Onis, & Hwang, 2005). In a longitudinal study of 2,874 Senegalese children ages 1 to 23 years old, Coly and Colleagues concluded that children stunted at early ages remained smaller than non-stunted children; the age-adjusted height deficit between the two groups was 6.6 and 9.0 cm in girls and boys, respectively (Coly et al., 2006). At follow up, women ages 18 to 23 had a 2.4 cm height deficit, while men ages 20 to 23 had a 2.8 cm height deficit.

The consequences of permanent stunting are not completely understood. Nonetheless, there is growing evidence that stunting in early life is associated with impaired health, and reduced educational and economic performance later in life. In a longitudinal study of five low and middle-income countries, children who were small at birth and stunted in their early childhood were more likely to be of short stature as adults, to have reduced lean body mass, diminished intellectual functioning, reduced schooling, and lower earnings (Victora et al., 2007).

Stunting at an early age due to malnutrition or recurrent infection results in both permanent cognitive impairment and structural changes in the brain that are associated with poor cognitive performance, lower school achievement, and a reduction in schooling of 0.9 years (Karaolis-Danckert et al., 2008; Chang, Walker, Grantham-Mcgregor, & Powell, 2002; Martorell, 2010).

Environmental factors such as inadequate water and sanitation can also lead to stunting. In a prospective eighteen month cohort study, Merchant and Colleagues (2003) examined the relationship between household water and sanitation, the risk of stunting, and reversal of stunting among 25,483 Sudanese children. The risk of stunting was lowest among children from homes that had both running water and sanitation compared to children from homes without these facilities (RR=0.79, 95% CI 0.69-0.90). Children who were initially stunted but came from homes with improved water and sanitation had a 17% greater chance of reversing stunting than those coming from homes without either facility (adjusted RR=1.17, 95% CI 0.99-1.38) (Merchants et al., 2003).

<u>Bone Growth:</u> Bones in the human body constantly change throughout the lifespan. There are two main steps of bone growth and development; ossification (bone formation) and removal (resorption) (Floyd 2007). At birth, the skeletal structure is primarily made of cartilage. As a child grows, cartilage slowly transforms into bone in a process known as ossification, which requires minerals and salts, especially calcium compounds, to be extracted from blood and deposited into bone. Bone remodeling involves the removal of old or damaged bone by osteoclasts (bone resorption) and the subsequent replacement of new bone formed by osteoblasts (bone formation). The purpose of bone remodeling is to repair micro-damage, adapt the skeleton to mechanical loading, and maintain calcium and

phosphorus homeostasis (Pietschmann et al., 2009). In the normal adult bone, there is a balance between bone resorption and bone formation, and there are no major net changes in bone mass or mechanical strength after each remodeling cycle (Feng & McDonalds, 2010). In children, bone formation exceeds bone resorption resulting in a net accumulation of bone tissue. Long bones grow in length (elongation) and width (thickness). Elongation is a continuous process from birth through adolescence resulting from the activity of two cartilage plates, known as epiphyseal plates. These plates are located between the shaft (the diaphysis) and the heads (epiphyses) of the bones. Elongation continues until epiphyseal plates thicken, ending the bone lengthening process. Ossification is fully complete by about age 25, but different bones stop lengthening at different ages (Haywood, 2009).

Bone development is influenced by a number of factors including nutrition, genetics, exposure to sunlight, hormonal secretions (especially parathyroid, estrogen, and gonadal hormones), physical exercise, and aging. Childhood and adolescence are critical time periods for skeletal development and the attainment of bone mass (Barconcelli et al., 2005). Recent studies showed that at least 90% of peak bone mass is acquired within the second decade of life and 25% is acquired during the 2-year period surrounding peak height velocity (Whiting et al., 2004; Bailey et al., 1999; Leonard & Zemel, 2002). At age 17, boys have already attained approximately 86%, and girls have attained approximately 93% of their adult bone mass (Baroncelli & Saggese, 2000; Barr & McKay, 1998; Fewtrell et al., 2009). Genetics are the main determinant of peak bone mass, however, there are many other important environmental factors such as nutrition, gender, ethnicity, endocrine status, and physical activity, as well as exposure to risk factors such as cigarette smoking and alcohol intake (Heaney et al., 2000; Gong et al., 2006; Borges 2006; Bounds et al., 2005; Cooper et al., 2006).

Peak bone mass is considered a main determinant of the risk of osteoporosis in later life. Failure to gain adequate bone mass during skeletal growth may predispose a person to the development of osteoporosis (Borges 2006), bone fractures, and bone deformity (Baroncelli & Saggese, 2000; Fewtrell et al., 2009). In a large prospective cohort study with 6,213 children averaging 9.9 years of age who were followed for two years, fracture risk was related to volumetric bone mass density (vBMD), with one standard deviation (SD) decrease in vBMD corresponding to an 89% increased risk of fracture (Clark et al., 2006). These results were consistent with an observation study of girls over eight and a half years. Girls who experienced a fracture had decreased bone mineral mass gain in the axial and appendicular skeleton and reduced vertebral bone size upon reaching pubertal maturity, suggesting that childhood fractures may be indicative of low peak bone mass and persistent bone fragility (Ferrari, Chevalley, Bonjour, & Rizzoli, 2006; Janz et al., 2004).

Osteoporosis is a bone thinning disease that causes bones to become fragile, increasing the risk of bone fractures after even a minor event, such as a fall from standing height. In the USA, osteoporosis is a public health threat for more than 44 million Americans. Approximately one in two women and one in four men over the age of fifty will break a bone as a result of osteoporosis. According to the National Osteoporosis Foundation (2005), lack of exercise, an unhealthy weight, improper nutrition, and the use of tobacco and alcohol are health behaviors related to osteoporosis. Other factors include gender, aging, race, and genetics (NCHS, 2012).

There is some evidence that black African people and their descendants have higher bone mineral density than other races. However, there is some evidence that African refugees have lower bone mineral density (Melton et al., 2002). A study examining bone density among 47 adult Somali refugees living in Minnesota found that the Somali refugees' bone density was lower than the genetically comparative African-American control group. Somali women had greater lumbar spine ($p < 0.01$) and femoral neck bone density ($p < 0.001$) than white women, even after adjusting for bone size, but there were significant differences between Somali and African-American women (Melton et al., 2002).

Childhood and adolescence are critical times for gaining bone mineral density, and therefore decreasing the risk of fractures and osteoporosis (Janz et al., 2006). Refugee children are at higher risk of lowered peak bone mass density due to environmental and nutritional challenges.

Nutrition and Bone Health

The associations between bone mass in children and adolescents and calcium intake have been examined across different populations and most studies suggest a positive association (Wang et al., 2003; Zu et al., 2000). The effect of calcium supplementation on height, bone mineral content (BMC), and bone mass density (aBMD) gain at different locations (radius, lumbar spine, and femoral neck) was measured using DXA in 384 healthy children (149 girls and 235 boys) (mean age was 7.9 years) (Chevalley et al., 2005). The authors concluded that gains in BMC, aBMD, and bone area were greater in the group eating calcium enriched food. The effect of the supplementation was greater in the appendicular skeleton (radial and femoral sites) than in the lumbar spine, but only among the girls (Bonjour et al., 1997; Chevalley et al., 2005). Finally, in a meta-analysis of 19 randomized controlled trials including 2,859 children aged 3 to 18 years, the study concluded that there was a positive effect of calcium supplementation (dose ranging from 300 to 1,200 mg/day) on total body BMC and upper limb aBMD with an effect-size of 0.14 (Winzenberg et al., 2008).

Vitamin D has a key role in bone metabolism and bone health, and plays a primary role in facilitating calcium absorption in the intestines (Cheng et al., 2003; Jones, 2005; Lehtonen-Veromaa et al., 2002). Some epidemiological studies show relationships between vitamin D deficiency and lower bone mineral density, higher bone turnover, and higher fracture incidence than in cases of vitamin D depletion (Cheng et al., 2003; Garabedian et al., 2005). Other studies showed that vitamin D supplementation increases bone mineral density, decreases bone turnover, and decreases the incidence of fracture. The Institutes of Medicine report on dietary intake of vitamin D and calcium defined the adequate intake of vitamin D for children aged 1–18 years to be 600 IU/ day (IOM, 2011). Vitamin D deficiency (lower than 15 nmol/L or 6 ng/ml) can lead to rickets and there is increasing evidence that sub-clinical vitamin D deficiency may also affect bone mineralization and hence risk of fractures. Vitamin D levels are also affected by sunlight exposure and the endocrine activity of parathyroid hormones. Citizens of Northern European countries with less sunlight exposure (e.g., Finland and Denmark) had lower vitamin D levels as compared to citizens of other European countries with longer periods of sun exposure (e.g. France and Spain) (Andersen et al., 2005; Cheng at al., 2005). Although evidence from epidemiological and interventional studies is not entirely consistent, there is strong evidence to suggest that vitamin D supplements (5–10 μg/day) may be sufficient to maintain normal levels of vitamin D and therefore enhance total bone mass, hip BMC, and lumbar spine aBMD in pre-menarche girls (Garabedian et al., 2005). Finnish girls' BMC accrual at the lumbar spine and hip was 12–17% higher after one year of supplementation with 5 or 10 μg/day of vitamin D3 compared to a placebo group (Fuleihan et al., 2006). In a recent randomized control trial determining the effectiveness of using vitamin D supplementation to improve bone mineral density in children and adolescents (ages 8 to 17 years), 541 participants received vitamin D supplements for more than 3 months and 343 participants received a placebo (Winzenberg et al., 2010).

The authors concluded that:

> targeting children and adolescents with low serum vitamin D could result in clinically important improvements in bone density but that vitamin D supplementation in healthy children and adolescents generally to improve bone density is not justified.
>
> Winzenberg et al., Calcium Supplementation for Improving Bone Mineral Density in Children

There was a trend ($p = 0.07$) towards a positive effect reported for aBMD at the lumbar spine, which was significant for girls ($p = 0.05$), but not boys (Winzenberg et al., 2010).

Obesity and Metabolic Disease

Malnutrition and infectious disease can stunt linear height, and may restrict fat and muscle mass growth (Norman et al., 2008). Catch-up growth related to height, as described in previous sections, also affects weight, and is referred to as catch-up fat. When children who are underweight, with lower than expected fat and lean mass during infancy or early childhood, whether due to malnutrition or illness, receive a nutrient rich, normal or high energy diet, they experience a catch-up in weight. This phenomenon is described in many research articles as catch-up fat (weight). Catch up weight is characterized by rates of fat gain that outpace lean tissue gain by as much as 2:1 (Wi & Boersma, 2002: Dullo, 2008). A child who recovers to a “normal weight” for height by the mechanism of catch-up fat will have a disproportionately higher fat mass. Additionally, fat accumulation during the catch-up phase appears to have a preferential abdominal distribution and has been associated with hyperinsulinemia (Horta, Sibbritt, Lima, & Victora 2009; Adair, L. S. 2008). Catch-up fat has also been linked to the development of obesity, diabetes, and other obesity related diseases (Eriksson et al., 2000; Sawaya et al., 2009). Emigrant and refugee children from developing countries may experience catch-up fat following relocation to environments with increased food security. Evidence suggests that adults who were low birth weight or who were stunted during infancy and childhood, but who then experienced catch-up growth, had higher susceptibility for central obesity, impaired glucose tolerance, diabetes, and cardiovascular disease later in life (Colle et al., 1996; Eriksson et al., 2000).

In countries undergoing a nutrition transition, children who are stunted in early childhood may have a greater risk of obesity in later life. Studies in Brazil, China, Russia, and South Africa suggest that stunted children have a two to eight times greater risk of becoming overweight and specifically increasing central fatness (Sawaya et al., 2009). Long-term consequences of early life exposures to nutritional adversity (e.g. famine) have been associated with increased risk of both childhood and adulthood diseases such as metabolic syndrome, hypertension, type 2 diabetes, obesity, and coronary artery diseases (Li et al. 2011; Stein et al., 2006; De Rooij et al., 2006; Ravelli et al., 1999).

In a cross-sectional study of 7,874 Chinese adults who were exposed to famine during infancy participants were exposed to the Chinese famine during fetal life and 4915 (62.4%) participants were exposed during childhood and early childhood, higher rates of metabolic syndrome (OR=3.13), hyperglycemia, type 2 diabetes (OR=6.20), and higher blood pressures (OR=1.89) were found, as compared to Chinese adults who never experienced early life famine (Li et al., 2011, Li et al., 2010). In general, the earlier in life the exposure was the stronger the association. The prevalence of hyperglycemia among non-exposed adults was 2.4% as compared to 5.7%, 3.9%, and 5.9% for people exposed in utero, in early childhood, and in late-childhood respectively (Li et al., 2010). Similarly, the prevalence of metabolic syndrome among those who were never exposed was 5.7%, while the prevalence among exposed groups was 7.7%, 8.4%, 7.6%, and 8.9% for in utero, early childhood, middle childhood, and late childhood respectively (Li et al., 2011).

In a Dutch famine study, the researcher concluded that prenatal exposure to famine was associated with higher BMI, higher waist circumference, lower glucose tolerance, higher risk of coronary artery disease, and higher lipid profile (Stein et al., 2006; Portrait et al., 2011). Exposure to maternal famine for at least ten weeks during gestation was associated with higher blood pressure in adulthood (OR=1.44) (Stein et al., 2006), and there was a significant association between exposure to under-nutrition during adolescence, and the presence of coronary disease and type 2 diabetes at ages 60–76 years (Portrait et al., 2011).

Data from the Maternal and Child Undernutrition Study Group indicates that lower birth weight and undernutrition in childhood are risk factors for high glucose concentrations, high blood pressure, and harmful lipid profiles in adulthood after adjusting for adult height and BMI (Victora et al., 2008). This observation was well documented in children who were born at a low birth weight or who were thin in early life and experienced catch-up growth later in their childhood. In a follow up study, Eriksson and Colleagues examined the relationship between catch-up height and death from coronary artery disease (CAD) in 3,641 men who were born between 1942-1943 and had at least ten measurements of height and weight during childhood. Results showed that death from CAD was associated with low birth weight.

The exact mechanism of catch-up growth is still unknown, but catch-up growth could be associated with adverse outcomes later in life. Adverse outcomes may be related to the disproportionately high fat mass associated with catch-up fat, or possibly to changes in hormones such as insulin and growth hormone during catch-up growth (Gunnel, et al., 1998; Eriksson et al., 1999).

The health implications of childhood obesity are becoming more evident as prevalence increases. Obese children show higher rates of hyperinsulinemia, increased adiposity, dyslipidemia, and insulin resistance (Weiss & Caprio, 2005). Freedman et al., 2005 reported that 70% of obese youth had at least one risk factor for cardiovascular disease (Freedman et al., 2005). A randomized clinical trial of a school-based intervention for youth at risk for type 2 diabetes, included 173 overweight and obese children (BMI ≥ 85th percentile) (46% male and 54% female; 49% Hispanic and 51% African-American) found that higher BMI was related to higher insulin resistance. All obese and overweight children demonstrated insulin resistance with elevated HOMA values (8.5–5.2), and pre-diabetes (glucose 100 –125 mg/dL) was present in 15% of the children (Holl et al., 2011).

In summary, catch-up fat could increase the risk of developing obesity and obesity related diseases, such as metabolic syndrome, in refugee children.

Modifying Factors

The overall goal of this dissertation research is to broadly identify how challenging environmental exposures impact physical growth, bone mineral content, and selected markers of metabolic health. However, there are two major current lifestyle factors, including physical activity and nutrition that could modify the relationship between previous physical environmental exposures and the outcome of interest and must be considered.

Physical Activity

Physical activity is associated with positive health outcomes such as decreased risk of obesity, lower incidence of cardiovascular disease, higher peak bone mass and higher muscle mass. The term physical activity refers to “any bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure” (Bouchard, Blair, & Haskell, 2007). Within this broad definition, all levels of physical activity intensity were included; vigorous, moderate and sedentary. Intensity, or magnitude, can be expressed in absolute or relative terms. On an absolute scale of 0–10, vigorous activities for children will be 7 or 8 (e.g. running, jumping rope, aerobic exercise, etc.) while moderate intensity will be 5 or 6 (e.g. walking, briskly walking, riding bike, etc). In relative terms, vigorous activities are those performed typically at ≥ 7.0 times the intensity of rest, and moderate activities are performed 3.0–5.9 times the intensity of rest (WHO, 2010; CDC, 2008).

Pooled data from the International Children's Accelerometer Database (comprising fourteen studies, including 20,871 children) showed that total physical activity was significantly and inversely associated with waist circumference, fasting insulin, and triglyceride levels after adjustment for age, sex, monitor wear time, and time spent being sedentary (Ridgeway, Brage, Anderssen, Sardinha, Andersen, & Ekelund, 2012). In an eight week exercise intervention program of 14 obese children (8 boys and 6 girls) with high fasting insulin levels, Bell and Colleagues (2007) demonstrated that a physical activity intervention program , comprising one hour sessions three times per week significantly improved subjects' insulin sensitivity (Mlbm 8.20 ± 3.44 to 10.03 ± 4.33 ml/kg/min, $P < 0.05$) (Bell et al., 2007). In a randomized control study of 67 obese children, the intervention group (6 months of one hour sessions three times per week) showed a significant decrease in systolic mean BP, decreased carotid artery thickness (a risk factor for atherosclerosis), decreased cardiovascular risk factors (LDL, HDL, fasting blood sugar, and CRP levels), and an increase in physical fitness as compared to the control group (Pedrosa, et al., 2011; Reinehr, de Sousa, Toschke, Andler, 2006; Resaland, Anderssen, Holme, Mamen, Andersen, 2010).

An abundance of evidence demonstrates that physical activity is associated with lower metabolic risk. In a systematic review, Janssen and Leblanc, 2010 reported that studies using a direct measure of physical activity (such as accelerometers) to examine the effects of physical activity on metabolic syndrome component risk reported (OR=6.79) (95% CI 5.11-9.03) in the least fit group compared to the most fit group (Janssen et al., 2010). Aerobic exercise was found to be significantly more effective than resistance training in improving metabolic syndrome components, particularly insulin resistance (Janssen & LeBlanc, 2010).

The findings of a relationship between physical activity and metabolic syndrome components have been more consistent when accelerometers were used to estimate physical activity. Barge and Colleagues, 2004, and Rizzo et al, 2007, examined the relationship between metabolic syndrome and physical activity levels (as measured by accelerometer) in 389 Danish and 517 Swedish children. Results showed a negative association between physical activity levels and metabolic syndrome (Barge et al., 2004; Rizzo et al., 2008). Other studies suggest that about 90 min/day of moderate to vigorous physical activity (MVPA) was effective in reducing the risk of metabolic syndrome, indicating a clear dose-response relationship (Anderson et al., 2008; Rizzo et al., 2008).

Normal-weight youth who have relatively high levels of physical activity tend to have less adiposity than youth with low activity levels. Among overweight and obese youth, interventions that increase the level of physical activity tend to show beneficial effects on health. Results of five randomized clinical trials showed that physical activity had positive results in decreasing adiposity as compared to controls. In one of these studies, Kriemler and Colleagues examined the effect of school-based interventions in reducing adiposity levels in 28 classes from 15 elementary schools during one school year. Intervention included three physical activity and two additional lessons (total five classes a week), daily short activity breaks, and physical activity homework. Results showed that children in the intervention group showed more negative changes in the Z score of the sum of four skinfolds (-0.12, 95 % CI -0.21 to -0.03; P = 0.009) as compared with controls. In addition, aerobic fitness increased in the intervention group (0.17, 0.01 to 0.32; P = 0.04) (Kriemler et al., 2008).

Weight-bearing physical activity increases bone mineral content and bone density. Studies have shown that even ten minutes of moderate to high impact activities performed two or three days per week, when combined with more general weight bearing aerobic activities (e.g., jogging, play, etc.) can have a modest effect on bone mineral density. Additionally, this combination is beneficial for cardiovascular risk factors and obesity prevention. One physical activity intervention, "Bounce at the Bell", was introduced to an elementary school classroom and consisted of bouncing for three minutes a day. After eight months, it was found that this inexpensive, short intervention successfully changed bone mass. Children in the intervention group gained significantly more BMC at the total proximal femur (2%) and the intertrochanteric region (27%) (McKay et al., 2005). Earlier weight-bearing intervention studies reported that early-pubertal girls gained 1.5–3.1% more BMC at the femoral neck and lumbar spine, whereas boys gained 1% at the femoral neck and 1.6% at the total body (when compared with controls) (MacKelvie et al., 2004; Cardadeiro, Baptista, Janz, Rodrigues, Sardinha, 2013).

Lack of physical activity (sedentary behavior) has been linked with an increased risk of obesity in children and adolescents. In a representative sample of 7,216 children ages 7 to 11 years, TV watching and video game use were risk factors for being overweight (17–44% increased risk) or obese (10–61%) (Tremblay & Williams 2003). Sedentary behaviors (watching TV, playing video games, and using computers and the internet) are also associated with poor nutrition habits such as decreased fruit and vegetable consumption, and greater consumption of high-fat, high-sugar snack foods, fast foods, and soft drinks, increasing the incidence of overweight and obesity (Manios et al., 2009). There are positive linear relationships between the time children spend in sedentary activities and their weight status. Canadian children who spent more than two hours of screen time per day were twice as likely to be overweight or obese as compared to children with one hour or less per day (Vandewater et al., 2004; Shields, 2005). In addition, time spent in sedentary activities was significantly and positively associated with metabolic syndrome markers and fasting insulin levels (Ekelund et al., 2012; Francis, Stancel, Sernulka-George, Broffitt, Levy, Janz, 2011).

In conclusion, physical activity (vigorous or moderate) and the time spent performing these activities play a critical role in the development of obesity and acquisition of peak bone mass. In order to completely appreciate the role of environment in growth it is important to consider the confounding or modifying effects of these factors.

Nutrition

Nutrition is an important factor in human health. In previous sections, potential long term health consequences of inadequate nutrition were described. One aspect of the resettlement/immigration process for refugees and emigrants that may have a major effect on health outcomes is a change in the nutritional environment. Transition to an improved nutritional environment can lead to an improvement in nutritional status, but this is not always the case. The increased availability and quality of food may improve physical growth, but it may also increase the risk of obesity. In the United States, current nutritional concerns are overconsumption of calories, added sugars, and saturated fats, and underconsumption of whole grains, fruits, and vegetables. This type of diet can contribute to obesity.

Despite relocation to an improved environment, food security may continue to be an issue for new emigrants and refugees. Food insecurity refers to lack of access to enough food for an active and healthy life for all household members because of financial constraints (Nord, Andrews, & Carlson. 2006). According to Anderson (1990), household food insecurity is defined as:

> whenever the availability of nutritionally adequate and safe foods or the ability to acquire acceptable foods in socially acceptable ways is limited or uncertain (p. 4).

Anderson, Does Interview Mode Matter for Food Security Measurement

In households experiencing food insecurity, some or all household members do not have access to enough food, and they may have reduced food intake, consume poor-quality food, or have disrupted eating patterns. Child hunger may occur, characterized by decreases in the quantity of food eaten by children (Sellen et al., 2002, Hadley & Sellen, 2006).

Refugees and emigrants are expected to have a particularly high prevalence of food insecurity due to the social and economic challenges associated with resettlement. One study found that 85% of households of recent refugees and emigrants from Africa were food insecure and 42% experienced child hunger (Hadley & Sellen, 2006). A similar study of Sudanese refugees living in Georgia (USA) were found to have high levels of food insecurity (73%) and childhood hunger (12%). Chilton and colleagues (2009) concluded that emigrant households were at higher risk of food insecurity than USA born households. Newly arrived emigrants had the highest risk of food insecurity (OR=2.45). Moreover, household food insecurity increased the risk of poor child health (OR=1.74) (Chilton et al., 2009). Sellen and Colleagues examined food security and child hunger in thirty emigrant and refugee families resettled in the UK. Results showed that all households were food-insecure, and 60% of children were experiencing hunger. In addition, child hunger and food insecurity were significantly associated with recent arrival (less than two years) (Sellen at al., 2002).

Food insecurity has paradoxically been found to increase the incidence of obesity in children, but research on the relationship between food insecurity and childhood obesity has inconsistent results. Some studies have found a positive relationship (Dubois et al., 2006; Casey et al., 2001, 2006; Jyoti et al., 2005), while others have found a negative or no relationship (Alaimo et al., 2001b; Kaiser et al., 2002; Martin and Ferris, 2007; Gundersen et al., 2008; Rose and Bodor, 2006). One study found that depending on the obesity measure, 12–57% of food-insecure children were obese (Grundeson at al., 2009). Possible reasons why food-insecure children are obese may include overconsumption of cheap, energy-dense foods, overeating at times when food is more plentiful, metabolic changes ensuring more efficient energy use, different standards of what constitutes an adequate diet, and parents giving children more food than needed when food is available (Alaimo et al., 2001b; Martin & Ferris, 2007; Gundersen et al., 2008;).

In conclusion, published literature shows that both physical activity and nutrition affect the association between environmental exposures and physical growth, BMC, obesity, and metabolic health. Evidence related to the unique experience of this study population is limited. Further study is necessary to minimize negative health consequences in this population.

CHAPTER 3

METHODOLOGY

Overview

This study was part of a pilot study conducted to identify obesity phenotypes among Sudanese emigrants and refugee families in the Iowa City, Iowa city metropolitan area. The primary study, which was funded by the Institute for Clinical and Translational Studies (ICTS) at the University of Iowa, was a cross-sectional study of 31 Sudanese families residing in Iowa City, Iowa. Professor Kathleen Clark (College of Nursing) was the Primary Investigator (PI) of the study. The study population included 58 adults and 64 children ages six years and older. The purpose of the study was to identify a unique obesity phenotype that represents a ‘catch-up’ fat phenomenon, to acquire preliminary data related to familial and environmental etiologies of this phenotype, and to identify health consequences related to this phenotype. Participants' bone mineral content (BMC) and body composition were measured, blood was collected to measure metabolic and cardiovascular risk indicators, and interviews were conducted addressing relocation, medical, and lifestyle factors that may influence the catch-up fat phenotype.

The intent of this dissertation research is to identify the relationship between early childhood exposures to the challenging environment in Sudan, neighboring countries, and/or refugee camps on physical growth, areal bone mass mineral density at the hip and spine, bone mineral content (BMC), body composition, and metabolic risk factors. This study included 64 Sudanese children ages six to eighteen years who participated in the primary study. All children had blood drawn to test fasting blood sugar, insulin, total cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL), and triglycerides. Physical measurements included height, weight, BMC, aBMD, fat mass, and lean mass. Information about puberty, physical activity, diet quality, high calcium and vitamin D food frequency was collected from the children using semi-structured interviews and self-reported instruments. Information about environmental exposures was collected through interviews with the children and their parents or guardians. Environmental exposures included duration of time living in Sudan, neighboring countries, refugee camps, and the USA, and family food insecurity. All children were asked to wear a pedometer for seven days to measure the general pattern of their physical activity, the total distance walked per day, and total steps per day.

Study Sample

In the primary study, Sudanese families residing in the Iowa City area with children above the age of six comprised the target population. According to the Sudanese Society, this community consists of more than 200 families and approximately 200–250 children. Most families originated in Northern Sudan and speak Arabic as a first language. Approximately 2/3 of the families are refugees or asylees and the other 1/3 are emigrants. The research team developed a strong and mutually respectful relationship with key community members including the Sudanese Society past-President, the religious leader, the Secretary of Public Relations, community organizers and advocates, and women's activists. The Sudanese Society maintains a directory of all community members, which served as a sampling frame for the primary study, and families with children over the age of six were identified from these records with the help of community leaders. Families were initially contacted by the key informant, who asked permission for the researcher to contact them for potential participation in the study. In addition, the Sudanese Society's Social Activity Organizer received approval from the Sudanese Board to send an informational e-mail to all community members explaining the purpose of the study, the inclusion criteria, the study procedure, and the contact information of the research team.

All children between the ages of six and eighteen who are members of the community and participated in the primary study (n= 64) were included in the present study. Children under six years old were excluded due to lack of references for body composition as well as children with known health problems associated with impaired physical growth (e.g. cerebral palsy, Down's syndrome, and Turner syndrome).

Instruments

The following section describes the instruments used for data collection in the primary study.

Growth

Growth is primarily assessed by height and weight. The most common growth indicators are height for age as a reflection of cumulative linear growth, weight for age to reflect the body mass and to monitor body mass growth, and weight for height to assess nutritional status and obesity (De Onis, 2009; O'Donnell, van Doorslaer, Wagstaff, & & Lindelow 2008). An individual child's growth can be represented as age and gender specific percentile scores or Z scores. In this dissertation study, growth measures were quantified by Z scores obtained by plotting height and weight, relative to age, on WHO Growth Standards Charts. These charts were developed using data from children ages 5–19 from multiple countries, and are used internationally to assess growth delays and malnutrition (De Onis, 2007; De Onis, Onyango, Borghi, Garza, & Yang, 2006). Weight was measured by electronic weight scale (Tanitia Corp) with minimal clothing and without shoes to the closest 0.1 pound. Accuracy of the scale was monitored daily with 50 pound calibration weights. Height was measured to the closest 0.1 inch using a wall mounted stadiometer.

Bone Mineral Content and Body Composition

Body composition (lean mass, fat mass, and bone mass) was measured using dual energy X-ray absorptiometry (DXA; GE Lunar Prodigy, Madison, WI, US). DXA exposes the region of interest to a low-intensity energy source, emitted from an X-ray tube. Any residual energy that passes through the body is detected by a sodium iodide scintillation counter. The energy intensity detected by the scintillation counter reflects the amount of energy attenuated by tissues of different density, enabling these scans to discriminate bone mass, fat mass and non-bone lean mass, giving a cross-sectional density profile of each subject. Subjects lie flat on the scan table and are positioned visually (using a computer monitor) for the lumbar spine, femoral neck, and total body scans (Williams, Wells, Wilson, Haroun, Lucas, & Fewtrell, 2006).

DXA measures bone mineral content and bone area. Areal Bone mineral density (aaBMD) (gm/cm^2) of a given region can be calculated by dividing the BMC (gm) by the bone area. Bone mineral content (BMC) with the head and areal bone mineral density aBMD at the hip (femoral neck), anterior-posterior lumbar spine, and total body, were measured. BMC for the total body and areal bone mineral density for the spine and left femoral neck were used as the summary measure. Fat and lean mass were measured in conjunction with the total body scan. Quality Assurance tests were run daily, and weekly calibrations were made using simulated bone phantom.

The DXA machine is housed in the research suite at the College of Nursing. All scans were performed by a trained researcher and all the cut-points were made by one researcher. The typical scan time was approximately ten minutes. The radiation exposure per whole-body scan is estimated to be 2 µSv, and for the three measurements together, it is estimated to be 5–10 µSv (Blake, Naeem, & Boutrus, 2006). The radiation exposure from the bone density scans is about the same amount of radiation that an individual would receive from 3 days of natural background radiation.

The DXA has high precision and accuracy in children (Ellis, Shypailo, Wong, & Abrams 2000; Ellis, Shypailo, Pratt, & Pond 1993). Precision is a measure of reproducibility and is expressed in terms of coefficient of variation (%CV). Accuracy refers to how closely a measured value approximates the actual value as determined by criterion techniques. The DXA has excellent reproducibility in the whole body with precision errors (1 SD) of 1.4–2% for fat mass (FM) and 1.1–1.5% for lean mass (LM) (Marqualis, Horlick, Thornton, Wang, Ioannidou, & Heymsfield, 2005). One study evaluated the reproducibility of whole body DXA scans in 49 children ages 5 to 17 years using Lunar Prodigy. Results showed that body composition and bone mass by DXA are highly reproducible among pediatric subjects; the Interclass (IC) agreement values were ≥ 0.989 for total body, ≥ 0.976 for legs and arms, and ≥ 0.875 for trunk and spine. CV values ranged from 0.18 to 1.97% for total body, and 0.96 to 6.91% for regional measures (Marqualis and colleagues, 2005). Recently, the validity of using DXA to monitor changes in both lean and fat mass was validated against MRI scans in a sample of 22 healthy children (16 boys and 6 girls) ages ranging from 8 to 11 years. Measures were repeated 24–36 months after the first measurement and results showed that DXA overestimated lean mass on average by 222 grams, and the concordance coefficient was 0.576. There were no significant differences in fat mass measurements between the two methods (the concordance coefficient was 0.907). At follow–up, the change in lean and fat mass from DXA were not significantly different from those changes measured by MRI (The coefficient of concordance between the two techniques was 0.88) (Bridge et al., 2011). DXA also provides both accurate and precise bone mineral measurements when tested against the criterion technique. In testing BMC, the criterion technique is the laboratory assessment of ashed bones, and DXA measurements of BMC are within 7–9% of ashed bone measurements (HO, Kim, Schaffler, & Sartoris, 1990). Ho and Colleagues examined the accuracy of DXA to measure bone mineral content and area density of lumbar vertebrae (L2-L3) in eleven cadavers using ashed bone. Results suggested an excellent correlation between bone mineral content measured with DXA and ash weight ($r = 0.963$, $P < 0.0001$) and a strong correlation between bone mineral density measured by DXA and ash density ($r = 0.881$, $P < 0.0001$) (Ho et al., 1991).

In this dissertation, bone mineral content with the head and areal bone mass density Z scores were quantified using the Baylor College of Medicine Body Composition Laboratory at the Children's Nutrition Research Center (CNRC) in Houston, Texas. Z-scores were calculated using their software, which is based on age and sex. This software can be used with both Lunar and Hologic DXA instruments. Bone mineral content Z scores are only available for the total body with the head included. Bone mineral density Z scores are available for the lumbar spine from ages 4 to 22 years, the femoral neck area from ages 5 to 19 years, and the whole body from ages 4 to 22 years. (http://www.bcm.edu/bodycomplab/mainbodycomp).

Metabolic Risk

Metabolic risk measures included fasting blood glucose (FBG), total cholesterol (TC), low density lipoprotein (LDL), high density lipoprotein (HDL), triglycerides, insulin, Homeostasis Model of Assessment Insulin Resistance (HOMA-IR) and C-reactive protein (CRP).

Total cholesterol (TC), low density lipoprotein (LDL), high density lipoprotein (HDL), and triglycerides were measured using the Cholestech LDX analyzer (Biosite, Inc., San Diego, California). The Cholestech LDX analyzer requires a single drop of blood, obtained by finger stick (capillary) or blood extraction (venous). The Cholestech LDX system uses reflectance photometry (the amount of light reflected from a solid surface) to measure the amount of substances in blood. The analyzer measures color changes of four reagent pads, then the analyzer converts the amount of color measured to a concentration which is then displayed on a liquid crystal display (LCD) screen.

The Cholestech LDX analyzer has been certified by the Cholesterol Reference Method Laboratory Network (CRMLN), which validates that the system meets the criterion standard for accuracy and reproducibility developed by the Centers for Disease Control and Prevention (CDC) (CRMLN Certification of POCT Lipid Methods, 2006). Results of a comparison study showed finger stick LDX profile values to be highly correlated ($r > 0.95$) with those from serum venous samples in 95 subjects. In children, the Cholestech LDX analyzer has shown consistent results when compared with other methods in different ethnic/ racial groups and in different clinical and research settings. Three of these markers (high triglyceride level, low HDL cholesterol level, and high fasting glucose) were used by the WHO to detect metabolic syndrome (WHO, 2005).

The Cholestech LDX optical system was calibrated each visit day using the Cholestech LDX Optics check cassettes. The result of each test was within the normal range limit (80–100) as described in the manual, and a special log for this test was kept for quality purposes. External quality control was performed on a weekly basis and documented as described in the manual. All blood samples were drawn by the researcher at the beginning of the appointment, and subjects were asked to fast for at least eight hours prior to the blood draw.

Insulin, FBS, HOMA-IR and CRP levels were measured from the obtained blood. Samples were centrifuged at 3,000 RPM for 10 minutes, and a total of 2mLs of serum was allocated and stored at –80° Centigrade until the end of the study. All blood specimens were transported to the pathology lab at The University of Iowa Hospitals and Clinics on dry ice for glucose and insulin analysis. Insulin values were obtained using the Chemiluminescent Immunoassay method, and glucose levels were assayed using the Hexokinase/UV method. Normal total insulin ranged from 2.6 - 24.9 µ/mL (fasting), and normal glucose levels ranged from 65–99 mg/dL.

Serum hs-CRP concentrations were determined in duplicate, using a high-sensitivity sandwich enzyme immunoassay (EIA; ALPCO Diagnostics, Windham, NH, USA). Normal values for adults ranged from 0.3-8.2 mg/L, with a sensitivity of approximately 0.05 mg/L. The average intra and inter-assay coefficient of variation were 6.0 and 11.6 %, respectively.

Interviews

A structured interview was completed with all participants. A physical activity questionnaire and Puberty Development Scale were self-reported, and when necessary, a parent either assisted the child or acted as a surrogate respondent. Information regarding environmental exposure data, time spent in Sudan, neighboring countries, or in refugee camps, age at each point, age and date at time of relocation to the USA and to Iowa City, and a brief medical history ascertaining current health problems of the child were obtained from one parent or guardian. Other information was collected through the standardized instruments described below. The entire interview took approximately 25 minutes. Most children spoke English, however the interview schedule was available in Arabic and English (Appendix A).

Puberty

Because puberty plays a major role in the timing of BMC accrual, pubertal stage must be considered. This was assessed using the Puberty Development Scale (PDS). The PDS is a self-report instrument which takes about 5 minutes to complete, and is designed to be used by adolescents to report development on five indices of puberty including growth, body hair, and skin changes (especially acne). Males are asked about vocal changes and growth of facial hair, while females are asked about breast development and age at onset of menstruation. Response options are: (1) not yet started, (2) barely started, (3) definitely started, (4) seems complete (Bond et al., 2005). In a longitudinal study of 335 young adolescent boys and girls, the PDS administered twice a year over three years, the PDS showed a good reliability ranged from 0.68 to 0.83 (Petersen, Crockett, Richards, & Boxer, 1988). The PDS correlations of puberty assessment with reports of both physicians and mothers of adolescent girls was 0.61 and 0.67 respectively (Brooks-Gun, Warren, Rosso, & Gargiulo, 1987; Carskadon & Acebo, 1993). Due to the personal nature of this assessment, it was self-administered by the child (and parent if needed) in a private room.

Physical Activity

Physical activity was evaluated using two methods; self-report questionnaires and a direct measure using pedometers (Omron HJ-720 IT). The Self-report Physical Activity Questionnaire for Adolescents and Children (PAQ_A and C) is designed to measure the frequency, intensity, and duration of physical activity of a child over the previous seven days. Activities include organized sports and recreational physical activity, as well as sedentary behaviors such as watching television, listening to music, using the computer, reading, talking on the phone, and visiting with friends. This tool was developed and validated by Kowalski and Colleagues to assess the general level of physical activity in children, and attempts to identify moderate to vigorous physical activity (MVPA) occurring during the last seven days (Kowalski, Crocker, & Faulkner, 2007; Kowalski, Crocker, & Kowalski, 1997).The PAQ has good internal consistency, and reliability (Kowalski, Crocker, & Faulkner, 1997; Kowalski, Crocker, & Kowalski, 1997). In a recent study of a group of Midwestern children, the validity correlation coefficients between the revised PAQ and the activity monitor were moderate (rho = 0.56 and 0.63). The Cronbach coefficient alpha measuring the internal consistency of the PAQ ranged from 0.72 to 0.88, and the test-retest reliabilities were 0.77 (Janz, Letuchy, Wenthe, & Levy, 2007). The majority of the children completed the questionnaire independently, and whenever assistance was required, one of the research team was available to answer questions.

Activity was measured directly using the Omron HJ-720 IT pedometer. A pedometer is an electronic motion sensor that uses dual-axis accelerometer technology to record the acceleration and deceleration of movement while walking or running in one direction. There are two different categories of pedometers; spring-levered and piezoelectric. Traditional spring-levered pedometers rely on a horizontal spring-suspended pendulum arm that moves up and down with each step, opening and closing an electrical circuit, whereas the piezoelectric pedometer measures acceleration at frequent time intervals, and the number of peaks or zero crossings is used to count steps. Both types of pedometers are typically worn on the waist at the midline of the thigh. However, some pedometers now have the ability to be worn in the pocket (chest pocket of a shirt or front pocket of pants), placed in a bag, hung around the neck, around the ankle, or wrist, or even attached to a shoe.

The pedometer used in this study was the Omron HJ-720 ITC, a dual axis electronic pedometer that can be worn in a pocket, around the neck, or on a belt loop. It uses two accelerometers mounted at 90° to each other, so the orientation of the pedometer within the pocket does not matter (i.e., it can be rotated 360°) as long as the front side of the pedometer is within 30° of vertical.

The Omron HJ-720 ITC uses the acceleration versus time curve to determine step counts. The Omron HJ-720 ITC allows user characteristics (age, height, weight, and gender) to be entered, and the output includes steps, aerobic steps (accumulated in continuous bouts of 10 minutes or longer), minutes for aerobic steps, amount of calories burned, and distance. This pedometer can store data in one hour epochs for a 7-day recall on the pedometer display and has a 41-day storable memory.

The software accompanying the pedometer allows researchers to assess pedometer 'wear time'. Any hour during which steps are taken is marked, and the total number of marks equals daily wear time. All data for a single user is combined in a single account, which can be viewed in any number of ways; by hour of the day, by day of the month, or by month of the year (McNamara, Hudson, & Taylor, 2010; Tudor-Locke, Sisson, Lee, Craig, Plotnikoff, & Bauman 2006).

The Omron HJ720 ITC pedometer is reported to be extremely accurate during laboratory and track walking at moderate and brisk speeds (Holbrook, Barreiram, & Kang 2009). Like the Yamax SW-200 and NL-2000, it fails to detect all steps taken at slow walking speeds. The Omron HJ720 ITC also has a four second delay, meaning that it only records steps taken in walking bouts of four seconds or longer (Silcott, Bassett, Thompson, Fitzhugh, & Steeves 2011). If a person walks for three seconds and stops, these steps are 'lost' and will not be recorded. Therefore, the Omron is likely to record fewer steps during activities of daily living than other pedometers. Nevertheless, the Omron is highly accurate for detecting steps taken during continuous walking bouts (Hasson, Haller, Pober, Staudenmayer, & Freedson, 2009; Holbrock, Barreiram & Kang 2009), regardless of body mass index, so it is well suited to walking interventions in overweight/obese individuals.

The reliability and validity of electronic pedometers in providing evidence for quantification of distance, assessment of total daily activities, and estimation of activity intensity and duration in the population of children ages 10 to 12 years old using triaxialometry and observation methods was reported as (tritrac $r=0.66$, pedometer $r=0.59$, $p<0.01$). In terms of convergent validity of pedometers, the correlation between pedometers and accelerometers ranged from (0.47 to 0.99), depending on environment and activity type. Stronger correlations ($r=0.98$) existed in results of combined measures.

The correlation between pedometers and heart rate monitors ranged from (r=0.49 to 0.83), depending on environment and activity type. Correlations were much stronger during unregulated activities (r=0.88) (Rowlands, Eston, & Ingledew, 1999; Schneider, Crouter, Lukajic, Bassett, 2004). Reliability of pedometers was tested by variability, right versus left placement, and variations between different pedometers. Reliability measures ranged from (ICC=0.51 to 0.92), and inter-pedometer measures ranged from (0.73 to 0.80) (Tudor-Locke et al., 2006).

Questionnaires

Food Security Questionnaire

Food insecurity was assessed because it can influence growth, and emigrants may be nutritionally insecure after resettlement. The full range of food insecurity cannot be captured by any single measure. Instead, a household's level of food insecurity should be determined by obtaining information on a variety of specific conditions, experiences, and behaviors that serve as indicators of food insecurity status. The Household Food Security Survey Module was used to measure household food insecurity. This instrument was originally developed by the USDA and has received international validation. The sensitivity and specificity of the full questionnaire were 0.89 and 0.93, respectively (Derrickson, Fisher, & Anderson, 2000; Connell, Nord, Lofton, & Yadrick 2004). Initially, we attempted to administer the full instrument (9 questions), however, feedback from families and key informants led us to focus on the least sensitive or offensive questions. We chose two questions relating to income and the affordability of food, and although food security is scored from zero to nine (lower scores representing food insecurity), each question was answered on a 3–point response scale: always, sometimes, and never (Cornell, 2004). In this study, these two questions will be used as a surrogate for household food insecurity. The first question, "In the last 12 months were there times when the food that you bought just didn't last and you didn't have money to get more?" which will serve as an indicator of food security status in the entire household. It indicates the ability to maintain a continuous source of food over the last twelve months. The second question "In the last 12 months did (you/or anyone in your household) ever cut the size of your meals or skip meals because there wasn't enough money for food?" which will be used as an indicator of the severity of food insecurity in the household over the last twelve months. It indicates the reduction in meal size and frequency as a response to food insecurity. The two questions were answered by each parent and/or guardian.

Diet Quality Questionnaire

Diet quality was assessed using a short screening instrument (9 questions). This tool was included to assess general consumption of categories of food that may be healthy or unhealthy and to determine the consumption frequency of fruit, vegetables, meat, sugar, beverages, and fast food meals (Di Noia & Contento, 2009; Hudson, Forman, Cantwell, Schatzkin, Albert, & Lanza 2006, Buzzard et al., 2001). The reliability of this instrument ranged from 0.62 to 0.83 (Thompson, Midthune, Subar, Kipnis, Kahle, & Schatzkin et al., 2007).

Questions were modified to reflect dietary and cultural customs of the study population (questions about eating pork were eliminated as they could be deemed offensive). In addition, food choices that were found to be common among the study population were added after consulting with the key informants; these food choices include lamb, okra, lubini beans, and tea with milk. Because children are less able to recall, estimate, and cooperate in usual dietary assessment procedures, information for children under seven years old was obtained from parents.

High Calcium Diet Questionnaire

Questions related to high calcium and high vitamin D intake were initially assessed using a modified version of the Food Frequency Questionnaire. During the study, children had difficulty recalling food items listed in the questionnaire, therefore a shorter version, consisting of fifteen items, was introduced. The short form was adapted from Molgaard and Colleagues (1997) and has a low burden on children. It takes about five minutes to complete and showed high reliability, validity, and reproducibility. The Pearson correlation of scores one week apart in a group of 41 children between the ages of nine and seventeen was reported as 0.76 (Yang, Berdine, & Boushey, 2010). The validity of the questionnaire was examined by weight and diet records in 23 children. Correlations between nutrient intake values of weighed food and estimates from the questionnaire showed Spearman Rank correlations of 0.60. Children were classified in the same quartile in the questionnaire and in the record 43% of the time while 1% was classified in the opposite quartile (Molgaard, Sanstrom, & Michaelsen, 1997). Interviewers were trained to ask indirect instead of direct questions when children had difficulty answering certain items (e.g. what did you have for breakfast today? vs. how often do you have milk for breakfast?).

Ideally, a comprehensive dietary assessment conducted by trained nutritionists using multiple 24 hour dietary recall periods would be completed. This measurement is expensive, complex, and beyond the scope of the pilot study and this dissertation research.

Food Frequency Questionnaire

Food frequency questionnaires (FFQ) are designed to assess habitual diet by asking the frequency with which food items or specific food groups are consumed over a reference period of time (e.g. one month or one year). Food frequency questionnaires can be used to provide both qualitative (portion size) and quantitative (e.g. ½ cup) descriptive information about food consumption patterns, and can also be used to investigate the link between certain diets and diseases (e.g. cancer). Food frequency questionnaires are designed to assess the ranking of intake within a population. They are an unreliable estimate of absolute intake and underestimation is common. Evidence shows that underestimation is likely to increase with the length of the food list (Cade, Thompson, Burley & Warm, 2002). As there are no universal dietary habits or patterns, there is also no universal FFQ. Ethnic, social, religious, geographical, and other differences prevent the standardization of a food list or the measurement of any population as compared to another. Additionally, cultural sensitivities preclude the use of a single FFQ, as certain foods or dietary habits may be considered offensive to certain populations. Measuring dietary intake in children and adolescents is challenging as children may have difficulty recalling quantities and describing the food they eat. The concept of time and estimation of mean frequency of food intake can also be problematic for children.

Clearly there is no ideal method to collect dietary information for children, nonetheless we used a short version of a FFQ. Short FFQs allow researchers to collect data more frequently, with less expense and processing time, and they lower the burden for participants as compared to more extensive dietary assessment methods. In addition, this assessment method may be of use as relational data, and could potentially be used in large studies.

Procedure

All data for the primary study were collected in the College of Nursing Research Suite. All families were contacted a day before the scheduled visit to remind them of the appointment and to inform them of what to expect from the visit. Families were reminded to fast for at least eight hours before the appointment time, and directions to the College of Nursing were provided. On the visit day, research team members greeted families at the College of Nursing entrance and guided them to a meeting room where the research team explained the research purpose and procedure (blood extraction, DXA, interviews, etc.) in both Arabic and English. The total time commitment for the entire family was approximately three hours. Participants over age thirteen were given written consent forms, and children younger than thirteen were given assent forms. Parents of children under eighteen provided parental consent. Consent documents were presented in both Arabic and English.

After signing consent or assent forms, children were accompanied to a different room to draw blood, and parents were given the option to attend. Local anesthesia cream was offered to all children and whenever requested, it was applied on the site before blood extraction. Blood draw attempts were limited to two, and if both attempts failed, capillary blood was obtained via finger stick method and used for the Cholestech Analyzer. A total of 10 mL of intravenous blood was drawn from the arm. One blood drop was removed from the blood tube for the Cholestech Analyzer cassette.

After the blood draw, children were guided back to the meeting room and provided with breakfast. Next, the comprehensive interview was conducted by one member of the research team with the child and his/her parents or guardians, as needed. The interview included the physical activity questionnaire, the high calcium food frequency questionnaire, and the diet quality questionnaire (see Appendix C). Following the interview, children ages eight to eighteen were directed to a private room to complete the Puberty Development Scale (PDS). Due to the sensitive nature of the PDS, maximal privacy was provided, and whenever possible, a same gender member of the research team was available to answer questions.

Following completion of the interview, children were guided to another room for height and weight measurement, followed by DXA scanning. All female subjects who were physically able to become pregnant provided a urine sample for a pregnancy test, which was conducted by a female Research Assistant (RA). Subjects were offered sweat pants to wear if there were any metal objects in their clothing. Subjects were asked to lay flat on the DXA table, and not to move during the exam. Younger children had the opportunity to observe if an older sibling was undergoing a DXA scan.

After the DXA scan, each child was presented with a pedometer and asked to wear it on their waist ten hours a day for seven days. Children were instructed to take off the pedometer only when they went to bed at night, or when they swam, showered, or bathed. Each pedometer was calibrated for weight, time, and strides. Stride length was measured by having each child walk ten steps with his/her normal stride, measuring the distance from start to end in inches, and then dividing the total distance by ten.

Blood specimens were allowed to clot for twenty to sixty minutes at 22–25° Centigrade. After the blood clotted, samples were centrifuged for thirty minutes to obtain serum. Blood tubes were then placed on a tube holder for fifteen minutes at room temperature, and then transferred into cryovials labeled with the subject ID, and stored at –80° C until analyzed.

In the primary study, each family was compensated $150 for their time, and at the end of seven days, one of the research team contacted the family to collect the pedometers and present the family with a $25 gift card from a local store.

Analytical Approach

Data Management

All physical measurements, interviews and questionnaires were entered using REDCAP software. Data were double entered by trained research assistants. All forms were reviewed for data logic, legibility, completeness, and any obvious errors. Data from each child's pedometer was transferred to Omron Bi Link Professional software version 1.0.0 and saved by subject ID. All paper forms were filed by participant ID number and stored in a locked file cabinet in the nursing research suite. Computerized data is accessible only through use of a password. Access to data is limited to the researcher team members only. Data analysis was completed using the SAS statistical package software.

Data Analysis

General Approach

Descriptive statistics were obtained for all variables using means, medians, and standard deviations for continuous variables, and frequencies and proportions for categorical variables. Variables were examined for accuracy and possible data acquisition error. All continuous variables were evaluated for normality with non-normally distributed variables transformed or categorized. Because the participants included siblings, the data did not meet the assumption of independence and therefore, mixed linear modeling or general estimating equation (GEE) was employed as the major analytic strategy to examine multivariate relationships between environmental exposure and health outcome.

Specific Analytic Plan

Analysis for each specific aim is detailed below.

<u>Aim1:</u> To describe the physical growth status and selected metabolic risk factors of Sudanese children living in Iowa City.

The growth variables of interest include weight, height, body mass index percentiles, weight for age, height for age, bone mineral content (BMC), fat mass, lean mass, bone mineral density at the neck of the femur, and lumbar spine bone mineral density. Additional measures of fatness include fat mass index (FMI) $\left(\frac{\text{fat mass(g)}}{ht\ (cm)^2}\right)$, lean mass index (LMI) $\left(\frac{\text{lean mass(g)}}{ht\ (cm)^2}\right)$ and body fat percent (BF%). The metabolic profile includes fasting blood glucose (FBG), insulin, high density lipoprotein (HDL), low density lipoprotein (LDL), total cholesterol, triglycerides, CRP levels, and HOMA-IR, calculated by $\left(\frac{\text{fasting Glucose(mg/dL) x fasting Insulin(μU/mL)}}{405}\right)$.

Growth status was also characterized by Z scores for weight for age and height for age calculated using WHO AnthroPlus software (2007) for children ages five to nineteen. Bone mineral content (BMC), and bone mineral density (aBMD) of the left femur and lumbar spine were characterized by Z scores calculated using Baylor College of Medicine Body Composition Lab software (www.bcm.edu/bodycomplab).

All variables were described using means and standard deviations for normally distributed variables and medians, ranges, proportions for non-normally distributed variables. Descriptive analyses were completed for children by age groups and gender when appropriate. We used the paired *t* test to examine the difference between the means for normally distributed variables, and the *Wilcoxon* test to examine differences between the medians for non-normally distributed variables. The Fisher exact test was used to examine the significance of the associations between the categorical variables.

Aim 2: To determine the association between environmental exposures, as defined by the duration and timing of residence in Sudan and neighboring countries, and children's a) physical growth b) bone mineral content and bone density at the hip and spine c) body composition (fat and lean mass) d) metabolic risk factors. Five hypotheses will be tested.

i) *Hypothesis 1*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI percentile, and LMI, and higher FMI Z scores.

ii) *Hypothesis 2*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for total body BMC and aBMD at the hip and spine.

iii) *Hypothesis 3*: Longer residence in Sudan or in neighboring developing countries will be associated with poorer metabolic risk indicators.

iv) *Hypothesis 4*: Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and BMC of the femoral neck and spine.

v) *Hypothesis 5*: Age at arrival to the USA will be positively associated with FMI and metabolic risks.

The independent variables are the duration (the total number of years) of time spent in Sudan and/or refugee camps and timing (age at arrival to the USA). The major dependent variables include 1) physical growth measured by Z scores 2) aBMD and BMC Z scores 3) Body composition (FMI and LMI Z scores) and 4) Metabolic risk factors as described in Aim 1. Generalized Estimation Equation (GEE) models were used to examine the association between dependent and independent variables. Initially, bivariate associations between each outcome of interest and each of the independent variables and covariates were examined, and then the variable 'gender' and the interaction between gender and environment were added to each model. Significance level was 0.05 for all models.

Aim 3: To determine if the relationship between environmental exposures, as defined by the duration and timing of residence in Sudan and neighboring countries, and children's a) physical growth b) bone mineral content and bone density at the hip and spine c) body composition (fat and lean mass) d) metabolic risk factors, are modified by the number of years spent in the USA, current physical activity, and current nutritional status. Five hypotheses were tested.

i.) *Hypothesis 1*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI, and LMI, and higher FMI Z scores, independent of number of years spent in the USA, current physical activity, and nutritional status.

ii.) *Hypothesis 2*: Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for total body bone mineral content and aBMD at the hip and spine, independent of number of years spent in the USA, current physical activity, and nutritional status.

iii.) *Hypothesis 3*: Longer residence in Sudan or in neighboring developing countries will be associated with poorer metabolic risk indicators, independent of years spent in the USA, current physical activity, and nutritional status.

iv.) *Hypothesis 4*: Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and aBMD of the femoral neck and spine, independent of number of years spent in the USA, current physical activity, and nutritional status.

v.) *Hypothesis 5*: Age at arrival to the USA will be positively associated with FMI and metabolic risks, independent of number of years spent in the USA, current physical activity, and nutritional status.

The third aim examined whether the association between environmental exposures, as defined by the duration and timing of residence in Sudan and neighboring countries, and the Z scores of physical growth, bone growth, BMC, and metabolic risk factors were modified by the number of years spent in the United States, current physical activity, and nutritional status as measured by food quality and food security. Six modifying variables were identified for each outcome variable. Current physical activity included three variables; average steps per day (derived from pedometers data), average activity in the last seven days, and average inactivity for the last seven days (calculated from the self-report physical activity questionnaires). Food security and food quality data each have one variable for food security. If the answer for the two food security questions were positive, the family was identified as food insecure, while if the answer for these two questions were negative, the family was identified as food secure. If a child reported in the diet quality questionnaire that they usually or often ate fruits or vegetables for a snack, we used the variable 'healthy snack' in the model. Time spent in the USA was calculated using the current age of children (time of interview minus age at arrival to the USA).

A backward approach was used for the fittest model selection; the P value was set at 0.2, and all modifying variables were entered into the model, then the variable with the highest P value was removed from the model, and the model was run again with the remaining variables, continuing to remove one variable at a time. This procedure continued until no variables remain or all remaining P values for the variables were less than 0.2.

The linearity of the relationship with the outcome variable was tested for each modifying variable using Cubic and Quadratic fitting modeling; whenever the Cubic and Quadratic models were significant, they were added to the model, otherwise they were removed. Next, time spent in Sudan or neighboring countries, and the age at arrival to the USA (for hypotheses 4 and 5) entered the model. FMI (as a measure of adiposity) was controlled for when associations between bone growth and metabolic factors were examined due to the fact that fat mass has a storing effect on bone growth and the development of future diseases.

Sample Size

A fixed sample size of 64 children and three major independent or covariates included in the final models can detect an effect size of 0.18 (moderate) with a power of 0.8 and a significance of 0.05. Using four independent variables with the same sample size (64 children), can detect an effect size of 0.2 with a power of 0.8 and significance level of 0.05. Using five independent variables and the same sample size (64 children), can detect an effect size of 0.22 with a power of 0.8 and significance level of 0.05 (Statistics Calculators http://www.danielsoper.com/statcalc).

CHAPTER 4

RESULTS

This chapter presents the study findings organized by sample characteristics and the specific aims and their related hypotheses.

Sample Characteristics

A total of 64 children, 31 boys (48.4%) and 33 girls (51.6%), between the ages of 5 and 18 years of age completed the study. Blood samples were collected from fifty-nine children, while five children (7.8%) refused to have blood drawn. A total body DXA scan was completed on sixty-three children, while one child had to be excluded due to an inability to lie still for the entire scan period.

The mean age for all children was 10.1 ± 3.3 years. The mean age for boys was 9.94 ± 3.24 years, while the mean age for girls was 10.21 ± 3.38 years. The majority of the children (n=45, 70.31%) were in elementary school; eight children, (12.5%) were in junior high school, and eleven (17.19%) were in high school. Most of the families (n=21, 63.6%) reported annual income less than USD $19,000, and one family earned more than USD $150,000. More than half of the children (n=33, 51.6%) were born in the USA, 14 children (21.9%) were born in Sudan, and the remaining children were born in different countries such as Saudi Arabia (n=9, 14%), Egypt (n=3, 4.7%), and several others. The non-USA born children were further categorized by age at arrival to the USA. Forty-two percent reported arrival in the USA between one and five years of age, while 45.2% reported arrival to the USA between the ages of five and ten years. Table 4.1 further summarizes socioeconomic and demographic data for all study participants, further categorized by gender.

Aim 1

The first aim is to describe the physical growth, bone growth, body composition, and metabolic risk factors of Sudanese children living in Iowa City.

Physical Growth, Bone, and Body Composition

Physical growth, bone, and body composition characteristics of the Sudanese children are presented in Table 4.2. The mean height and weight for all children was 142.8 cm ± 18.6 cm and 39.3kg ± 18.3kg, respectively. Girls had a higher mean weight and lower mean height than boys. The mean BMI percentile for all children was 53.1 ± 33.15. Boys had higher mean BMI percentiles ($\bar{x}$=54.5 ± 30.02) than girls ($\bar{x}$=51.76 ± 36.18), however, this difference was not statistically significant (p=0.69).

Body fat percent (BF%) was calculated for all children and classified by gender. The mean BF% for all children was 26.03 ± 11.3 and the median was 23.3. Girls had a significantly higher BF% median and a wider range than boys (girls' Median 27.16, Range 38.34; boys' Median 19.54, Range 36.46). There was a significant difference between the two medians (0.0086). The mean fat mass was 11.4 ± 10.2 kg, while the mean lean mass was 27.9 ± 9.6 kg. When fat mass was classified by gender, there was a significant mean difference between boys ($\bar{x}$ =8.69 ± 6.72) and girls ($\bar{x}$=13.89 ± 12.1) (t *(61)* = 2.13, p = 0.04). In addition, fat mass range almost doubled in girls compared to boys (girls=49.9 kg, boys=25.7 kg). The mean Fat Mass Index (FMI) for all children was 5.13 ± 3.6. The mean FMI for girls (6.19 ± 4.15) was significantly greater than the mean of 3.96 ± 2.32 observed for boys (p = <0.01). The mean lean mass was slightly higher in boys than in girls (29.5 kg vs. 26.4 kg) and the mean lean mass index was higher in boys than girls but was not statistically significant ($\bar{x}$= 13.56 ± 1.77vs $\bar{x}$= 12.8 ± 1.43).

The mean total BMC (including the head) for all children was 1471.5 gm ± 718.4, while the mean BMC without the head was 1134.32 gm ± 659.58. There were no significant differences in mean BMC between boys and girls. Mean aBMD at the hip and spine were 0.83 ± 0.165 and 0.8 g/cm^2 ± 0.216, respectively. The girls' mean spinal aBMD was higher than the boys but there was no statistical significant difference between boys' and girls' means. Table 4.2 summarizes physical growth data of all subjects classified by gender.

Growth and Body Composition Statistics

In order to describe these physical, bone and body composition measures relative to other children, percentiles or z scores were calculated using normative data and software from the CDC, WHO, and the Baylor College of Medicine. These are presented in Table 4.3. The median height for age Z score was 0.35 (range -2.69 – 2.72) and the median weight for age Z score was 0.28 (range -2.45 – 2.16). Across gender, boys' height for age Z score medians were higher and had wider ranges than girls (0.59 vs. 0.34), while girls had higher median weight for age Z scores than boys (0.36 vs. 0.20). These differences were not statistically significant. A weight for age Z score was available only for children who were less than 10 years old at the time of data collection (WHO, 2005).

Overall, the median of BMC Z scores was (- 0.71 range = 5.14), the aBMD Z score median and range at spine and hip were (Median = -0.53, Range = 5.71) and (Median = -0.13, range = 5.12) respectively. Across gender, the median BMC Z, hip aBMD Z, and spine aBMD Z scores were lower in boys than in girls, however, there were no statistical differences observed between the genders. The overall lean mass index Z score (LMIZ) mean was 0.49 ± 0.75 and the fat mass index Z score (FMIZ) mean was -

0.57 ± 1.51. Both measures were higher in girls than boys; FMIZ was (-0.358 vs. -0.790) and LMIZ was (-0.51 vs. -0.37), there were no statistical differences in the means between the genders, Table 4.3 summarizes these findings.

Metabolic Risk Factors

Metabolic risk factors were examined in 59 children. Mean fasting blood glucose was within normal limits for all children ($\bar{x}$= 81.2 mg/dL ± 6.7) with all fasting blood glucose levels less than 100 mg/dL. There were no significant differences in mean FBS between boys ($\bar{x}$=81.17 ± 7.36) and girls ($\bar{x}$=81.21 ± 6.04), (t (57) = 0.02 p=0.98). HOMA-IR was calculated in 57 children. The overall median was 1.02 and the range was 5.07 (boys' Median 0.83, Range 2.19; girls' Median 1.08, Range 5.1). When classified by gender, the HOMA-IR range in Sudanese girls was twice as high as the range in boys (5.4 vs. 2.5), however, there were no statistically significant difference between the medians across the genders.

The mean total cholesterol for children was within normal limits ($\bar{x}$= 152.8 ± 29.3). The median total cholesterol for girls was 17.5 points higher than the median for boys (Median= 156.5, Range= 118) and (Median=139.0, Range 124). It is also noted that while mean triglycerides were within normal limits ($\bar{x}$= 68.7 ± 27.3 mg/dL, Median 62), when classified by gender, the boys' median was higher than the girls' (boys' Median=79.5, Range 103; girls' Median= 71, Range 71). There was no statistical significant difference between the genders.

The C Reactive Protein (CRP) mean was 2.3 mg/dL ± 4.3 with a wide range from 0.1 mg/dL to 18.7 mg/dL. The distribution of CRP is highly skewed with more than 50% of the subjects' CRP levels ≤ 0.51 mg/dL. Across gender, girls mean and median CRP levels were higher than boys (girls' $\bar{x}$= 2.54±4.48, Median= 0.56; boys' $\bar{x}$= 1.98± 4.06, Median=0.45), however there were no statically significant differences between the means (t (55) = 0.43, p=0.67) or the medians (P = 0.21).

Hazard Groups

Hazard groups were created for each of the physical growth, bone growth, and metabolic risk factors in order to better appreciate potential health risks. The hazard groups were based on WHO, CDC, and American Academy of Pediatrician classifications and aimed to identify children below expected growth patterns relative to age, or those having above normal metabolic risk factors. These hazard groups were summarized in Tables 4.4 and 4.5.

BMI percentile was classified according to WHO and CDC standards into four groups; underweight (BMI Percentile < 5), normal (85 < BMI percentile > 5th), overweight (BMI percentile >85), and obese (BMI Percentile >95). Seven children (10.9%) were classified as underweight. More than a quarter of the children (n=17, 26.5%) were identified as overweight or obese by BMI percentile, girls more often than boys (n= 10, 30% vs. n=7, 23%).

In agreement with other studies, BF% was categorized according to gender; boys < 25%, boys > 25%, girls < 32%, girls > 32% (Kwon, Janz, Burn, & Levy, 2011). Following this categorization, 35.5% of the girls and 27.3% of the boys were identified as having higher body fat (Table 4.25). More than half (53.3%) of the girls born outside the USA had BF% > 32%, compared to only 12.5% among girls born in the USA. More than one-third of the boys (35.3%) born in the USA had BF% >25% compared to only 18.8% for the boys born outside the USA. There were no differences in BF% between girls or boys born inside or outside the USA.

Height for age and weight for age were classified using WHO standards. Children were considered severely stunted for height if their height for age was more than 2 standard deviations below the mean, and moderately stunted if their height for age was one or more standard deviations below the mean. Three children (4.7%) (2 girls and 1 boy) were severely stunted with a height for age more than 2 standard deviations below the mean, and 6 other children (9.4%) were moderately stunted (4 girls and 2 boys) (Table 4.7)

Weight for age was only calculated for children who were less than 10 years of age at the time of data collection, and in this study, that included 32 children (15 boys and 17 girls). Weight for age is used as an indicator of nutrition status. Children are considered nutritionally stunted if their weight for age is two or more standard deviations below the mean, and moderately stunted if their weight for age is one standard deviation below the mean. Over one-third of children (n=11, 34.5%, 7 girls, 4 boys) under the age of ten were either stunted or moderately stunted. Importantly, 29.4 % of the girls under the age of ten were stunted for their weight (Table 4.7).

Lipid profile high risk groups were categorized using guidelines from an expert panel for Cardiovascular Health and Risk Reduction in Children and Adolescents (2011). According to this guideline, the following cut-off points were considered acceptable: total cholesterol less than 170 mg/ dL, LDL less than 110 mg/dL, triglycerides less than 90 mg/dL, and HDL more than 45mg/dL. In this study, we combined the borderline group with the high risk group in order to identify children who fell outside normal limits and may be at higher risk of developing metabolic disease in the future.

Nearly one-fourth (n=15, 23.4%) of the children had either borderline or high cholesterol levels, 9.38 % (n= 6) had high LDL levels, 32.8% (n=21) had high triglyceride levels, and 19% (n=12) had low HDL levels. Twice as many girls as boys had high cholesterol and triglycerides (n=10, 30.3%), (n=15, 45.5%) vs. (n=5, 16.1%) and (n=6, 19.4%) respectively. Using the Fisher exact test, gender differences were significant only for triglycerides. Girls were twice as likely to be in the triglycerides high risk group as boys (OR 2.035, CI95%; 0.99, 4.2) (Table 4.10).

Fasting Blood Glucose groups were also classified using the same guidelines mentioned previously, and >100 mg/dL was considered high. HOMA-IR was calculated using the HOMA calculator from the Diabetic Trial Unit, University of Oxford. A HOMA-IR level of (1.8) is considered the most acceptable cut off point by many epidemiological studies, (Kurtoğlu et al., 2010; Madeira et al., 2008) and was therefore used for this study. The majority of subjects (87.3%) had normal fasting blood glucose levels, none were high (≥ 100mg/dL), and 8 children (12.7%) showed low fasting blood glucose (< 69 mg/dl). HOMA-IR indicated that 15.63% (n=10) of the children have a higher sensitivity to insulin, most of them were girls (n=7). However, the Fisher exact test showed that there was no significant association between gender and either high fasting blood glucose or HOMA-IR (p=0.71, p=0.198 respectively). CRP levels were measured in 57 children. Ten children (15.6%) had high CRP levels including six girls (20.7%), and four boys (14.3 %).

The body composition and bone growth measures (FMI, LMI, BMC, aBMD at hip and spine) were grouped by Z scores into five categories (Group 1 < -2sd; -2sd < Group 2 < -1sd; -1sd < Group 3 < +1sd; +1sd < Group 4 < +2sd; Group 5 > +2sd). The purpose of this categorization was to describe potential risks by better understanding the distribution of each growth measure in relation to the expected normal distribution. Table 4.6 summarizes these measures for all children, classified by gender.

The distribution of LMIZ and FMIZ did not follow the expected normal distribution (Table 4.7). Only 36% (n= 23) of all children had FMIZ scores that fell ±1 sd of the mean. Most of the others (n= 34, 53.1%) had FMIZ scores that were more than 1 SD below the mean, and 11% (n= 7) had FMIZ scores more than 1sd above the mean. This distribution pattern was similar for both boys and girls. Overall, 53.1% (n= 34) of the children had LMIZ scores that fell +1 sd of the mean. All of the remaining children (n= 30) had LMIZ scores that were more than 1 sd below the mean. While the proportion of girls whose LMIZ scores were more than 1 SD below the mean was double that of the boys (n=8, 24.24% vs. n=4; 12.90%), a greater proportion of boys (n=10, 32%) were more than 2 sd below the mean as compared to girls (n=8, 24%).

One bone growth measure (aBMD at the hip) showed a pattern close to a normal distribution curve, with 65% of children falling between -1 and +1 standard deviation, 14% had hip aBMD that was more than 1 SD below the mean, and 20% had values more than 1 SD above the mean. Only 58% of the Sudanese children had spine aBMD values within 1 SD of the mean. While 33% of the spine aBMD values were more than 1 sd below the mean, only 10% were more than +1 sd above the mean. Similarly, 62% of the subjects had total body BMCZ scores (minus head) that were within 1 sd of the mean while 38% of the BMCZ values were more than 1sd below the mean. The Fisher exact test showed no statistically significant association between gender and any of the measures.

USA Born and non-USA Born Children

Subjects were categorized by birth country into two groups; those born inside the USA, and those born outside the USA to determine if differences in physical growth bone and body composition existed between these groups. Over half (n=33, 51.6%) of the children were born in the USA, while the other children (48.4%) were born outside the USA in a variety of countries across Africa and the Middle East. Tables 4.8 and Table 4.9 summarize differences between these two groups with Table 4.8 further categorized by gender. Children born in the USA had higher frequencies of stunting in height (n=8, 24%) and weight (n=9, 37.5%) compared to those born outside the USA (n=1, 3.12%) and (n=2, 25%) respectively. Children born outside the USA had higher percentages of obesity and overweight as measured by BMI percentiles (n=10, 32.26%) than those born in the USA (n=7, 21.21%). Children born in the USA generally had lower Z scores in all bone and body composition measures. Most notably, children born in the USA had significantly lower (Median= -0.03) hip aBMDZ and BMCZ (Median= -1.0) scores compared to those born outside the USA (Median= 0.22 and Median= -0.29) respectively. The median LMIZ scores were 0.7 SD lower for those born in the USA although this difference was not significant.

Aim 2

The goal of this aim is to determine the association between environmental exposures (defined by the duration and timing of residence in Sudan and neighboring countries), and children's a) physical growth, b) total bone mineral content and aBMD at the hip and spine, c) body composition (fat and lean mass), d) metabolic risk factors. Five hypotheses were tested and results are presented for each hypothesis.

Hypothesis 1

Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI, and LMI, and higher FMIZ scores.

To test this hypothesis, bivariate associations between the duration of residence in Sudan and Z scores for all physical growth and body composition variables were modeled separately. Because, descriptively, gender differences in growth and body composition existed, models were adjusted for gender and potential interaction between gender and the duration of residence in Sudan or neighboring countries. Longer residence in Sudan was associated with lower weight for age Z scores (p= 0.07) and lower LMIZ scores (p= 0.06). No other associations between growth and body composition variables and the duration of residence in Sudan approached significance even after adjusting for gender and the gender and duration of residence interaction (Table 4.10).

Hypothesis 2

Longer residence in Sudan or neighboring developing countries will be associated with lower Z scores for total body bone mineral content and aBMD at the hip and spine.

No significant associations were observed between duration of residence in Sudan/ neighboring countries and aBMD (at the hip and spine) or total body BMC including the head. No modification existed by gender or the interaction between gender and the number of years spent in Sudan/ neighboring countries (Table 4.11).

Hypothesis 3

Longer residence in Sudan or in neighboring developing countries will be associated with poorer metabolic risk indicators.

Seven metabolic risk factors were individually examined for their associations with the duration of residence in Sudan or neighboring countries. These included fasting blood glucose, HOMA-IR, triglyceride levels, total cholesterol, LDL, HDL and CRP levels. Children who lived more years in Sudan or in neighboring countries prior to immigrating to the USA had higher LDL levels (β= 2.997, SE 0.86, p= 0.0005), and Higher HOMA-IR levels (β= 0.03, SE 0.02, p= 0.08). Gender impacted the relationship between several other metabolic risk factors. When gender was added to the models, triglyceride and CRP levels were positively associated with the number of years spent in Sudan or neighboring countries (β= 11.9, SE 5.41, p=0.027) and (β=0.5, SE 0.23, p=0.03) respectively. When the interaction between gender and time spent in Sudan or neighboring countries was added to the models, results showed that triglyceride levels were positively associated with the number of years spent in Sudan or neighboring countries (β= 2.92, p=0.01) (Table 4.12)

<u>Hypothesis 4</u>

Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and BMC of the femoral neck and spine, and positively associated with FMIZ.

Contrary to our hypothesis, children who were older when they entered the USA had higher height for age Z scores (β= 0.06, SE 0.03, p=0.05). Age at arrival to the USA was inversely associated with weight for age Z scores, but only after adjusting for gender (β=-0.42, p=0.01). This indicates that female children who entered the USA at an older age had lower weight for age Z scores than boys. There were no significant associations found between bone growth measure Z scores and age at arrival to the USA (Table 4.13).

Hypothesis 5

Age at arrival to the USA will be positively associated with FMI and metabolic risks.

Age at arrival to the USA was not associated with FMIZ scores (β = 0.0045, p=0.95). Although there were no significant bivariate associations between the metabolic risk factors (fasting blood glucose, HOMA-IR, LDL, HDL, triglycerides, total cholesterol and CRP levels) and age at arrival to the USA, when adjusted for gender, girls who were older when they entered the USA had higher HOMA-IR, triglyceride, and CRP levels (β= 0.29, SE 0.15, p=0.005), (β= 0.14, SE 0.07, p= 0.05) and (β=0.5, SE 0.25, p=0.05), respectively (Table 4.14). When adjusting for the interaction between gender and age at arrival to the USA, there was interaction between females and the age at arrival to the USA (β=2.08, SE 1.12, p=0.05).

Aim 3

Aim 3 examined whether the association between environmental exposure (as defined by the duration and timing of residence in Sudan or neighboring countries) and the outcome of interest (physical growth measures, bone mineral content, bone density at both the hip and spine, body composition measures, and metabolic risk factors) was modified by the number of years spent in the USA, current physical activity level, and/or nutritional status (measured by food quality, calcium intake, and food security). Results for Aim 3 are presented in order according to the related hypotheses. Because potentially important confounding or modifying variables have not yet been described (food security, nutritional status, and physical activity), descriptive data will also be presented in order to clarify results.

Food Security, Nutrition and Physical Activity

Food Security

Food security information was obtained from parents by asking two questions about the food security status in the household. The first question was used to indicate whether the household was food secure or not (In the last 12 months were there times when the food that you bought just didn't last and you didn't have money to get more?). The second question was used to measure the severity of food insecurity (In the last 12 months did (you/or anyone in your household) ever cut the size of your meals or skip meals because there wasn't enough money for food?).

Almost forty percent of the families (N=25) reported some food insecurity. One-fourth of the families (n=16, 25%) reported that food sometimes did not last until the end of the month, while nine families (14.1%) reported that food often did not last until the end of the month. Twenty families (31%) reported that they either sometimes (n=17, 26.6 %) or often (n=3, 4.7%) had to cut the size of or skip meals due to food shortage. One-fifth of the families who answered yes to the first question (N=5, 20%) reported that they had to cut the size of or skip meals due to food shortages. Food security data are summarized in Table 4.15.

Nutrition

Most of the Sudanese children (n=45, 71.43%) ate at least three meals per day, while 17.5% (n=11) ate two meals per day. All children reported having at least one dessert per day and 18 (32.5%) reported eating more than two desserts per day. All children (n=62, 100%) ate at least one snack per day, while nearly three-fourths (n=46, 71.9%) reported having more than one snack per day, and nearly half (n=28, 45.2%)

reported eating two snacks per day. Children reported eating a variety of foods for snacks, but reported eating the following often: fruit (33.3%), chips (23.8%), sweets (19.05%), and candy (17.5%). Of the foods eaten often for snacks, vegetables were the least frequent (9.3%) (Table 4.16).

Almost 40% of children reported eating at fast food restaurants at least once a week (n= 25, 39%), with 10 (16%) eating fast food more than once per week. Children reported eating fast food because of nice drive-thrus (98.4%), good service (88.9%), and cheap (88.9%) and tasty food (85.7%).

Physical Activity

Physical activity was measured directly using Omron pedometers and indirectly using self-reported physical activity questionnaires. The pedometers were worn by 59 of the 64 subjects (92.2%) for a total sum of 398 days, but only 54 (84.4%) of the children wore the pedometer long enough to have their data included in the study. Nearly one-fourth of the total pedometer days (n=99, 24.9%) were excluded due to inadequate use, either because children wore the pedometers for less than 8 hours per day, totaled less than 2,500 steps per day, or wore the pedometer for less than three days. The daily hour and step minimum requirement was the recommendation of a major population study (Tudor-lock et al., 2011), and the three day minimum was instituted to increase sample representativeness.

The average pedometer wear time for all subjects was 5.8 days (minimum 3 days, maximum 9 days), and steps averaged 7,300 per day ($\bar{x}$= 7359 ± 24060), significantly less than the recommended 12,000 for boys, 10,000 for girls, and 10,000 for all adolescents. Only two boys (4.3 %) and none of the girls met the moderate to vigorous physical activity criteria for children (more than 13,000 steps per day) as recommended for (Tudor-Lock et al., 2011).

The average steps per day among children under 12 was ($\bar{x}$= 7170 sd = 2,597), and only 3 (6.4%) of the children (two boys (4.3%) and one girl (2.1%)) were identified as active (>12,000 steps per day for boys, >10,000 steps per day for girls), while 93.6% of children under 12 were identified as inactive (<12,000 steps per day for boys, <10,000 steps per day for girls) (Table 4.17).

Among the 17 adolescents (9 boys and 8 girls) aged 12 and over, steps per day averaged nearly 7,900 ($\bar{x}$ = 7899.7 ± 1715), but none of the boys and only two of the girls (11.8%) were identified as active (> 9,000 steps per day). Among adolescents (both boys and girls), 10,000 to 11,700 steps per day is associated with 60 minutes of MVPA per day. None of the male and only one of the female adolescents (5.9%) met this criterion. Gender differences among adolescents were significant, and it was noted that females took significantly more steps. Five of the adolescent females fell above the 3rd quartile (9,749 steps per day), and 4 of these girls fell above the 90^{th} percentile (11,121 steps per day), while 4 boys scored higher than the gender classified 90^{th} percentile (8,882 steps per day). In regards to the other variables from pedometer data, there were no significant differences between genders except for the average aerobic steps per day, which was significantly higher for boys ($\bar{x}$ =1315.0 ± 2850) than for girls ($\bar{x}$ =169.4 ± 523.4, p = 0.04) (Table 4.17).

Sudanese children were questioned about types of activities, frequency of activities, and intensity of activities using a self-report physical activity questionnaire. Many subjects (39%) reported that they always actively participated during physical education classes, but were not physically active in the morning (n=30, 51.72%), while nearly three-fourths (n=42, 72.4%) were very active in the afternoons. On weekends, 40% of the study subjects (n=23) were inactive, and only one-fifth (n=11, 19.3%) reported being highly active. Wednesday and Thursday were reported to be the most active days, with many subjects reporting high activity levels (n=30, 52.6%), and (n=29, 50.9%), respectively. Saturday was the least active day with one-fourth of the subjects (n=14, 24.6%) reporting being highly active.

Less than one-fourth of the subjects (n=13, 22.03%) reported that they were very active, and a majority (n=33, 55.9%) reported being inactive during their free time. More than half (n=33, 56.9%) reported that they watched TV more than 2 hours per day during the last week, while some (n=17, 29.3%) played video games in their free time (Tables 4.17 and 4.18).

Two variables derived from the physical activity questionnaire will be included in the analysis for Aim 3; overall physical activity score, and overall physical inactivity score. The detailed process of variable calculation was explained in the methodology section (Chapter 3). One variable derived from pedometer use, average steps per day, will also be included in the model as a continuous variable.

Hypothesis 1

Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for weight for age, height for age, BMI, and LMI, and higher FMIZ scores, independent of number of years spent in the USA, current physical activity, and nutritional status.

Height for age Z score was significantly associated with current physical inactivity (β= -3.64, p=0.04). Children who reported greater overall physical inactivity, measured by self-report questionnaire, had lower height for age Z scores. After controlling for this modifying factor, height for age Z score and time spent in Sudan or neighboring countries were not associated (Table 4.20).

Two hypothesized modifying variables were significantly associated with LMIZ scores; duration of residence in the USA, and average steps per day. On average, children who had lived for a longer time in the USA had lower LMIZ scores (β=-0.05, p=0.02), and children who had higher physical activity (defined as number of steps taken per day) had higher LMIZ scores (β=0.07, p=0.08). After controlling for these modifying variables, longer duration of residence in Sudan was associated with poorer LMIZ (β= -0.06, p=0.001) (Table 4.20).

Two hypothesized modifying factors were associated with FMIZ score; food insecurity and average steps per day. On average, children who experienced food insecurity had lower FMIZ scores (β= -4.58, p= 0.08), and children with higher average steps per day had lower FMIZ scores (β= -0.35, p= 0.03). After controlling for these two factors, more time spent in Sudan was not associated with FMIZ scores (β= -0.07, p= 0.54) (Table 4.20).

Hypothesis 2

Longer residence in Sudan or in neighboring developing countries will be associated with lower Z scores for total body BMC and aBMD at the hip and spine, independent of number of years spent in the USA, current physical activity, and nutritional status.

Two modifying variables were significantly associated with hip aBMDZ scores;

duration of residence in the USA, and the quadric effect of average steps per day. Generally, children who spent fewer years in the USA had higher hip aBMDZ scores (β= -0.1, p= 0.06), and children who had more average steps per day had higher hip aBMDZ scores (β=0.4, p= 0.02). Adjusting for these two variables, time spent in Sudan was associated with hip aBMDZ scores; children who spent more time in Sudan had higher hip aBMDZ scores (β=0.11, p= 0.01). Spine aBMD and Total BMC Z scores were associated only with fat mass index (FMI); children with a higher FMI had higher spine aBMD and higher total BMC Z scores (β=0.1, $p< 0.0001$) and (β= 0.20, $p< 0.0001$), respectively. Adjusting for FMI, the number of years spent in Sudan was not associated with spine aBMD or total BMC Z scores (Table 4.21).

<u>Hypothesis 3</u>

Longer residence in Sudan or neighboring developing countries will be associated with poorer metabolic risk indicators, independent of years spent in the USA, current physical activity, and nutritional status.

Seven metabolic risk factors (fasting blood glucose, HOMA-IR, HDL, LDL, total cholesterol, Triglycerides, and CRP level) were examined (Table 4.22). Fasting blood glucose was associated with two modifying factors; FMI and the physical activity cubic effect. Children who had higher FMI and higher scores of self-report physical inactivity had higher fasting blood glucose (β=0.22, $p< 0.0001$) and (β= 1.56, p= 0.02). Similarly, HOMA-IR was associated positively with FMI and the cubic effect of average steps per day. In general, children who had a higher FMI had higher HOMA-IR levels (β= 0.19, $p<0.0001$), and consequently, as average steps per day vary, so do HOMA-IR levels (β= 0.01, $p<0.0001$).

Triglyceride levels were associated inversely with average steps per day, (β= 0.001, $p< 0.0001$). CRP levels were associated with FMI, and in general, children with a higher FMI had higher CRP levels ((β= 0.23, $p<0.0001$). Controlling for all of these factors, time spent in Sudan was significantly associated with CRP levels (β= -0.26, $p<0.0001$), and children who spent more years in Sudan had higher levels of CRP after adjusting for FMI (Table 4.22).

<u>Hypotheses 4 and 5</u>

Age at arrival to the USA will be inversely associated with height for age, LMI, total body BMC, and BMC of the femoral neck and spine, and positively associated with FMI and metabolic risks, independent of number of years spent in the USA, current physical activity, and nutritional status.

Height for age Z score was negatively associated with two modifying factors; the quadric effect of number of years children spent in USA and the cubic effect of self-report physical inactivity score (β=-0.02, $p< 0.0001$) and (β= -0.13, $p< 0.03$), respectively. After controlling for these two factors, height for age was positively associated with age at arrival to the USA, and children who arrived at a younger age to the USA had higher height for age Z scores (β=0.094, p=0.005).

LMIZ scores were associated inversely with time spent in the USA, with children who spent more years in USA having lower LMIZ scores (β = -0.12, p=0.01). After adjusting for this modifying factor, children who arrived at a younger age had lower LMIZ scores (β =-0.09, p=0.04) (Table 4.23). Bone growth measures (spine aBMD and total BMC Z scores) were associated with FMI (β =0.1, $p<0.0001$) and (β =0.19, $p<0.0001$), and in general, children who had a higher FMI had higher spine aBMD and total BMC Z scores. Controlling for FMI, neither bone growth measure was associated with age at arrival to the USA (Table 4.23).

Three hypothesized modifying factors were associated with the FMIZ score. Overall, children who spent more years in the USA had higher FMIZ scores (β =0.16, p=0.01), while children who had higher average steps per day or experienced food insecurity had lower FMIZ scores (β = -0.30, p=0.06), (β = -4.50, p<0.0001). Adjusting for these three modifying factors, age at arrival to the USA was not associated with FMIZ scores (Table 4.23).

Seven metabolic risk factors were examined for an association with age at arrival to USA. Fasting blood glucose was associated positively with FMI, and children who had higher FMI had higher fasting blood glucose (β =0.53, p=0.05). Fasting blood glucose was also associated with self-report physical inactivity, and fasting blood glucose varied with variations in physical inactivity (β =1.40, p=0.03), however, the association was not linear. After controlling for these factors, fasting blood glucose was not associated with age at arrival to the USA.

HOMA-IR was associated with two modifying factors; FMI and average steps per day. Children with higher FMI had higher HOMA-IR (β =0.11, p<0.0001); there was a non-linear change in HOMA-IR levels as the average steps per day changed (β =0.005, p<0.0001). Triglyceride levels were associated with average steps per day, and there was a non-linear relationship between triglycerides and average steps per day; as average steps per day changes, triglyceride levels also change (β =0.004, p=0.001). Controlling for this modifying factor, age at arrival to the USA was not associated with triglyceride levels. LDL levels were associated with physical inactivity, and children reporting higher physical inactivity scores had higher LDL levels (β= -6.4, p=0.016). Controlling for physical inactivity levels, age at arrival to the USA was not associated with LDL levels (Table 4.24).

Table 4.1 Selected Demographic Data and Social Characteristics of Sudanese Children, by Gender

	All Children		Boys		Girls	
Variable	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Age (in Years)	10.08	3.29	9.94	3.24	10.21	3.38
School Grade	N	%	N	%	N	%
Elementary	45	70.31	20	64.52	25	75.00
Junior High	8	12.50	7	22.58	1	3.03
High School	11	17.19	4	12.90	7	21.21
Birth Country	N	%	N	%	N	%
USA	33	51.56	16	51.61	17	51.52
Sudan	14	21.88	7	22.58	7	21.21
Saudi Arabia	9	14.06	6	19.35	3	9.09
Egypt	3	4.69	0	0.00	3	9.09
Other	5	7.80	2	6.46	3	9.09
Age at Arrival to USA	N	%	N	%	N	%
0	33	53.23	16	53.33	17	53.10
1 - 5 Years	13	20.97	7	23.33	6	18.80
5 - 10 Years	14	22.58	6	19.98	8	25.00
> 10 Years	2	3.23	1	3.33	1	3.10
Family Income (in USD)	N	%				
< 10,000	12	36.36				
10,000 - 19,000	9	27.27				
20,000 - 29,000	7	21.21				
30,000 - 39,000	4	12.12				
> 50,000	1	3.03				

Table 4.2 Physical Growth, Bone Growth, and Body Composition Characteristics of Sudanese Children

	All Children		Boys (n=31)					Girls (n=33)				
Variable	x̄	SD	x̄	SD	Med	Min	Max	x̄	SD	Med	Min	Max
Height (cm)	142.81	18.62	144.33	19.55	142.00	111.76	172.72	141.40	17.88	139.70	115.80	171.45
Weight (kg)	39.31	18.26	37.81	15.19	34.40	19.05	62.10	40.72	20.88	31.30	17.96	103.87
BMI (wt/ht^2)	0.18	0.04	17.39	2.96	17.00	10.10	23.80	19.11	5.46	17.16	13.10	37.30
Lean Mass (kg)	27.87	9.64	29.48	10.38	25.30	16.43	54.07	26.41	8.81	22.55	14.94	46.89
Fat Mass (kg) **	11.41	10.17	8.69	6.72	6.37	3.00	28.66	13.89	12.10	10.50	28.50	52.72
(BF%) *	26.03	11.32	21.77	9.80	19.54	8.14	44.60	29.91	11.35	27.16	14.61	52.95
LMI	13.16	1.63	13.56	1.77	13.30	9.58	18.12	12.81	1.43	12.55	10.39	16.84
FMI **	5.13	3.56	3.96	2.32	3.16	1.28	9.95	6.19	4.15	4.87	1.98	18.95
Total BMC (g)	1,471.49	718.38	1,449.94	630.60	1,243.00	6,642.20	2,849.06	1,491.00	799.20	1,136.90	666.39	3,361.38
BMC less head (g)	1,134.32	659.58	1,116.10	591.90	908.52	391.40	2,408.90	1,153.10	732.40	849.10	416.70	2,940.90
Hip aBMD (g/cm^2)	0.83	0.17	0.84	0.13	0.81	0.66	1.06	0.83	0.19	0.75	0.58	1.27
Spine aBMD (g/cm^2)	0.80	0.22	0.76	0.18	0.72	0.53	1.18	0.83	0.25	0.73	0.56	1.43

Note: BMI, Body Mass Index; FMI, Fat Mass Index; LMI, Lean Mass Index; BF%, Body Fat Percent; Spine aBMD, Lumbar Spine Bone Mineral Density; Hip aBMD, Hip Bone Mineral Density; Total BMC, Total Bone Mineral Content; BMC-H, Total Bone Mineral Content Less Head.

Differences between boys' and girls' means use T test for normally distributed variables and Wilcoxon test for non-normally distributed variables.

* $p < 0.01$, ** $p < 0.05$.

Table 4.3: Physical Growth, Bone Growth, and Body Composition Z Scores and Percentiles for Sudanese Children

	All Children			Boys (n=31)					Girls (n=33)				
Variable	$\bar{x}$	SD	Med	$\bar{x}$	SD	Med	Min	Max	$\bar{x}$	SD	Med	Min	Max
BMI Percentile	53.08	33.15	51.40	54.52	30.02	50.00	1.30	97.20	51.76	36.18	56.70	20.00	98.90
HAZ	0.28	1.11	0.35	0.34	0.91	0.59	-1.38	1.50	0.23	1.28	0.34	-2.69	2.72
WAZ	0.20	1.06	0.28	0.36	0.98	0.20	-1.33	2.16	0.05	1.14	0.36	-2.45	1.44
LMIZ	-0.49	0.75	-0.41	-0.51	0.80	-0.60	-2.44	0.98	-0.37	0.76	-0.26	-1.79	0.98
FMIZ	-0.57	1.51	-0.62	-0.79	1.64	-0.60	-4.50	1.38	-0.36	1.29	-0.28	-2.63	1.67
BMCZ	-0.55	1.16	-0.71	-0.65	1.01	-0.79	-2.10	2.23	-0.46	1.29	-0.44	-2.66	2.48
SaBMDZ	0.05	1.04	-0.53	-1.33	0.96	-0.23	-2.62	1.54	0.23	1.10	0.09	-3.10	1.74
HaBMDZ	-0.46	1.09	-0.13	-0.42	1.08	-0.65	-2.15	2.23	-0.50	1.12	-0.49	-2.07	2.50

Note: HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score; LMIZ, Lean Mass Index Z Score; FMIZ, Fat Mass Index Z Score; BMCZ, Total Body Bone Mineral Content Z Score; SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; HaBMDZ, Hip Bone Mineral Density Z Score.

Table 4.4 Selected Metabolic Risk Factors for Sudanese Children

	All Children			Boys (n=31)					Girls (n=33)				
Metabolic Factor	$\bar{x}$	SD	Med	$\bar{x}$	SD	Med	Min	Max	$\bar{x}$	SD	Med	Min	Max
Total Cholesterol (mg/dL)	152.80	29.30	151.00	147.48	30.47	139.00	106.00	230.00	157.93	27.59	156.50	106.00	224.00
HDL (mg/dL)	58.90	17.50	57.00	57.45	17.43	54.00	28.00	99.00	60.27	17.67	59.50	20.00	100.00
Triglycerides (mg/dL)*	68.70	27.30	62.00	61.34	24.31	79.50	45.00	152.00	88.10	20.24	71.00	45.00	127.00
LDL (mg/dL)	85.30	24.70	83.50	82.22	29.10	79.50	34.00	137.00	88.10	20.24	85.50	48.00	130.00
Glucose (mg/dL)	81.20	6.70	81.00	81.17	7.36	81.50	66.00	100.00	81.21	6.04	80.00	68.00	98.00
Insulin Total (mcu/mL)*	10.30	8.40	8.20	8.16	4.73	6.50	2.70	20.20	12.48	10.70	8.40	3.30	46.90
Non-HDL	94.70	24.10	94.00	90.80	25.20	88.50	56.00	151.00	98.47	22.70	99.00	58.00	148.00
HOMA-IR*	1.28	1.02	1.02	1.03	0.60	0.83	0.34	2.53	1.54	1.28	1.08	0.41	5.41
CRP Levels	1.60	2.70	0.51	1.40	2.86	0.45	0.11	12.72	1.76	2.63	0.56	0.09	8.87

Note: HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; NON-HDL, Non High Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

*$p < 0.05$.

Table 4.5 Hazard Groups for BMI, Height, and Weight for Sudanese Children

		All Children (n=64)		Boys (n=31)		Girls (n=33)	
Variable	Variable Categories	N	%	N	%	N	%
BMI Percentile Groups	Underweight	7	10.94	3	9.68	4	12.12
	Normal Weight	40	62.50	21	67.74	19	57.58
	Overweight	12	18.75	5	16.13	7	21.21
	Obese	5	7.81	2	6.45	3	9.09
Body Fat %	Obese	18	29.69	9	27.30	9	29.03
	Non-Obese	46	71.90	24	72.70	22	70.10
HAZ Group	Stunted	3	4.69	1	3.23	2	6.06
	Moderately Stunted	6	9.38	2	6.45	4	12.12
	Normal	34	53.13	16	51.61	18	54.54
	Above Normal	20	31.25	12	38.71	8	24.24
	Upper Limit	1	1.56	0	0	1	3.03
WAZ GROUPS	Stunted	7	21.88	2	13.33	5	29.41
	Moderately Stunted	4	12.50	2	13.33	2	11.76
	Normal	19	59.38	9	60.00	10	58.83
	Above Normal	0	0	0	0	0	0
	Upper Limit	2	6.25	2	13.33	0	0

Note: Underweight, BMI Percentile < 5^{th}; Normal, BMI Percentile > 5th and < 85^{th}; Overweight, BMI Percentile >85^{th} Obese, BMI Percentile >95th.

Stunted, <-2sd below mean; Moderately stunted, <-1sd below mean; -1>Normal<1; Above Normal > 1sd above mean; Upper Limit, >2sd above mean.

HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score.

Fisher exact test was used to test categorical variables significant differences between groups.

Table 4.6 Selected Metabolic Factor Hazardous Groups for Sudanese Children

		All Children		Boys		Girls	
Variable	Categories	N	%	N	%	N	%
CRP	Low (1.0 mg/L)	40	0.63	21	75.00	19	65.52
	Average (1.0 - 3.0 mg/L)	7	0.11	3	10.71	4	13.79
	High (> 3.0 mg/L)	10	0.16	4	14.29	6	20.69
Glucose (Fasting)	Low (< 69 mg/dL)	8	12.70	3	10.00	5	15.15
	Average (70 - 110 mg/dL)	55	87.30	27	90.00	28	84.85
	High (>110 mg/dL)	0	0	0	0	0	0
Total Cholesterol	Normal (≤ 170 mg/dL)	49	76.56	26	83.37	23	69.70
	High (> 170 mg/dL)	15	23.44	5	16.13	10	30.30
HDL	Low (≤ 40 mg/dL)	12	18.75	7	22.58	5	15.15
	Acceptable (> 40 mg/dL)	52	76.56	24	77.42	28	84.85
LDL	Normal (≤ 110 mg/dL)	58	90.63	27	87.10	31	93.94
	High (> 110 mg/dL)	6	9.38	4	12.90	2	6.06
HOMA-IR	Normal (< 1.8)	54	84.38	28	90.32	26	78.79
	High (≥ 1.8)	10	15.63	3	9.68	7	21.21
Triglycerides*	Normal (≤ 75 mg/dL)	43	67.20	25	80.65	18	54.55
	High (> 75 mg/dL)	21	32.80	6	19.35	15	45.45

Note: Note: HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; NON-HDL, Non High Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

Fisher exact test was used to test categorical variables significant differences between groups.

* $p < 0.05$.

Table 4.7: BMI, Bone, and Body Composition Z Score Categories for Sudanese Children

		All Children (n=64)		Boys (n=31)		Girls (n=33)	
Variable	Categories	N	%	N	%	N	%
FMIZ	Stunted	25	39.06	13	41.94	12	36.36
	Moderately Stunted	9	14.06	4	12.90	5	15.15
	Normal	23	35.94	11	35.48	12	36.36
	Above Normal	7	10.94	3	9.68	4	12.12
	Upper Limit	0	0	0	0	0	0
LMIZ	Stunted	18	28.13	10	32.26	8	24.24
	Moderately Stunted	12	18.75	4	12.90	8	24.24
	Normal	34	53.12	17	54.84	17	51.51
	Above Normal	0	0	0	0	0	0
	Upper Limit	0	0	0	0	0	0
HaBMDZ	Stunted	2	3.13	1	3.23	1	3.03
	Moderately Stunted	7	10.94	5	16.13	2	6.06
	Normal	42	65.63	20	64.52	22	66.66
	Above Normal	11	17.19	5	16.13	6	18.18
	Upper Limit	2	3.13	0	0.00	2	6.06
SaBMDZ	Stunted	3	4.69	0	0	3	9.09
	Moderately Stunted	18	28.13	10	32.26	8	24.24
	Normal	37	57.81	18	58.06	19	57.57
	Above Normal	4	6.25	1	3.23	3	9.09
	Upper Limit	2	3.13	2	6.45	0	0
BMCZ	Stunted	18	32.73	10	34.48	8	30.77
	Moderately Stunted	3	5.45	2	6.90	1	3.85
	Normal	34	61.82	17	58.62	17	65.39
	Above Normal	0	0	0	0	0	0
	Upper Limit	0	0	0	0	0	0

Note: FMIZ, Fat Mass Index Z Score; LMIZ, Lean Mass Index Z Score; HaBMDZ, Hip Bone Mineral Density Z Score; SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; BMCZ, Total Body Bone Mineral Content Z Score.

Stunted, <-2sd below mean; Moderately stunted, < -1sd below mean; -1>
Normal <1; Above Normal > 1sd above mean; Upper Limit, > 2sd above mean.

Table 4.8 Differences in Risk Categories Between Sudanese Children Born in the USA and Children Born Outside the USA

	USA Born Group (N= 33; 16 Boys and 17 Girls)					Non-USA Born Group (N=31; 15 Boys and 16 Girls)				
Variable	$\bar{x}$	SD	Med	Min	Max	$\bar{x}$	SD	Med	Min	Max
Age*	8.42	2.45	8.00	5.00	14.00	11.84	3.18	12.00	6.00	17.00
LMIZ	-0.57	0.85	-0.76	-1.79	0.98	-0.43	0.69	-0.05	-2.44	0.71
FMIZ	-0.48	1.32	-0.46	-2.63	1.51	-0.64	1.64	-0.39	-4.50	1.67
HAZ	0.02	1.25	0.31	-2.69	2.52	0.55	0.90	0.63	-1.01	2.72
WAZ	0.13	1.16	0.12	-2.45	2.16	0.37	0.77	0.51	-1.07	1.44
HaBMDZ**	-0.23	0.96	-0.03	-2.62	1.70	0.36	1.05	0.22	-1.58	2.50
SaBMDZ	-0.62	0.98	-0.65	-3.10	1.18	-0.28	1.20	-0.43	-2.02	2.61
BMCZ**	-0.86	1.10	-1.00	-2.66	1.25	-0.23	1.14	-0.29	-1.94	2.48

Note: HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score; LMIZ, Lean Mass Index Z Score; FMIZ, Fat Mass Index Z Score; BMCZ, Total Body Bone Mineral Content Z Score; SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; HaBMDZ, Hip Bone Mineral Density Z Score.

*$p < 0.0001$, **$p < 0.05$.

Table 4.9 Differences in Selected Metabolic Risk Factors Between Children Born in the USA and Children Born Outside the USA

		Children Born in the USA		Children Born Outside the USA	
Variable	Categories	N	%	N	%
Fasting Blood Glucose	Low (< 69 mg/dL)	6	18.18	2	6.67
	Average (70-110 mg/dL)	27	81.82	28	93.33
	High (> 110 mg/dL)	0	0.00	0	0.00
HOMA-IR	Normal (< 1.8)	29	87.88	25	80.65
	High (≥ 1.8)	4	12.12	6	19.35
Total Cholesterol	Normal (≤ 170mg/dL)	27	81.82	22	70.97
	High (> 170mg/dL)	6	18.18	9	29.03
HDL	Low (< 40 mg/dL)	7	18.18	5	16.13
	Acceptable (≥ 45 mg/dL)	26	81.82	26	83.87
LDL	Normal (≤ 110 mg/dL)	31	93.94	27	87.10
	High (> 110 mg/dL)	2	6.06	4	12.90
Triglycerides	Normal (≤ 75 mg/dL)	22	66.67	21	67.74
	High (> 75 mg/dL)	11	33.33	10	32.26
CRP Level	Low (1.0 mg/L)	20	71.43	20	68.97
	Average (1.0-3.0 mg/L)	2	7.14	5	17.24
	High (> 3.0 mg/L)	6	21.43	4	13.79
BMI Percentile	Underweight	4	12.12	3	9.68
	Normal	22	66.67	18	58.06
	Overweight	5	15.15	7	22.58
	Obese	2	6.06	3	9.68
HAZ	Stunted	3	9.09	0	0
	Moderately Stunted	5	15.15	1	3.23
	Normal	18	54.54	18	58.07
	Above Normal	6	18.18	12	35.48
	Upper Limit	1	3.03	1	3.23
WAZ	Stunted	6	25.00	1	12.50
	Moderately Stunted	3	12.50	1	12.50
	Normal	13	54.16	6	75.00
	Above Normal	0	0	0	0
	Upper Limit	2	8.33	0	0

Note: HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score; HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

Underweight, BMI Percentile < 5th; Normal, BMI Percentile > 5th and < 85th; Overweight, BMI Percentile >85th; Obese, BMI Percentile >95th.

Stunted, <-2sd below mean; Moderately stunted, <-1sd below mean; -1> Normal<1; Above Normal > 1sd above mean; Upper Limit, >2sd above mean.

Table 4.10 Associations Between Physical Growth and Body Composition Z Score Measures and Time Spent in Sudan

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
WAZ	Time Spent in Sudan	-0.16	0.09	-0.33	0.01	-1.80	0.07
	Adjusted for Gender	-0.32	0.24	-0.78	0.15	-1.34	0.18
	Interaction Between Gender and Time Spent in Sudan	-0.04	0.06	-0.16	0.08	-0.64	0.52
HAZ	Time Spent in Sudan	-0.04	0.03	-0.11	0.03	-1.21	0.23
	Adjusted for Gender	-0.43	0.32	-1.05	0.20	-1.34	0.18
	Interaction Between Gender and Time Spent in Sudan	0	0.05	-0.09	0.09	0.01	0.99
LMIZ	Time Spent in Sudan	-0.05	0.02	-0.09	0.00	-1.91	0.06
	Adjusted for Gender	0	0.21	-0.41	0.42	0.02	0.98
	Interaction Between Gender and Time Spent in Sudan	0.03	0.04	-0.05	0.12	0.75	0.46
FMIZ	Time Spent in Sudan	0.04	0.05	-0.05	0.13	0.92	0.36
	Adjusted for Gender	0.49	0.35	-0.20	1.18	1.38	0.17
	Interaction Between Gender and Time Spent in Sudan	0	0.07	-0.13	0.13	0.06	0.95

Note: HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score; LMIZ, Lean Mass Index Z Score; FMIZ, Fat Mass Index Z Score.

Table 4.11 Associations Between Bone Growth Z Score Measures and Time Spent in Sudan

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
SaBMDZ	Time Spent in Sudan	0.00	0.04	-0.08	0.09	0.09	0.93
	Adjusted for Gender	-0.17	0.27	-0.71	0.37	-0.61	0.54
	Interaction Between Gender and Time Spent in Sudan	-0.11	0.07	-0.25	0.03	-1.51	0.13
HaBMDZ	Time Spent in Sudan	-0.03	0.05	-0.13	0.07	-0.60	0.55
	Adjusted for Gender	0.20	0.24	-0.27	0.67	0.85	0.40
	Interaction Between Gender and Time Spent in Sudan	-0.02	0.09	-0.19	0.15	-0.26	0.79
BMCZ	Time Spent in Sudan	0.02	0.04	-0.10	0.05	-0.59	0.55
	Adjusted for Gender	0.14	0.26	-0.38	0.66	0.53	0.60
	Interaction Between Gender and Time Spent in Sudan	-0.05	0.06	-0.18	0.07	-0.79	0.43

Note: SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; BMCZ, Total Body Bone Mineral Content Z Score; HaBMDZ, Hip Bone Mineral Density Z Score.

Table 4.12 Associations Between Metabolic Risk Factor Measures and Time Spent in Sudan

Dependent Variable	Independent Variable	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Fasting Blood Glucose	Time Spent in Sudan	-0.02	0.22	-0.46	0.42	-0.10	0.92
	Adjusted for Gender	0.06	1.70	-3.27	3.39	0.04	0.97
	Interaction Between Gender and Time Spent in Sudan	0.40	0.54	-0.65	1.45	0.75	0.46
HOMA-IR Log	Time Spent in Sudan	0.03	0.02	0.00	0.07	1.75	0.08
	Adjusted for Gender	0.26	0.15	-0.03	0.56	1.76	0.08
	Interaction Between Gender and Time Spent in Sudan	0.04	0.03	-0.03	0.10	1.04	0.30
Total Cholesterol Log	Time Spent in Sudan	0.01	0.01	-0.01	0.02	0.89	0.37
	Adjusted for Gender	0.04	0.05	-0.06	0.13	-0.72	0.47
	Interaction Between Gender and Time Spent in Sudan	0.02	0.02	-0.01	0.05	1.44	0.15
Triglycerides Log	Time Spent in Sudan	0.01	0.01	-0.01	0.03	1.42	0.16
	Adjusted for Gender	11.94	5.41	1.33	22.55	2.21	0.03
	Interaction Between Gender and Time Spent in Sudan	2.92	1.15	0.66	5.18	2.53	0.01
LDL	Time Spent in Sudan	3.00	0.86	1.32	4.68	3.50	0.00
	Adjusted for Gender	-0.79	5.49	-11.56	9.98	-0.14	0.89
	Interaction Between Gender and Time Spent in Sudan	-1.21	1.66	-4.47	2.05	-0.72	0.47
HDL	Time Spent in Sudan	-0.48	0.60	-1.65	0.69	-0.80	0.43
	Adjusted for Gender	3.49	2.87	-2.14	9.12	1.21	0.22
	Interaction Between Gender and Time Spent in Sudan	1.39	0.86	-0.30	3.08	1.61	0.11
CRP Log	Time Spent in Sudan	-0.08	0.06	-0.19	0.04	-1.33	0.19
	Adjusted for Gender	0.50	0.23	0.05	0.95	2.16	0.03
	Interaction Between Gender and Time Spent in Sudan	0.08	0.10	-0.11	0.26	0.82	0.41

Note: HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

Table 4.13 Associations Between Age at Arrival to the USA and Physical Growth, Bone Growth, and Body Composition Measures

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
WAZ	Age at Arrival to USA	0.01	0.07	-0.14	0.15	0.12	0.90
	Adjusted for Gender	-0.42	0.16	-0.73	-0.10	-2.57	0.01
	Interaction Between Gender and Time Spent in USA	-0.15	0.09	-0.32	0.03	-1.66	0.10
HAZ	Age at Arrival to USA	0.06	0.03	0.00	0.12	1.93	0.05
	Adjusted for Gender	-0.32	0.24	-0.79	0.15	-1.34	0.18
	Interaction Between Gender and Time Spent in USA	-0.02	0.05	-0.13	0.08	-0.47	0.64
LMIZ	Age at Arrival to USA	-0.01	0.03	-0.07	0.05	-0.34	0.74
	Adjusted for Gender	0.03	0.23	-0.43	0.48	0.12	0.91
	Interaction Between Gender and Time Spent in USA	-0.05	0.05	-0.15	0.05	-0.98	0.32
FMIZ	Age at Arrival to USA	0.00	0.07	-0.14	0.15	0.06	0.95
	Adjusted for Gender	0.27	0.34	-0.40	0.94	0.79	0.43
	Interaction Between Gender and Time Spent in USA	0.08	0.07	-0.07	0.22	1.08	0.28
SaBMDZ	Age at Arrival to USA	0.04	0.04	-0.04	0.12	0.93	0.35
	Adjusted for Gender	-0.16	0.27	-0.70	0.37	-0.59	0.56
	Interaction Between Gender and Time Spent in USA	-0.08	0.10	-0.27	0.11	-0.86	0.39
HaBMDZ	Age at Arrival to USA	0.06	0.04	-0.02	0.13	1.49	0.14
	Adjusted for Gender	0.12	0.23	-0.33	0.58	0.52	0.60
	Interaction Between Gender and Time Spent in USA	-0.06	0.08	-0.22	0.09	-0.80	0.42
BMCZ	Age at Arrival to USA	0.05	0.03	-0.01	0.11	1.54	0.12
	Adjusted for Gender	0.11	0.26	-0.40	0.62	0.42	0.67
	Interaction Between Gender and Time Spent in USA	0.01	0.08	-0.14	0.15	0.07	0.95

Note: HAZ, Height for Age Z Score; WAZ, Weight for Age Z Score; LMIZ, Lean Mass Index Z Score; FMIZ, Fat Mass Index Z Score; SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; BMCZ, Total Body Bone Mineral Content Z Score; HaBMDZ, Hip Bone Mineral Density Z Score.

Table 4.14 Associations Between Age at Arrival to the USA and Metabolic Risk Factors

Dependent Variable	Independent Variable	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Fasting Blood Glucose	Age at Arrival to USA	-0.02	0.27	-0.56	0.51	-0.09	0.93
	Adjusted for Gender	-0.12	1.66	-3.37	3.12	-0.07	0.94
	Interaction Between Gender and Time Spent in USA	0.81	0.61	-0.39	2.01	1.32	0.19
HOMA-IR Log	Age at Arrival to USA	0.02	0.02	-0.02	0.07	0.95	0.34
	Adjusted for Gender	0.29	0.15	-0.01	0.59	1.87	0.06
	Interaction Between Gender and Time Spent in USA	0.06	0.05	-0.03	0.15	1.34	0.18
Total Cholesterol Log	Age at Arrival to USA	0.00	0.01	-0.01	0.01	-0.06	0.95
	Adjusted for Gender	0.03	0.05	-0.06	0.12	0.60	0.55
	Interaction Between Gender and Time Spent in USA	0.02	0.02	-0.02	0.05	0.96	0.34
Triglycerides Log	Age at Arrival to USA	0.01	0.01	-0.01	0.03	1.04	0.30
	Adjusted for Gender	0.14	0.07	0.00	0.27	1.98	0.05
	Interaction Between Gender and Time Spent in USA	0.02	0.03	-0.04	0.08	0.64	0.52
LDL	Age at Arrival to USA	1.21	1.02	-0.79	3.22	1.19	0.23
	Adjusted for Gender	4.34	6.63	-8.64	17.33	0.66	0.51
	Interaction Between Gender and Time Spent in USA	1.78	2.60	-3.32	6.89	0.69	0.49
HDL	Age at Arrival to USA	-0.08	0.81	-1.68	1.51	-0.10	0.92
	Adjusted for Gender	3.12	3.01	-2.79	9.03	1.04	0.30
	Interaction Between Gender and Time Spent in USA	2.08	1.12	-0.10	4.27	1.87	0.06
CRP Log	Age at Arrival to USA	0.00	0.05	-0.10	0.11	0.02	0.99
	Adjusted for Gender	0.50	0.25	0.00	0.99	1.95	0.05
	Interaction Between Gender and Time Spent in USA	-0.12	0.08	-0.27	0.02	-1.46	0.10

Note: HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

Table 4.15 Self-reported Diet Quality and Food Security for Sudanese Children

Question 1: Food Security		N	%
Food Did Not Last Until the End of the Month	Often	9	14.06
	Sometimes	16	25.00
	No	39	60.94
Cut the Size of or Skipped a Meal	Often	3	4.69
	Sometimes	17	26.56
	No	44	68.75
Question 2: Diet Quality		N	%
Number of Meals per Day	2	11	17.46
	3	45	71.43
	4	7	11.11
Number of Desserts per Day	1	38	67.86
	2	13	23.21
	3	4	7.14
	4	1	1.79
Number of Snacks per Day	1	18	29.03
	2	28	45.16
	3	10	16.13
	4	6	9.68
How Often Do You Eat at a Fast Food Restaurant	Everyday	2	3.39
	Once a Week	15	25.42
	More Than Once a Week	8	13.56
	Once a Month	17	28.81
	More than Once a Month	12	20.34
	When I Absolutely Have To	5	8.47

Table 4.16 Distribution of Snacks Types for Sudanese Children

	Rare		Sometimes		Often		Usually	
	N	%	N	%	N	%	N	%
Fruits	9	14.29	16	25.40	21	33.30	17	27.00
Vegetables	37	58.73	20	31.75	6	9.34	0	0.00
Pastry	39	61.90	16	25.40	6	9.34	2	3.20
Sweets	35	55.56	11	17.46	12	19.05	5	7.90
Candy	23	36.51	24	28.10	11	17.46	5	7.90
Chips	25	39.68	17	27.00	15	23.81	6	9.50
Nuts	45	71.43	8	12.70	8	12.70	2	3.20

Table 4.17 Physical Activity Characteristics of Sudanese Children Derived from Pedometers

	All Children (N=54)			Boys (N=29)			Girls (N=25)		
Variable	$\bar{x}$	SD	Med	$\bar{x}$	SD	Med	$\bar{x}$	SD	Med
Number of Days	5.80	1.80	6.00	5.60	1.90	6.00	6.00	1.60	6.00
Total Time Worn (Hours)	87.40	31.60	88.00	83.80	31.00	87.00	91.70	32.40	90.00
Average Time Worn (Hours)	14.90	1.80	14.70	14.80	1.50	14.70	15.00	2.20	14.80
Total Number of Steps	43,462.70	21,697.10	40,125.00	43,593.10	24,417.60	38,179.00	43,311.30	18,546.30	40,125.00
Average Steps Per Day	7,359.60	2,406.20	7,160.90	7,631.40	2,762.30	7,924.10	7,044.20	1,921.10	6,541.20
Average Aerobic Steps*	784.60	2,178.90	16.50	1,315.00	2,850.00	36.00	169.40	523.50	10.00
Average Time Worn (Hours)	14.90	1.80	14.70	14.80	1.50	14.70	15.00	2.20	14.80
Total Number of Steps	43,462.70	21,697.10	40,125.00	43,593.10	24,417.60	38,179.00	43,311.30	18,546.30	40,125.00
Total Calories Consumed	851.40	525.60	709.50	887.20	562.10	712.00	810.00	487.90	707.00
Total Distance Walked	15.70	8.00	14.10	16.40	8.70	14.10	15.00	7.10	14.10

Note: $p < 0.05$.

Table 4.18 Self-Report Physical Activity for Sudanese Children

	All Children	
	N	%
Most Frequent Physical Activity Type		
Running	141	0.06
Basketball	130	0.06
Bicycling	111	0.05
Soccer	114	0.05
Physically Active During Physical Education Classes		
Did Not Do	13	22.03
Hardly Ever	6	10.17
Sometimes	4	6.78
Quite Often	13	22.03
Always	23	38.98
Physically Active During Morning		
Inactive	30	51.72
Moderate	10	17.24
Most Active	18	31.03
Physically Active During Afternoon		
Inactive	13	22.41
Moderate	29	50.00
Most Active	42	72.41
Physically Active During Evening		
Inactive	28	48.28
Moderate	14	24.14
Most Active	16	27.59
Physically Active During Weekend		
Inactive	23	40.35
Moderate	23	40.35
Most Active	11	19.30
Physically Active Free Time		
Inactive	33	55.93
Moderate	13	22.03
Most Active	13	22.03
Watch Television		
> 2 Hours per Day	33	56.90
< 2 Hours per Day	25	43.10
Play with Video, Computer, or Electronic Device		
> 2 Hours per Day	17	29.31
< 2 Hours per Day	41	70.69

Table 4.19 Physical Activity Levels of Sudanese Children by Day of the Week

	Physically Inactive		Moderately Active		Most Active	
Day of the Week	N	%	N	%	N	%
Monday	20	35.10	11	19.30	26	45.60
Tuesday	20	35.10	12	21.10	25	43.90
Wednesday	22	38.60	5	8.80	30	52.60
Thursday	21	36.80	7	12.30	29	50.90
Friday	25	43.90	6	10.50	26	45.60
Saturday	23	40.40	20	35.10	14	24.60
Sunday	24	42.10	17	29.80	16	28.10

Table 4.20: Associations Between Time Spent in Sudan and Physical Growth and Body Composition Measures Adjusted for Current Physical Activity, Food Security, and Diet Quality as Modifying Factors

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
HAZ	Time Spent in Sudan	0.01	0.04	-0.06	0.09	0.34	0.73
	Self-report Physical Inactivity	-3.64	1.69	-6.94	-0.33	-2.16	0.03
	Time Spent in USA	0.08	0.12	-0.16	0.32	0.66	0.51
	Time Spent in USA Quadric Effect	-0.01	0.01	-0.03	0.00	-1.49	0.14
	Self-report Physical Inactivity Quadric Effect	1.29	0.65	0.02	2.56	2.00	0.05
	Self-report Physical Inactivity Cubic Effect	-0.13	0.07	-0.27	0.02	-1.69	0.09
FMIZ	Time Spent in Sudan	-0.07	0.12	-0.31	0.16	-0.61	0.54
	Time Spent in USA	0.21	0.14	-0.07	0.49	1.47	0.14
	Food Insecurity	-4.58	2.66	-9.79	0.62	-1.73	0.08
	Average Steps Per Day	-0.35	0.17	-0.68	-0.03	-2.12	0.03
LMIZ	Time Spent in Sudan	-0.06	0.02	-0.10	-0.03	-3.67	0.00
	Time Spent in USA	-0.05	0.02	-0.10	-0.01	-2.36	0.02
	Average Steps Per Day	0.07	0.04	-0.01	0.16	1.73	0.08
	Self-report Physical Inactivity	0.07	0.12	-0.15	0.30	0.65	0.52
	Healthy Snack Consumption	-0.36	0.24	-0.83	0.12	-1.46	0.14

Note: HAZ, Height for Age Z Score; BMIZ, Body Mass Index Z Score; LMIZ, Lean Mass Index Z Score; FMIZ, Fat Mass Index Z Score.

Table 4.21 Associations Between Time Spent in Sudan and Bone Growth Measures Adjusted for Current Physical Activity, Food Security, and Diet Quality as Modifying Factors

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
HaBMDZ	FMI	-0.04	0.04	-0.12	0.04	-1.04	0.30
	Time Spent in Sudan	0.11	0.04	0.03	0.19	2.57	0.01
	Time Spent in USA	-0.10	0.05	-0.20	0.00	-1.91	0.06
	Average Steps Per Day	0.40	0.17	0.06	0.74	2.31	0.02
	Average Steps Per Day Quadric Effect	-0.02	0.01	-0.04	0.00	-1.96	0.05
SaBMDZ	Time Spent in Sudan	0.00	0.04	-0.08	0.09	0.04	0.97
	FMI	0.10	0.02	0.06	0.15	4.31	<.0001
	Self-report Physical Activity	0.03	0.02	-0.01	0.08	1.47	0.14
BMCZ	Time Spent in Sudan	-0.02	0.03	-0.08	0.03	-0.88	0.38
	FMI	0.20	0.02	0.15	0.24	8.92	<.0001
	Self-report Physical Inactivity	0.13	0.10	-0.07	0.33	1.29	0.20

Note: SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; BMCZ, Total Body Bone Mineral Content Z Score; HaBMDZ, Hip Bone Mineral Density Z Score.

Table 4.22 Associations Between Time Spent in Sudan and Metabolic Risk Factors Adjusted for Current Physical Activity, Food Security, and Diet Quality as Modifying Factors

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Fasting Blood Glucose	Time Spent in Sudan	-0.02	0.16	-0.33	0.28	-0.14	0.89
	FMI	0.22	0.06	0.10	0.35	3.58	0.00
	Self-report Physical Inactivity	29.05	17.06	-4.40	62.49	1.70	0.09
	Self-report Physical Inactivity Quadric Effect 2	-12.75	5.98	-24.46	-1.03	-2.13	0.03
	Self-report Physical Inactivity Cubic Effect	1.56	0.64	0.30	2.82	2.42	0.02
HOMA-IR Log	Time Spent in Sudan	0.00	0.02	-0.04	0.05	0.15	0.88
	FMI	0.19	0.04	0.11	0.27	4.61	<.0001
	Average Steps Per Day	1.86	0.46	0.97	2.75	4.09	<.0001
	Average Steps Per Day Quadric Effect	-0.21	0.06	-0.32	-0.11	-3.89	<.0001
	Average Steps Per Day Cubic Effect	0.01	0.00	0.00	0.01	3.58	0.00
HDL	Time Spent in Sudan	-0.60	0.56	-1.71	0.50	-1.07	0.28
	Food Insecurity	-8.21	5.78	-19.54	3.12	-1.42	0.16
LDL	Time Spent in Sudan	2.69	0.96	0.80	4.56	2.79	0.01
	FMI	0.94	1.17	-1.36	3.24	0.80	0.42
	Self-report Physical Inactivity	-1.73	3.87	-9.32	5.85	-0.05	0.65
Triglycerides Log	Time Spent in Sudan	0.02	0.01	0.00	0.03	1.67	0.09
	Average Steps Per Day	0.80	0.26	0.28	1.31	3.02	0.00
	Average Steps Per Day Quadric Effect	-0.10	0.03	-0.16	-0.03	-3.07	0.00
	Average Steps Per Day Cubic Effect	0.00	0.00	0.00	0.01	3.03	0.00
CRP Log	Time Spent in Sudan	-0.26	0.07	-0.39	-0.13	-3.92	<.0001
	FMI	0.23	0.05	0.12	0.33	4.23	<.0001
	Average Steps Per Day	-0.36	0.89	-2.11	1.39	-0.41	0.69
	Average Steps Per Day Quadric Effect	0.05	0.12	-0.18	0.27	0.40	0.69
	Average Steps Per Day Cubic Effect	0.00	0.00	-0.01	0.01	-0.44	0.66
	Time Spent in USA	-0.07	0.14	-0.34	0.19	0.50	0.59
	Healthy Snack Consumption	0.44	0.28	-0.11	0.99	1.57	0.12
	Food Insecurity	0.12	0.46	-0.77	1.02	0.27	0.79

Note: HDL, High Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

Table 4.23 Associations Between Age at Arrival to the USA and Physical Growth and Body Composition Measures Adjusted for Current Physical Activity, Food Security, and Diet Quality as Modifying Factors

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	P
LMIZ	Age at Arrival to USA	-0.09	0.04	-0.17	-0.01	-2.09	0.04
	Time Spent in USA	-0.12	0.04	-0.20	-0.03	-2.63	0.01
	Average Steps Per Day	0.07	0.05	-0.02	0.17	1.54	0.12
	Healthy Snack Consumption	-0.39	0.24	-0.87	0.08	-1.61	0.11
	Self-report Physical Inactivity	0.17	0.13	-0.08	0.42	1.36	0.17
HAZ	Age at Arrival to USA	0.09	0.03	0.03	0.16	2.83	0.00
	Time Spent in USA	0.21	0.09	0.03	0.39	2.28	0.02
	Time Spent in USA Quadric Effect	-0.02	0.01	-0.03	-0.01	-2.85	0.00
	Self-report Physical Inactivity	-3.73	1.37	-6.42	-1.04	-2.72	0.01
	Self-report Physical Inactivity 2	1.33	0.53	0.30	2.36	2.53	0.01
	Self-report Physical Inactivity 3	-0.13	0.06	-0.25	-0.01	-2.15	0.03
SaBMDZ	Age at Arrival to USA	0.02	0.04	-0.06	0.11	0.55	0.58
	FMI	0.10	0.03	0.05	0.15	3.92	<.0001
	Physical Activity Active Score	0.04	0.02	0.00	0.07	1.83	0.07
HaBMDZ	Age at Arrival to USA	0.06	0.04	-0.01	0.13	1.62	0.11
	FMI	0.07	0.04	-0.01	0.15	1.66	0.10
	Average Steps Per Day	0.18	0.24	-0.29	0.64	0.76	0.45
	Average Steps Per Day Quadric Effect	-0.01	0.01	-0.03	0.02	-0.47	0.64
BMCZ	Age at Arrival to USA	0.03	0.02	-0.01	0.08	1.44	0.15
	FMI	0.19	0.02	0.15	0.24	8.59	<.0001
	Self-report Physical Inactivity	0.15	0.11	-0.07	0.36	1.34	0.18

Note: SaBMDZ, Lumbar Spine Bone Mineral Density Z Score; BMCZ, Total Body Bone Mineral Content Z Score; HaBMDZ, Hip Bone Mineral Density Z Score; HAZ, Height for Age Z Score; LMIZ, Lean Mass Index Z Score.

Table 4.24 Associations Between Age at Arrival to the USA and Metabolic Risk Factor Measures Adjusted for Current Physical Activity, Food Security, and Diet Quality as Modifying Factors

	Parameter	Estimate	Standard Error	95% Confidence Limits		Z	P
FMIZ	Age at Arrival to USA	-0.10	0.08	-0.26	0.06	-1.20	0.23
	Time Spent in USA	0.16	0.06	0.05	0.27	2.76	0.01
	Average Steps Per Day	-0.30	0.16	-0.62	0.01	-1.91	0.06
	Food Insecurity	-4.50	1.33	-7.11	-1.89	-3.38	0.00
Fasting Blood Glucose	Age at Arrival to USA	-0.05	0.21	-0.47	0.37	-0.23	0.82
	FMI	0.53	0.27	0.01	1.05	2.00	0.05
	Self-report Physical Inactivity	26.79	16.79	-6.12	59.69	1.60	0.11
	Self-report Physical Inactivity 2	-11.59	5.91	-23.17	0.00	-1.96	0.05
	Self-report Physical Inactivity 3	1.40	0.64	0.16	2.65	2.21	0.03
HOMA-IR Log	Age at Arrival to USA	0.00	0.01	-0.03	0.02	-0.26	0.79
	FMI	0.11	0.02	0.07	0.14	6.17	<.0001
	Average Steps Per Day	1.37	0.26	0.85	1.89	5.20	<.0001
	Average Steps Per Day Quadric Effect	-0.15	0.03	-0.21	-0.09	-5.05	<.0001
	Average Steps Per Day Cubic Effect	0.00	0.00	0.00	0.01	4.61	<.0001
HDL	Age at Arrival to USA	-0.22	0.76	-1.71	1.27	-0.29	0.77
	Food Insecurity	-8.99	6.31	-21.36	3.37	-1.43	0.15
LDL	Time Spent in USA	0.43	0.99	-1.51	2.37	0.44	0.66
	FMI	1.86	1.30	-0.70	4.42	1.43	0.15
	Physical Inactivity	-6.44	2.67	-11.68	-1.20	-2.41	0.02
Triglycerides Log	Age at Arrival to USA	0.02	0.01	0.00	0.04	1.58	0.11
	Average Steps Per Day	0.87	0.27	0.34	1.40	3.22	0.00
	Average Steps Per Day Quadric Effect	-0.10	0.03	-0.16	-0.04	-3.22	0.00
	Average Steps Per Day Cubic Effect	0.00	0.00	0.00	0.01	3.14	0.00

Table 4.24 Continued

CRP Log	Age at Arrival to USA	-0.03	0.08	-0.18	0.13	-0.35	0.73
	Average Steps Per Day	-1.62	1.21	-4.00	0.76	-1.34	0.18
	Average Steps Per Day Quadric Effect	0.17	0.14	-0.10	0.44	1.23	0.22
	Average Steps Per Day Cubic Effect	-0.01	0.00	-0.02	0.00	-1.22	0.22
	Time Spent in USA	-0.06	0.10	-0.25	0.13	-0.65	0.52
	Healthy Snack Consumption	0.54	0.34	-0.13	1.21	1.58	0.11
	Food Insecurity	0.10	0.38	-0.64	0.84	0.26	0.79

Note: FMIZ, Fat Mass Index Z Score; HDL, High Density Lipoprotein; HOMA-IR, Homeostatic Model Assessment Insulin Resistance; CRP, C Reactive Protein.

CHAPTER 5

DISCUSSION

The purpose of this research was to describe the physical growth status, bone mineral content, bone mineral density, body composition, and metabolic risk of Sudanese emigrant children, and to determine the relationship between these measures and exposure to an adverse environment as measured by duration and timing of residence in Sudan and neighboring countries. An additional purpose was to determine whether associations between environmental exposures and growth and health effects were modified by physical activity and current nutritional status.

Height and Weight Stunting

Fourteen percent of the Sudanese children in this study were stunted, with stunting being more prevalent among children born in the USA than outside the USA (24% vs. 3.2%), and among females than males (16% vs. 12%). The prevalence of weight stunting (severe and moderate) among study subjects was 34.5%, and of those, 22% were categorized as severe underweight (weight for age Z score below mean < -2sd).

The rate of height stunting in this study was 14%, less than other African refugee and emigrant studies. In one study, the overall rate of stunting among Western Sahara refugees was 20.9%, while another study showed that 20% of South African children were stunted. African children living in developing countries showed a rate of stunting as high as 29% (Nisbet, 2011; Kimani-Murage et al., 2011).

Although the rate of stunting observed in this study may be somewhat lower than in other studies, stunting, particularly if it becomes permanent, represents a serious health problem. Stunting (short height for age) and underweight (low weight for age) are important public health indicators. These parameters collectively combine information about linear growth retardation and weight for length/height. Stunting and growth delay are significant issues affecting childhood development, and both can lead to permanent negative consequences. The consequences of permanent stunting are not completely understood. Nonetheless, there is growing evidence that stunting in early life is associated with impaired health and reduced educational and economic performance later in life (Victora et al., 2007; Dewey & Begum, 2011). Children stunted in early childhood were more likely to be of short stature as adults and to have reduced lean body mass. In a longitudinal study of 2,874 Senegalese children ages 1 to 23, Coly and Colleagues concluded that children stunted at early ages remained smaller than non-stunted children; the age-adjusted height deficit between the two groups was 6.6 and 9.0 cm in girls and boys, respectively (Coly et al., 2006). At follow up, women ages 18 to 23 had a 2.4 cm height deficit, while men ages 20 to 23 had a 2.8 cm height deficit.

Stunting and growth retardation may present an increased risk of metabolic syndrome. Short stature causes body fat to be distributed over a smaller body surface area, and may predispose children to increased risk of chronic disease (Hoffman & Klein, 2011). Stunted children may have economical and academic disadvantages including low educational achievement and work productivity (Dewey & Begum, 2011). Many studies report that children under four years old who live in stressful and/or deficient environments have rates of height stunting of more than 20% (Grijalva-Eternod et al., 2012). Interventional studies suggest that early intervention in stunted children is the most effective at changing outcome measures. While intervention may achieve positive results, prevention of stunting and growth delay is a better goal.

Contrary to our expectations, we found that a greater proportion of Sudanese children who were born in the United States were height and weight stunted as compared to those born in Sudan or neighboring countries. The reason for this is not clear. Our observed height stunting rates of 10% for children born in the USA are similar to those of low-income African American children (Ogden et al., 2009; Ogden, Lamb, Carroll , & Flegal, 2011), and therefore could reflect economic and social realities as well as racial discrimination experienced by that group as suggested by (Proos, 2009; Bose, 2011). Another possible explanation is that the study participants born in the USA were, as a group, younger than those who were born in Sudan and neighboring countries. Children who are malnourished, especially when young, are expected to be stunted in height, but can rebound in height when adequate nutrition becomes available, or the cause of the stunting (famine, trauma) is alleviated. Because the children in our study who were born outside the USA were older than the children born in the USA, they had a greater opportunity for recovery of height or weight. Follow-up of the Sudanese children born in the USA is needed to determine whether the stunting will reverse as they get older.

Obesity and Overweight

The rate of overweight and obesity among our study participants was 26.5%, lower than the rate reported in American children and adolescents (31.8%) and similar to the rate of other Sudanese children who immigrated to Canada (29%) (Ogden et al., 2011; Nisbet, 2011).

Children born in the USA had lower rates of obesity or overweight as compared to children born outside the USA. Although this phenomenon needs further research, one possible explanation is that as a group, children born in the USA were younger and as their height and weight increases with age so does their BMI, the most commonly used measure of fatness, which may simply reflect normal growth in children and adolescents and cannot account for growth spurts. Children's growth is not uniform and is sensitive to many factors (e.g. nutrition), making it difficult to compare all children. There is evidence that BMI of immigrant children increases as they spend more time in the USA. In a follow-up study of 69 African refugee children over 6–24 months, 57% of underweight children became normal weight, and 2% of normal weight children moved to the next higher weight category after arrival in the USA (Hervey, Vargas, Klesges, Fischer, Trippel, & Juhn, 2008). Other studies comparing children of the same ethnicity in their home and resettled countries found that BMI percentiles vary widely. A study of Haitian born children found that for each year of residency in the USA, BMI percentile increased by 3.7% (Stein et al., 2010). These results suggest that children may acculturate easily, which may lead to detrimental changes in diet and/or physical activity, resulting in weight gain. Other research suggest that food security increases with time spent after immigration to developed countries such as the USA, Canada, and Australia, and weight can be expected to increase as food security increases (Sellen et al., 2002). In our research, of the children who experienced food insecurity, nearly three-quarters (72%) were born outside the USA, while two-thirds (66.7%) of the children living in food secure households were born in the USA. Other studies have suggested that as food security improves after immigration to the USA, rates of obesity and overweight may decrease as food is made consistently available, preventing what may be a common occurrence of overconsumption of food after times of food shortage by a household (Gundersen et al., 2008).

Body Composition (FMI & LMI)

We used Z scores based on NHANES population data for height adjusted fat mass and height adjusted lean mass to compare the body composition of Sudanese children to the USA African-American population. Our data suggests that Sudanese children have substantially lower lean mass and fat mass than would be expected based on a normal distribution. Just over 53% of the participants had FMIZ scores that were more than 1SD below the mean, and 19% had LMIZ scores that were more than 1 SD below the mean. Only 11% had FMIZ scores more than 1sd above the mean and none of the children had LMIZ scores more than 1 sd above the mean**.**

This is the first study we are aware of examining height adjusted fat mass and lean mass among Sudanese emigrant children. Other studies primarily reported on BMI, and a few examined BF%, making it difficult to compare these results. The reasons for lower FMI and LMI measures in these children is not completely understood. It is widely accepted that fat and lean mass are established early in life, track from childhood into adulthood, and may be familial (Guo et al., 1997; Garn, 1997; Salbe et al., 2002). In a seven year follow-up study, Cheng and colleagues concluded that lean mass and fat mass were highly correlated between mothers and daughters and suggested that it is possible to identify children who are prone to develop low lean mass and high fat mass (Cheng et al., 2009). In this research we suggest that the subjects had low body size, and consequently, low fat and lean mass indices. Body size can reflect a genetic component, where small size parents will have small size children, as demonstrated by Cheng and colleagues findings where body size explained 59% and 78% of the variance in fat mass and lean mass, respectively (Cheng at al., 2009). These findings concur with the unpublished data of Clark et al., 2013, which found that body composition among Sudanese adults fell in the lower 15th percentile for lean mass and higher 60th percentile for fat mass when compared to NHANES study (Clark et al., 2013).

It is important to monitor body composition (lean mass and fat mass) during growing years especially during puberty, because the change in lean and fat mass can serve as a indicators of metabolic processes, and thus hold related information regarding current and future chronic health such as cardiovascular disease, type 2 diabetes and obesity (Siervogel et al., 2003). The research on children with low body size were very limited however, in adults, results suggested that low muscle mass may be associated with different metabolic risk factors according to body size phenotype (Kim et al., 2013). In their study Kim and colleagues found that men with the metabolically abnormal but normal weight showed a unusually increased risk of low muscle mass (OR= 11.30, 95%CI: 1.73 -73.28) compared with those with metabolically healthy normal weight (Kim et al., 2013)

Bone Growth

The Z scores for BMC, hip aBMD, and Spine aBMD also suggest that the Sudanese children in this study have lower bone growth than that of African Americans and therefore may be at greater risk for fracture later in life. The BMCZ of almost 38% of the Sudanese children was more than -1 standard deviation (SD) below the mean while 14% had hip and 33% had spine aBMD scores more than 1 SD below the mean. Failure to achieve optimal bone mass during childhood and adolescence results in suboptimal peak bone mass, which has been connected to bone fractures and increased risk of osteoporosis later in life (Glizans et al., 2007; Kalwakof et al., 2010).

It is not clear why Sudanese children have lower bone growth measures. In children, low bone growth Z scores can be due to bone loss, poor accretion, small body size, or delayed maturation. It is also possible that low bone growth is related to low physical activity, environmental factors (nutritional factors), and/or genetic factors. Physical activity during childhood has been shown to increase bone mass and hence bone density in children, and serves as a protective factor against future bone disease such as osteoporosis. Hunter and colleagues recently argued that even short bouts of physical activity during childhood may have persistent benefits into adulthood even if that physical activity stops (Hunter, Almsteadt, & Janz, 2011).

There is some evidence that adult women who emigrated from Sudan and settled in the USA have significantly lower spine aBMDZ scores compared with the normative values of African Americans and Caucasians (Gong et al., 2006). Gong and colleagues explained that both nutritional factors (such as milk intake) and length of stay in the USA have a positive effect on total body mineral content and aBMD ($p < 0.015$) ($p < 0.02$) respectively. Other more recent research showed that genetic predisposition was a possible explanation for low aBMDZ scores, and concluded that allele frequencies in the frequencies of microsatellite alleles in four genes were significantly different in the Sudanese population (Gong et al., 2006). More detailed research is necessary in this group including genetic predisposition and comprehensive nutritional factors.

Metabolic Health

In this study, seven metabolic risk factors were evaluated including Fasting Blood Glucose, LDL, HDL, triglycerides, total cholesterol, and CRP levels. While most children fell in the lower risk groups, 15.6% had high HOMA-IR, 16% had high CRP levels, 32.8% had high triglycerides, 23.4% had high total cholesterol, 9% had high LDL, and 12% had low HDL.

Insulin resistance and glucose intolerance are significant risk factors for hypertension, cardiovascular disease, and type 2 diabetes. The development of type 2 diabetes mellitus is induced by decreased insulin sensitivity leading to increased insulin production. This imbalance causes a predisposition to several metabolic disorders such as early atherosclerosis, progressive obesity, and dyslipidemia (Friedman, et al., 2011). Some studies have concluded that higher BF% and BMI percentiles are associated with higher HOMA-IR and fasting blood glucose levels (Ruiz, Rizzo, Ortega, Loit, Veidebaum, & Sjoostrom, 2007), while other studies have concluded that even HOMA-IR and fasting blood glucose were not enough to detect type 2 DM. A sample of 94 obese children (ages 8–20 years old) who met the criteria for screening or had type 2 DM found that 91% had normal fasting blood glucose and HOMA-IR, however, when these measures were combined with BMIZ score and family history, the relationship was significant. Clearly the diagnosis and detection of type 2 DM in children can be difficult (Greig F, Hyman S, Wallach E, Hildebrandt T, Rapaport R. 2012).

The rate of type 2 diabetes among this study's participants was low, with all subjects maintaining normal fasting blood glucose levels, and only 10 (15.63%) of the Sudanese children had high HOMA-IR levels. This was not what we expected to find as other studies have shown that 100% of obese children and adolescents had higher fasting blood glucose and HOMA-IR levels (Holi, Jaser, Womack, Jefferson, & Grey 2011; Raven 2004).

Adolescence is a higher risk period for the development of type 2 diabetes because the transient physiological status in insulin resistance induces extra stress on pancreatic beta cells (Goran M, Ball G, Cruz L, 2003). One study found a significant difference in the rate of insulin resistance between pre-pubertal and pubertal children. In the pre-pubertal children, 37% of boys and 27.8% of girls showed insulin resistance, while in the pubertal children, 61.7% of boys and 66.7% of girls showed high insulin resistance (Kurtoğlu, Hatipoğlu, Mazıcıoğlu, Kendirici, Keskin, & Kondolot, 2010). In this study, pre-pubertal and pubertal boys and girls had the same fasting blood glucose and HOMA-IR levels.

High lipid profile factors (LDL, HDL, Triglycerides, total cholesterol, and CRP levels) were found in many study subjects. Lipid profile factors are closely related to obesity and associated with risk of cardiovascular disease, diabetes, and other chronic diseases. In a review of 11 studies examining the relationship between lipid profile and the development of metabolic syndrome, lipid profile was associated with the risk of metabolic syndrome with effect size ranging from 0.1 to 0.59, after adjusting for BMI and BF% (Lloyd, Langley- Evans, & MCMullen, 2012).

CRP is a sensitive marker of inflammation. Age, sex, BMI, adiposity, and physical inactivity are associated with elevated CRP levels (Abrasmon & Vaccarino, 2002), which can, in adults, indicate subclinical disease, such as the risk of cardiovascular disease, type 1 diabetes, and metabolic syndrome. The association in children is not clear. Recently, in a study examining the association between CRP levels and metabolic risk factors among 324 healthy children, CRP levels were higher in subjects in the highest quartile of BMI and BF% than those in the lowest quartile (BMI $P < 0.001$), (BF% $P = 0.01$) (Moran et al., 2008). Weiss and colleagues concluded that in obese children and adolescents, insulin resistance is associated with elevated CRP levels and adverse cardiovascular outcomes (Weiss et al., 2004). In this study, CRP level was not associated with BMI percentile, BF%, or insulin resistance, however, CRP levels were strongly associated with HDL (P=0.003).

Metabolic risk factors were less prevalent in children and adolescents with high physical activity levels (2.6%) as compared to children who reported low physical activity levels (4.3%) (Pan, Charlotte, & Pratt, 2008). There is sufficient evidence suggesting an association between physical activity and CRP levels (Syrenicz A, Garanty-Bogacka B, Syrenicz, 2006), and stronger evidence associating physical fitness and CRP levels. One study concluded an association between cardio-respiratory fitness and CRP of -0.49 in 9-year-old children, and children falling in the upper quartile of CRP levels had a relative risk 11.3 times higher for CVD risk factors as compared to children in the lowest quartile (Anderson et al., 2011). In this study there was no association between CRP levels and physical activity levels, however, the rate of all metabolic risk factors except for insulin resistance was higher for inactive children than for active children when activity was measured by the self-report physical activity questionnaire. Inactive children and adolescents had higher rates of metabolic risk factors when physical activity was measured by pedometer.

CRP is an acute phase reactant and recent research has shown it to be a more powerful predictor of cardiovascular risk than classic markers such as LDL cholesterol (Ridker, 2003). Normal values for CRP are not well defined, however, values less than 1.0 mg/L are considered low risk, 1.0–3.0 mg/L are considered medium risk, and greater than 3.0 mg/L high risk (Pearson et al., 2003). There is a significant genetic component to

CRP concentration, but recent investigations have observed an association with adiposity, fitness, physical activity, and diet (Lande, Pearson, Vermillion, Auinger & Fernandez, 2008).

Examining CRP differences across gender showed that 60% of the children in the high risk group were females, this result was consistent with other findings reported by another study which found higher CRP concentrations in girls compared to boys (Cook et al., 2000). In their study, Cook and colleagues concluded that CRP levels were 47% higher in girls than boys, and increase with age by 15% each year. In our study, 60% of the CRP high risk group were born in the USA. There were no statistical differences between gender and birthplace. The other body composition and fatness measures (FMI, LMI, BMI, BF%) did not successfully differentiate between high and low CRP risk groups.

Much of the current literature indicates that adiposity has the greatest impact on CRP concentration, and that the association with PA and fitness is mediated by body fatness (Ruiz et al., 2007). Results are inconsistent regarding the potential impact of PA on CRP levels in children. In adults there is evidence that CRP levels decrease progressively with increasing levels of PA, independent of body fatness measures (Plaisance & Grandjean, 2006). Results of our study showed all children in the CRP high risk group took less than 10,000 steps per day, while none of the children who took more than 10,000 steps per day had high CRP levels.

Socioeconomic and Demographic Status

More than 50% of the Sudanese children in this study were born in the USA. The majority of participants born outside the USA were born in countries such as Sudan and

Egypt and arrived in the USA around the year 2000. Family income and employment data was collected from parents or legal guardians. Although many of the parents are college graduates, many are unemployed and receive federal government assistance in the form of Section 8 housing and food stamps. If parents are employed, they typically work in unskilled or minimum wage jobs, and the majority of study participants are classified as low-income. Only one participant reported an annual family income more than $40,000. This participant is employed by the Department of Defense and works outside of the USA.

These results are consistent with other studies of African and Sudanese people who have immigrated to Western countries. Studies in the United Kingdom, Canada, and Australia concluded that the majority of Sudanese families were low income, with 40% of families reporting annual income less than $15,000 (Willis & Nkwacha, 2006). Commonly, emigrants and refugees are educated and skilled members of the workforce in their home countries. While they may hold advanced degrees and earn relatively large salaries in highly regarded jobs at home, differences in education and licensing requirements may render emigrants unemployable in all but the lowest paying, least skilled jobs in their new country. New emigrants and refugees often experience language barriers and may have difficulty navigating a Western style egalitarian system based more on merit and procedure rather than on family or social connections and graft, as may have been common in their home country.

Low income families face many challenges including food insecurity, low diet quality, and lack of health insurance, leading to health care inaccessibility. Many middle to upper income Americans receive health insurance through their employer, and employers often subsidize the cost of insurance for their employees, who are able to afford coverage in part due to discounted group rates insurers offer to employers. Low income families may not be offered health care insurance coverage through their employer, due to the lack of personnel benefits or the transient (seasonal, temporary, part-time, non-contract) nature of their employment. These families may receive government sponsored health care which may provide very minimal coverage. Purchasing an individual plan directly from an insurer can be cost prohibitive, especially for low income families.

In the USA, diet quality differs by social class and other demographic characteristics. A strong positive association exists between income level and diet quality (Hazel, Casavale, & Guenther, 2013). In general, higher income is associated with greater adherence to dietary recommendations, and one study showed that adults in the highest income group met minimum dietary recommendations at double the rate of the lowest income group for total vegetables, milk, and oils (Kirkpatrick, Dodd, Reedy, & Krebs, 2012).

People living in low income neighborhoods face serious challenges in accessing quality food. A 2009 study in Roxbury, Pennsylvania determined that many low-income families living there had limited access to affordable healthy food options (Fulp, McManus, & Johnson, 2009). Another study found that there were fewer supermarkets and/or food stores offering affordable and varied food in lower-income black neighborhoods compared with wealthier white neighborhoods, and there was a positive association found between fruit and vegetable intake and the number of supermarkets in African-American neighborhoods (Morland, Wing, Diez Roux, & Poole, 2002). There is a significant financial barrier to healthy eating for low income families, which is simply the cost of food, resulting in low income families having poorer dietary practices than families with higher income levels (Blisard, Stewart, Joliffe, 2004).

In this study, 40% of the Sudanese families reported experiencing food insecurity, and 20% of these families reported that they had skipped meals or cut the size of meals because they did not have enough food. Comparatively, according to the USDA, in 2011, 79% of American households with children present were food secure throughout the year while 21% of households with children were food insecure at some time during the year (USDA, 2012). While the 40% figure in our study is already significantly higher than the national rate, it must be noted that due to the extremely sensitive nature of this subject, families may have underreported their experience with food insecurity and the real number may be higher.

Food security is closely related to income, employment status and education level (Che & Chen, 2001). In households headed by an unemployed adult, the prevalence of food insecurity among children was three and a half times as high as in households headed by one or more full-time employed adults. Even so, 75% of food-insecure children live in households with one or more adults employed either full time (60 percent) or part time (15 percent). The majority of Sudanese adults in this study were unemployed, underemployed, or working in low wage unskilled jobs, therefore, it is no surprise that the study participants had higher rates of food insecurity. There was a significant positive relationship between family income and food security ($P = 0.004$, Odd Ratio 18.35). These results were consistent with other studies on Sudanese emigrants and refugees. A 2011 study of Sudanese people immigrating to Canada found over half

(54.1%) were food insecure while an earlier study reported food insecurity associated with unemployment status and family income in 53% of Sudanese people immigrating to the USA (Nisbet, 2011; Hadley, Zodhiates & Sellen, 2004). Another study reported lower rates of food insecurity in Sudanese people immigrating to Canada (33.2%), but the rate of food insecurity was still three times that of the Canadian population (Simich, Hamilton, & Baya, 2006).

Household food security typically increases with the number of years spent in the new home country and decreases with the number of children in the household. In a Canadian study, the odd ratio of experiencing food insecurity three years after immigration was (0.64), while another study showed high rates of food insecurity (73%) for families who had been in the USA less than one year, decreasing significantly (33%) for families in the USA more than three years. Another study showed that households with more than two children had a higher odd ratio of being food insecure (OR 3.95) (Nesbit, 2011). Due to the small sample size in this dissertation research, we were unable to observe any association between either the number of years in the USA or number of children in each family and food security.

Food security is especially important for children because nutrition affects their current and future health and development. Many studies report that food security is associated with body composition measures (BMI, BMI percentiles, and BF%), as well as bone growth measures, specifically bone mineral content (Eischer-Miller et al., 2011). We examined the association between food security and metabolic risk factors, bone growth measures, and body composition measures, and found no significant associations. There was a highly significant association between birthplace (inside or outside the USA) and food security. Nearly three-fourths (72%) of the food insecure children were born outside the USA (P=0.004), (RR=2.7, CI: 1.3, 5.6).

Aim 2 Discussion

Studies demonstrate that physical growth (height and weight) are very sensitive to both positive and negative environmental exposures. Additionally, nutritional factors play a major role in the physical growth of children. This study provides evidence that environmental exposure at an early age may be associated with poorer health conditions and physical growth parameters. The number of years spent in Sudan and neighboring countries was associated with lean mass index Z scores, and while I expected that weight and height would also be affected, children who spent time in Sudan and neighboring countries were not at higher risk of being stunted in height or weight. These findings were consistent with other findings, including the fact that bone growth measures were not associated with time spent in Sudan or neighboring countries. Surprisingly, children who spent more time in the USA showed higher rates of stunting for both height and weight, but not for bone growth measures.

One possible explanation for these findings was that nutritional factors and family finances differed so significantly between Sudan and the USA. Children born in Sudan who later immigrated to the USA were typically born into a relatively high socioeconomic status. Upon migration to the USA, these Sudanese children and their families found themselves at a significantly lower socioeconomic status. Many parents did not speak English, and were not qualified to obtain a similar level of employment after migration, leading to unemployment or significant underemployment. Additionally, most parents were not familiar with Western culture, did not have prior exposure to

American dietary habits, and struggled with food selection.

The lack of familiar foods and the lack of knowledge about foods available in the USA appeared to contribute to the poor food choices of Sudanese families. Food that is cheap, plentiful, and easy to prepare is not necessarily the best food for a child's growth and development. Studies examining nutrition among African refugees and asylum seekers in the USA and Switzerland found participants ate fewer fruits and vegetables and more prepared foods upon arrival to their host country due to p, taste, familiarity, and ease of preparation (Willis & Buck, 2007; Kruseman, Barandereka , Hudelson , & Stalder, 2005). The lower socioeconomic status of new emigrant families appeared to have a negative effect on nutrition, and lack of time and money may lead to a decrease in food preparation at home and an increase in meals eaten away from home which has been associated with lower income (Devine, Connors, Soba, & Bisogni 2003).

This study concluded that environmental exposures Sudanese children faced in Sudan or neighboring countries prior to immigration, and in the USA after resettlement can predict, HDL, triglyceride, and CRP levels.

Modifying Factors

When the associations mentioned in Aim 2 were examined for the effect of possible modifying factors (current nutritional status, time spent in the USA, and current physical activity), current physical activity level and inactivity levels were the most obvious modifying factors affecting the association between the outcome variables and the independent variables. Physical activity positively modified the association between body composition (FMIZ, LMIZ), hip aBMD, HOMA-IR, and triglyceride levels, and the time spent in Sudan or neighboring countries. While the physical inactivity levels negatively modified the association between HAZ and glucose levels and time spent in Sudan or neighboring countries. These results were interesting and consistent with many other studies where physical activity in children had a significant positive effect on bone growth, body composition, and metabolic risk factors. At the same time, physical inactivity (sedentary behavior) and its negative effect on children's health, including the increased risk of obesity, has been thoroughly discussed in recent literature. TV watching and video game playing were recognized as the most inactive behaviors children experienced, and there is substantial evidence linking the number of hours of TV viewing and the incidence of being overweight (17%–44% increased risk) or obese (10%–61%) (Tremblay & Williams, 2003). Other studies reported a dose-response relationship between screen time (TV and computer) and metabolic syndrome in adolescents (aged 12–19 years) (Mark & Janssen, 2008).

Limitations and Future Direction

To our knowledge, this is the first study to examine the relationship between environmental exposure, physical growth, bone growth, and metabolic risk factors in Sudanese children. There are some limitations in this study. First, as a cross-sectional study, rather than a longitudinal study, the ability to demonstrate a causal relationship is limited. Second, our sample size is small and may cause uneven distribution across some of the variables. Third, we did not use random selection for our participants, and that may cause some degree of bias. It is possible that because of our monetary remuneration, more low income families chose to participate in this study.

There are also limitations related to the measurements we used, including the self-report measures for physical activity, food frequency, diet quality, and the puberty scale.

Self-report food frequency measures have high recall bias which might affect study results. Food security and physical activity questionnaires based on self-report may be subject to the participant feeling pressured to give responses perceived as desirable. At the beginning of this study, we administered the puberty development scale and the high calcium food frequency questionnaires because these two measures are very important in bone and physical growth in children. In the middle of the study, we had to modify the high calcium food frequency questionnaire based on participant feedback and poor response reliability. Almost half of the study subjects completed the modified version, however, during the data analysis phase, these two questionnaires were found to be incomparable, making the data entirely unusable. Food insecurity is a sensitive topic and parents or guardians may be embarrassed or afraid to report that their children are not getting enough to eat, so food insecurity among participants may be underreported. Additionally, parents may have answered questions pertaining to food security incorrectly, falsely believing that their children have not experienced food insecurity. The food insecurity questionnaire we used was a modified version containing only two questions instead of the original nine questions which could limit the validity of the questionnaire.

We successfully collected blood from the majority of the participants with a high response rate to obtain metabolic risk data. However, one limitation related to the metabolic risk data is the family history of diabetes. There is a strong association between family history and insulin resistance, fasting blood sugar, and metabolic syndrome, which was not controlled for in this study.

This study has the potential to identify unique long term health risks of Sudanese emigrant children and will provide knowledge important to the planning and implementing of future interventions on emigrant children.

Implications for Research

It is important to understand the nature of association between the exposure to environmental challenges and the physical and bone growth status and metabolic risk factors of children of Sudanese families. Furthermore, identifying the modifying factors of this association is an important step in developing appropriate intervention programs and design further studies. Pre-pubertal and pubertal stages are critical times in human development as major changes in body composition such as peak bone mass acquisition, fat mass distribution, and others occur during these times. Clearly, children of Sudanese immigrants have low physical and bone growth measures and unhealthy body composition measures. It is not clear if these measures are a consequence of the emigration process, transitional life, or early exposure to an adverse environment. While pre-migration exposures cannot be prevented, a better understanding of the consequences of these exposures and discovery of modifying factors can minimize adverse effects. Intervention programs would be particularly beneficial in pre-adolescence as this is the time when children can be easily influenced and are most likely to adhere to healthy lifestyle behaviors, behaviors which are more likely to persist throughout adolescence and adulthood if implemented at this time. Education in the areas of physical activity and healthy eating should be a major focus for future research with new immigrants, and addressing barriers to physical activity may be especially important among Sudanese children.

Public health policymakers should facilitate an environment that enables

Sudanese children and their families to lead healthy lifestyles. Motivation for physical activity in the early phase of an immigrant's arrival could help arrest the development of obesity among immigrants over time. Moreover, the initiation of culturally sensitive physical activity centers might also have a substantial ameliorating impact on these adverse health conditions.

APPENDIX

Child History Questionnaire

SUDANESE HEALTH STUDY

Child History (from Mother and/or Father)

We are now going to ask you questions about your children

Child History Form:

1. Child ID#___________

2 What is your child's name? (First and last name) ________________________

3. What is your child's birthdate? (mm/dd/yy)________________

4. What is your child's gender? …….Male 1 Female 2

5. What is his/her current school grade? (K-12) __________

6. Please list all of the countries this child has lived in prior to coming to the United States starting from birth:

Country	How old was your child when first moved there?	How many months did they live there?	Code (leave blank)
___________	Birth ___________	___________	___________
___________	___________	___________	___________
___________	___________	___________	___________
___________	___________	___________	___________

8. Does your child have any health problems or have they had any health problems in the past that required treatment by a health care provider?

Yes ………………… 1
No ………………….. 2
Don't know………… 8

Child History Questionnaire Continued

If yes, what is/was the problem?

	Health Concern	Code	Months			HCP		Current	
	Health Concern	Code	Months	Yes	No	Yes	No	Medication	Code
9	______________	______	_______	1	2	1	2	__________	______
10	______________	______	_______	1	2	1	2	__________	______
11	______________	______	_______	1	2	1	2	__________	______
12	______________	______	_______	1	2	1	2	__________	______
13	______________	______	_______	1	1	1	2	__________	______

Diet Quality Questionnaire

SUDANESE HEALTH STUDY
Diet Quality Questionnaire - Children

1. How many meals do you have in a normal day?
    - One
    - Two
    - Three
    - More than three times

2. How many times do you have a dessert a day?
    - One
    - Two
    - Three
    - More than three times

3. How many snacks do you have in a normal day?
    - One
    - Two
    - Three
    - More than three

4. When you have a snack, how often do you eat each of the foods listed below?

   (Please circle the number)

	rarely	sometimes	often	most often	usually
Fruits	1	2	3	4	5
Vegetables	1	2	3	4	5

Diet Quality Questionnaire Continued

Pastry/ Pasta	1	2	3	4	5
Sweets/Dessert	1	2	3	4	5
Candy	1	2	3	4	5
Chips	1	2	3	4	5
Nuts	1	2	3	4	5

5. Do you usually enjoy fast food?
   - Yes
   - No
6. What's your favorite fast food place?
   - McDonald's
   - Wendy’s
   - Dunkin Donuts
   - Burger King
   - Subway
   - Others
   - Hardee’s
   - Sonic
7. Why do you like the place you chose above the best? Please select all that apply.
   - It has good food
   - It has good service
   - It is cheap
   - It has a nice drive through if I am in a hurry it and it is clean inside too
   - It has the coffee I need to get by in the morning
   - Others
8. How often do you eat fast food?
   - Everyday
   - Once a week

Diet Quality Questionnaire Continued

- Twice a week
- Three or more times a week
- Once a month
- A few times a month
- Whenever I absolutely must
- Never

9. What do you usually order when you get fast food?

- A burger
- A cheeseburger
- Chicken pieces
- A salad
- French fries
- Others:

High Calcium Food Frequency Questionnaire Version 1

SUDANESE HEALTH STUDY
Food Frequency Questionnaire – Child

High Calcium Food Choices *We would like to get an idea of your general diet.* *Please indicate how often you consumed each type of food in the last year.*					
	Day	Week	Month	Year	Rarely/Never
Hamburgers or beef any kind					
Cheeseburgers					
Lamb					
Chicken - any kind					
Sardines (Any Brand)					
Tuna fish/fish sandwich/cod/etc.					
Spaghetti/lasagna/pasta & tomato sauce					
Pizza (two slices)					
Macaroni & cheese/ cheese potatoes/etc.					
Baked beans/lima/pinto					
Tofu - half cup					
Tomatoes/tomato juice					
Broccoli/collards/greens					
Green salad					
Potatoes-any kind					
Creamed soup					
Oranges/tangerines/grapefruit (actual fruit)					
Orange or grapefruit juice					
Eggs					
Waffles/ pancakes					
White bread / rolls / crackers					
Dark bread / corn bread / muffins					
Kisra (Arabic bread)					
Cottage cheese - half cup					
Cheese (any kind-one slice or a spread)					
Yoghurt – reg (LABAN)					
Cream Cheese (Labanah)					
Goat Cheese (any brand)					
Yogurt - low fat or frozen					
Whole milk-one glass					
2% or 1% milk-one glass					

High Calcium Food Frequency Questionnaire Version 1 Continued

Skim milk-one glass					
Ice cream - half cup					
Pudding - half cup					
Chocolate candy - one bar					
Coffee (reg) with milk or cream - one cup					
Coffee (decaf) with milk or cream - one cup					
Black or sweetened coffee or tea (reg)					
Black or sweetened coffee or tea (decaf)					
Tea with milk or cream					
Caffeinated soft drinks - one can					
Bagel/English muffin					
Cereal fortified with calcium					
Juice fortified with calcium					
Donuts / cookies / cake / pastry					
Lubini beans – (Termus)					
Okra (cooked or raw)					

These next questions are about times that you may have tried to lose weight or gain weight.

10. Have you ever tried to lose weight?

Yes ………………….	1	[if yes, go to # 2a]
No …………………..	2	[if no, go to # 3]

2. Interviewer: Ask, "what did you do to lose weight?" (listen to the participant's response and select one of the following categories. Do not lead with the definitions. More than one may apply).

2a. Defined weight management

____

[Any structured weight management program, including but not limited to Weight Watchers, Atkins, grapefruit, Zen macrobiotic, vegetarian, Tops, physician or dietician prescribed programs, exercise.]

High Calcium Food Frequency Questionnaire Version 1 Continued

Yes …………………. 1
No ………………….. 2

2b. Restrained eating ____

[Any efforts to limit or restrict total intake that do not fit with a structured program. Skipping meals, eating less than they want, going hungry, eating partial portions.]

Yes …………………. 1
No ………………….. 2

2c. Purged ____

[Any efforts that include vomiting, excessive exercise and or chewing food and spitting it back out.]

Yes …………………. 1
No ………………….. 2

Thumbnail sketch Comments from interviewer:

3. Have you tried to gain weight?

Yes …………………. 1
No ………………….. 2

Interviewer: Ask generally, what they did to gain weight (listen to the participant's response and briefly describe in the thumbnail sketch).

Thumbnail sketch of weight gain efforts

4. What do you do to gain weight?

High Calcium Food Frequency Questionnaire Version 2

SUDANESE HEALTH STUDY
Food Frequency Questionnaire – Child

Group of Food Item	Portion size	No of Items
Milk		
1. Breakfast	Glasses	
2. Before lunch	Glasses	
3. Lunch	Glasses	
4. Afternoon	Glasses	
5. Dinner	Glasses	
6. Evening	Glasses	
Other Kinds Of Milk (E.G. Coca Milk)	Glasses	
Yoghurt	Glasses	
Cream Cheese	Spoon	
Cereal	cup	
Cheese	Slices	
Bread	Slices of Bread	
Eggs	numbers	
Nuts	Handful	
Ice Cream	Cup/ Glasses	
Chocolate	Bars	
Fruits 1. Dried 2. Fresh		
Juice	Glasses	
Soft Drinks	Glasses	
Vegetables	Serving size	
Dinner With Meat		
Dinner With Fish		

These next questions are about times that you may have tried to lose weight or gain weight.

11. Have you ever tried to lose weight?

Yes …………………. 1 [if yes, go to # 2a]
No ………………….. 2 [if no, go to # 3]

High Calcium Food Frequency Questionnaire Version 2 Continued

2. Interviewer: Ask, "what did you do to lose weight?" (listen to the participant's response and select one of the following categories. Do not lead with the definitions. More than one may apply).

2a. Defined weight management

____

[Any structured weight management program, including but not limited to Weight Watchers, Atkins, grapefruit, Zen macrobiotic, vegetarian, Tops, physician or dietician prescribed programs, exercise.]

Yes …………………. 1
No ………………….. 2

2b. Restrained eating ____

[Any efforts to limit or restrict total intake that do not fit with a structured program. Skipping meals, eating less than they want, going hungry, eating partial portions.]

Yes …………………. 1
No ………………….. 2

2c. Purged ____

[Any efforts that include vomiting, excessive exercise, and/ or chewing food and spitting it back out.]

Yes …………………. 1
No ………………….. 2

Thumbnail sketch Comments from interviewer:

3. Have you tried to gain weight?

Yes …………………. 1
No ………………….. 2

High Calcium Food Frequency Questionnaire Version 2 Continued

Interviewer: Ask generally, what they did to gain weight (listen to the participant's response and briefly describe in the thumbnail sketch

Thumbnail sketch of weight gain efforts

4. What do you do to gain weight?

Physical Activity Questionnaire

SUDANESE HEALTH STUDY
Physical Activity – Child

We would like to know about the physical activity you have done in the last 7 days. This includes sports, exercise, games or dance that made you sweat, made your legs feel tired, or made you breathe hard, like soccer or weight lifting.
REMEMBER: There are no right or wrong answers – this is not a test. It is OK to ask your parents to help you answer the questions. Please use a black pen to fill out the questionnaire. PLEASE ANSWER ALL QUESTIONS AS HONESTLY AND ACCURATELY AS YOU CAN – THIS IS VERY IMPORTANT.

---

1. PHYSICAL ACTIVITY (Do not include P.E. classes)
Have you done any of the following activities in the LAST 7 DAYS? If yes, put an "X" in the box that matches how many times per week you did each individual activity and write down, on average, how many minutes at a time you did it. "X NONE" if you did not do the activity. Finally, if the activity was organized, that is a coached sport or lessons, put an "X" in the "Yes Organized" box. Start with today and go backwards for seven days total. Note: Put an "X" in only one box per row for "Times in the Last Week."

	Times in the Last Week					Organized	
	None	1 to 2	3 to 4	5 to 6	7 or more	Yes	No
Aerobic Dance	☐	☐	☐	☐	☐	☐	☐
Baseball, Softball	☐	☐	☐	☐	☐	☐	☐
Basketball	☐	☐	☐	☐	☐	☐	☐
Bicycling, Scooter	☐	☐	☐	☐	☐	☐	☐
Calisthenics, Pilates	☐	☐	☐	☐	☐	☐	☐
Cheerleading, Poms	☐	☐	☐	☐	☐	☐	☐
Dance (Ballet, Jazz, Other)	☐	☐	☐	☐	☐	☐	☐
Football	☐	☐	☐	☐	☐	☐	☐
Golf	☐	☐	☐	☐	☐	☐	☐
Gymnastics, Tumbling	☐	☐	☐	☐	☐	☐	☐
Horseback Riding	☐	☐	☐	☐	☐	☐	☐
Ice Hockey, Figure Skating	☐	☐	☐	☐	☐	☐	☐
Marching Band, Flags	☐	☐	☐	☐	☐	☐	☐
Martial Arts, Tae Kwon Do	☐	☐	☐	☐	☐	☐	☐
Rock Climbing	☐	☐	☐	☐	☐	☐	☐
Running, Track/Field, Jogging	☐	☐	☐	☐	☐	☐	☐
Skateboarding, Rollerblading	☐	☐	☐	☐	☐	☐	☐
Sledding, Snow Boarding, Skiing	☐	☐	☐	☐	☐	☐	☐

Physical Activity Questionnaire Continued

Soccer	☐	☐	☐	☐	☐	☐	☐
Swimming	☐	☐	☐	☐	☐	☐	☐
Tennis, Badminton, Racquetball	☐	☐	☐	☐	☐	☐	☐
Treadmill, Elliptical, Cardio	☐	☐	☐	☐	☐	☐	☐
Volleyball	☐	☐	☐	☐	☐	☐	☐
Walking Briskly for Exercise	☐	☐	☐	☐	☐	☐	☐
Weight Lifting	☐	☐	☐	☐	☐	☐	☐
Wrestling	☐	☐	☐	☐	☐	☐	☐
Other (list)	☐	☐	☐	☐	☐	☐	☐
Other (list)	☐	☐	☐	☐	☐	☐	☐

For the rest of the questions, please put an "X" in the box beside the one best answer for each question.

2. In the last 7 days, DURING YOUR PHYSICAL EDUCATION (P.E.) CLASSES, how often were you very active (playing hard, running, jumping and throwing)? Mark the first one if you did not have P.E. in the last week, or if your school does not have P.E. Mark only one.

☐ I didn't do P.E. in the last seven days
☐ Hardly ever
☐ Sometimes
☐ Quite often
☐ Always

3. In the last 7 days, on how many days DURING THE MORNING were you very active (for example: playing sports, exercise classes, strenuous work activity)? Morning means the time after waking and before lunch. Mark only one.

☐ None
☐ 1 morning in the last week
☐ 2 to 3 mornings in the last week
☐ 4 to 5 mornings in the last week
☐ 6 to 7 mornings in the last week

4. In the last 7 days, what did you normally DO AT LUNCH (besides eating lunch)? Mark only one.
☐ Sat down (talking, reading, doing school work)
☐ Stood around or walked around
☐ Ran, exercised, or played a little bit
☐ Ran, exercised, or played quite a bit

Physical Activity Questionnaire Continued

☐ Ran, exercised, or played hard most of the time

5. In the last 7 days, on how many days DURING THE AFTERNOON were you very active (for example: playing sports, exercise classes, strenuous work activity)? Afternoon means the time after lunch before dinner. Mark only one.

☐ None
☐ 1 afternoon in the last week
☐ 2 to 3 afternoons in the last week
☐ 4 to 5 afternoons in the last week
☐ 6 to 7 afternoons in the last week

6. In the last 7 days, on how many days DURING THE EVENING were you very active (for example: playing sports, exercise classes, strenuous work activity)? Evening means the time after dinner. Mark only one.

☐ None
☐ 1 evening in the last week
☐ 2 to 3 evenings in the last week
☐ 4 to 5 evenings in the last week
☐ 6 to 7 evenings in the last week

7. How many times did you do sports, dance, play games, strenuous work, or exercise in which you were very active LAST WEEKEND (Saturday and Sunday)? Mark only one.

☐ None
☐ 1 evening in the last weekend
☐ 2 to 3 evenings in the last weekend
☐ 4 to 5 evenings in the last weekend
☐ 6 to 7 evenings in the last weekend

8. Which ONE of the following five statements describes you best for the last 7 days? Read all 5 before deciding on the one answer that describes you. Mark only one.

☐ All or most of my free time was spent doing things that involved little physical effort, for example, watching TV/videos/DVD, doing homework, doing instant messaging/email/internet, or playing video/computer/electronic games.
☐ I sometimes (1 to 2 times in the last week) did physical things in my free time, for example, played sports, went running, swimming, bike riding, did aerobics.
☐ I often (3 to 4 times in the last week) did physical things in my free time.
☐ I quite often (5 to 6 times in the last week) did physical things in my free time.
☐ I very often (7 or more times in the last week) did physical things in my free time.

Physical Activity Questionnaire Continued

9. How many hours per day did you WATCH TELEVISION in the last week? Include the time you spent watching movies or programs on video or DVD. Do not count television or videos watched in school. Mark only one.

☐ I watched less than 1 hour/day or not at all.
☐ I watched at least 1 hour/day, but less than 2 hours/day.
☐ I watched at least 2 hours/day, but less than 3 hours/day.
☐ I watched at least 3 hours/day, but less than 4 hours/day
☐ I watched 4 hours/day or more.

10. How many hours per day did you PLAY VIDEO, COMPUTER, OR ELECTRONIC GAMES in the last week (for example: Playstation®, X-Box®, Wii®, computer games, or games on the web)? Mark only one.

☐ I did these less than 1 hour/day or not at all.
☐ I did these at least 1 hour/day, but less than 2 hours/day.
☐ I did these at least 2 hours/day, but less than 3 hours/day.
☐ I did these at least 3 hours/day, but less than 4 hours/day.
☐ I did these 4 hours/day or more.

11. How many hours per day did you do instant messaging, email, or browse the Internet in the last week? Do not count school or work-related computer use. Mark only one.

☐ I did these less than 1 hour/day or not at all.
☐ I did these at least 1 hour/day, but less than 2 hours/day.
☐ I did these at least 2 hours/day, but less than 3 hours/day.
☐ I did these at least 3 hours/day, but less than 4 hours/day.
☐ I did these 4 hours/day or more.

12. How many MINUTES PER DAY did you talk or text on a phone in the last week? Do not count school or work-related phone use. Mark only one.
☐ I talked/texted on the phone less than 15 minutes/day or not at all.
☐ I talked/texted on the phone at least 15 minutes/day, but less than 30 minutes/day.
☐ I talked/texted on the phone at least 30 minutes/day, but less than 60 minutes/day.
☐ I talked/texted on the phone at least 60 minutes/day, but less than 120 minutes/day (less than 2 hours/day)
☐ I talked/texted on the phone 120 minutes/day or more (2 hours/day or more)

13. Were you SICK in the last week, or did anything prevent you from doing your normal physical activities?
☐ Yes
☐ No
If yes, what prevented you?
____

Physical Activity Questionnaire Continued

14. How often did you participate in physical activity (like playing sports, dancing, exercising, or any other physical activity) for each day in the last week? Work back 7 days from today and be sure to include spare time, sports teams, work-related activities, and school activities like P.E., intramurals, and athletics.

	None	Little Bit	Medium	Often	Very Often
Monday	☐	☐	☐	☐	☐
Tuesday	☐	☐	☐	☐	☐
Wednesday	☐	☐	☐	☐	☐
Thursday	☐	☐	☐	☐	☐
Friday	☐	☐	☐	☐	☐
Saturday	☐	☐	☐	☐	☐
Sunday	☐	☐	☐	☐	☐

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