Growth, Body Composition and Nutritional Status of Children and Adolescents in Lafia and Doma Local Government Areas of Nasarawa State, Nigeria

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DECLARATION

I Monday Nwankwo declare that the work in the thesis titled **''Growth, Body Composition and Nutritional Status of Children and Adolescents in Lafia and Doma Local Government Areas of Nasarawa State, Nigeria"** was carried out by me in the Department of Human Anatomy, Faculty of Basic Medical Sciences, Ahmadu Bello University, Zaria. The information used for my literature review was fully acknowledged in the text and references. This thesis has not been presented in any scientific gathering, neither has it been presented for another degree or diploma at any University.

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CERTIFICATION

The thesis, titled **Growth, Body Composition and Nutritional Status of Children and Adolescents in Lafia and Doma Local Government Areas of Nasarawa State, Nigeriaby Monday NWANKWO** meets the regulations governing the award of degree of Master of Science in Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literacy presentation.

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DEDICATION

This thesis is dedicated to the memory of my late parents. May this work stand as a small gesture of my abiding gratitude.

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ABBREVIATIONS

The following abbreviations are used in this study:

AUC: Area Under Curve

BAZ: BMI-for-age Z-score

BMI: Body mass index

CDC: Centre for Disease Control

CED: Chronic Energy Deficiency

FN: False Negative

FP: False Positive

HAZ: Height-for-age Z-score

LGA: Local Government Area

LMS: Lamda, Mu and Sigma

MAM: Moderate Acute Malnutrition

MUAC: Mid-upper arm circumference

NCHS: National Centre for Health Statistics

NHANES III: Third National Health and Nutrition Examination Survey

NHBPEP: National High Blood Pressure EducationProgram

NPV: Negative Predictive Value

OR: Odds ratio

ROC: ReceiverOperating Characteristic Curve

PPV: Positive Predictive Value

SAM: Severe Acute Malnutrition

SD: Standard Deviation

SN: Sensitivity

SP: Specificity

TN: True Negative

TP: True Positive

UAFA: UpperArm fat area

UAMA: UpperArm muscle area

UNICEF: United Nations Children's Fund

WAZ: Weight-for-age Z-score

WHO: World Health Organization

WHZ: Weight-for-Height Z-score

YI: Youden Index

ABSTRACT

Assessment of nutritional status of children and adolescents is a good indicator of socio-economic growth of a community. The best worldwide indicator of children and adolescents' well-being is growth. The assessment of growth provides information about health and nutritional status of children and adolescents. In Nigeria, little attention is paid to the growth of children > 5 years. As a result, data on growth and nutritional status of children and adolescents in Nigeria are limited. Anthropometric measures have long been used for assessments of growth and nutritional status, but percentile ranges for healthy Nigerian children and adolescents are currently unavailable. Anthropometric and socio-demographic data from 7,321 children and adolescents from Nasarawa State were collected from preschool, nursery, primary, junior and senior secondary schools from Lafia (urban setting) and Doma (rural setting) Local Government Areas. The nutritional status was examined by converting measurementsto z-scores using the World Health Organization growth reference. z-scores for height <-2 and <-3 were considered as moderate stunting and severe stunting (that is, shortstature); BMI z-scores <-2 and <-3 were considered as moderate thinness and severe thinness (or underweight) and those> +1 and > +2 as overweight and obesity, correspondingly. Meanz-scores and the prevalence below or above these cut-offswere calculated by age and sex. Deviation from the expectedmean of zero was tested with a one-sample *t*-test within agegroups, and differences in mean z-scores between boys andgirls with an unpaired sample *t*-test.The Lamda, Mu and Sigma (LMS) method was used to constructsix (6) smoothed-percentile reference curves and the LMS parameters needed for z-score estimation by age and sex were generated. The prevalence of moderate and severe stunting for the overall population are 20.3% and 6.5%, respectively, whereas, the prevalence of moderate and severe thinness for the combined population were 32.6%

and 14.2%respectively. The prevalence of overweight and obesity were respectively 2.7% and 0.6%. The prevalence of stunting and thinness were higher in boys (21.1% and 36.1% respectively) than in girls (18.0% and 29.5% respectively). Compared to the WHO reference, percentiles of height and BMI of children and adolescents from Nasarawa State were generally lower. This difference was appreciably more pronounced in boys than in girls. Age- and sex-specific-smoothed-percentiles and corresponding LMS variables for height, weight, BMI, skinfold thicknesses (biceps, triceps, sub-scapular and supra-iliac), MUAC and its derived measures (UAMA and UAFA) were fitted. Multiple logistic regression demonstrated that moderate stunting was affected by father's educational background, compared to mother's level of education. In contrast, severe stunting had stronger association with mother's level of education than father's educational background. However, ethnicity was not associated with stunting. Parent's educational background was not associated with moderate thinness. However, father's level of education showed stronger association with severe thinness compared to mother's level of education. Moreover, stepwise logistic regression showed the order of influence of parent's level of education as mothers with no formal education > father with no formal education > father attaining primary education > mother attaining secondary education. In conclusion, this study revealed a high prevalence of stunting, thinness and low level of overweight and obesity among children and adolescents from Lafia and Doma Local Government Areas indicating growth faltering and malnutrition. Children and adolescents from these Local Government Areas fall below WHO centile references. This study established up-to-date centile curves for height, weight, BMI, MUAC and its derived measures and skinfold thicknesses. These reference curves describe the current status of these anthropometric markers and can be used as a basis for comparison in future studies.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Growth has been much used as the best global indicator of well-being in children and adolescents. Anthropometric evaluation of school-aged children and adolescents alike encompasses the use of growth standard and/or reference for determining their growth pattern, nutritional status and well-being (Wang *et al.,* 2006). Growth reference/chart is a distribution used for comparative purposes while a growth standard shows optimal growth all children have capacity to attain (WHO MGRSG, 2006). The major significance of growth monitoring at infancy is to assess the sufficiency of neonatal feeding in physiological or pathological conditions (Sachs *et al*., 2006). Subsequently, it is an early indicator of adverse health conditions to achieve the most desired care in order to minimize chances of morbidity and mortality (Scherdel *et al*., 2016).

Assessment of anthropometric measure is a rapid non-invasive and inexpensive means of screening for growth, undernutrition (such as underweight, stunting and wasting), overnutrition (such as overweight and obese) and well-being in children and adolescents(WHO 1995; Wang *et al*., 2006; AAP, 2014). The WHO growth references have historically harped on undernutrition than overnutrition despite the growing need to deal with obesity problem (Araújo *et al.,* 2017). Nevertheless, double burden of malnutrition is a major public health problem around the globe, with the industrialized and transitional economies dealing with effects of overnutrition while developing countries for instance sub-Saharan Africa such as Nigeria experiencing more of alarming level of undernutrition among the poor and growing level of overnutrition among the elites

(Wright*et al.,* 2018) . The WHO estimates that 18% of children and adolescents aged 5 to 19 years worldwide were either overweight or obese in 2016 (WHO, 2017). Despite this rise in overweight and obesity, the prevalence of stunting continues to be on the increase, at about 40% in Africa, a rate that couldn't plummet in the past three decades ago and the level has not been promising to decrease (de Onis *et al.,* 2011).

Height and weight are the common anthropometric indicators for monitoring growth, nutritional status and general well-being. However, weight is recognized as by far being more sensitive than height in infants (Ong *et al.,* 2000). Height is said to reflect chronic responses to stress while weight reflect acute response to stress (Cameron, 2007). Since the physical growth of children is sensitive to environmental stressors, growth is both an indicator of well-being and health at individual and population level (Goldstein and Tanner, 1980; Henneberg and Louw, 1998;Nhantumbo *et al*., 2013). It is generally believed that the response of child to environmental stress is to grow slower (Cameron, 1991). As a result, growth of children in developing countries where environmental stressors are common on the child has led to lower increments of height and weight gain and being lower than median following weaning (Cameron, 2007).

Historically, health-care providers globally have used national growth references mostly produced in industrialized countries. In 2006, the WHO developed and published growth standards from birth to 5 years of age and birth reference for school-aged children and adolescents aged 5 to 19 years (WHOMGRSG, 2006; de Onis *et al.,* 2007), and recommended their use all over the world (de Onis *et al.,* 2012). The 2006 growth standard was developed to overcome the limitations of the 1978 WHO/NCHS Growth References (Wang *et al.,* 2006). One of its major limitations is its representativeness; the growth

reference for children ages 0 to 23 months was based on data collected from a group of mainly formula-fed children in the Ohio Fels Longitudinal Study. Furthermore, studies have revealed difference in growth pattern of formula-fed babies from that of breast-fed babies (Victora *et al*., 1998; de Onis and Onyango 2003). The WHO2007 Growth Reference was developed based on recommendations made by experts in 2006 to show continuity with the 2006 growth standard and to address the imperfections in previous growth references and of particular interest is to address how undernutrition and overweight are assessed (Wang *et al.,* 2006).

The demographic health survey in Nigeria conducted by National Centre for Health Statistics have often studies the growth and nutritional status of children 0 to 59 months old. Thus, there is no domestic study with cross-national outlook in Nigeria, with population well over 200 million that has documented the nutritional status of children and adolescents. Such study is expected to consider the peculiarities of Nigerian children and adolescents in terms of demography, environment, socio-economic conditions, lifestyle and diet. This has become necessary because both genetic and environmental factors impact the growth of a child(Tanner, 1962; Eveleth and Tanner, 1990; Haa and Campirano, 2006; Wang *et al.,* 2006).

MUAC measures the diameter of the upper arm and along with triceps skinfold thickness (TSFT) gauges both subcutaneous fat stores and muscle mass (Frisancho, 1981). The measurement of MUAC has been used for children and occasionally applied to pregnant women to rapidly assess nutritional status (WHO, 2013). Its measurement is simple and requires minimal equipment, MUAC can serve as an alternative index of nutritional status,

especially in situations whereby measurements of height, weight or age are not feasible to collect or in cases of bedbound or amputated patients (Addo *et al.,* 2017).

Although the WHO did not include the MUAC in the 2007 growth charts for school children and adolescents aged 5 – 19 years (WHO, 2006; Mramba *et al.,* 2017), the Multicentre Growth Reference Study Group considered it for children 0 – 59 months (WHO, 2006). However, only limited reference data (6 – 59 months of age) for MUAC have been published. In children aged 0 – 59 months old, the WHO/UNICEF joint statement recommends the use of MUAC and weight-for-height z-score (WHZ) with cut-off points < 115 mm and <−3, respectively for identification of severe wasting (WHO/UNICEF, 2009; WHO, 2013). However, the data between these two indicators are inconsistent when classifying different children as severely wasted (ENN,2012; Laillou *et al.,* 2014). Additionally, the indicators predict mortality risk in children differently with MUAC having better predictive performance than WHZ (Briend and Zimicki, 1986; Briend *et al.,* 1987; Briend *et al.,* 2012).

Recently, analysis of MUAC body composition and its derivative outcome indicators; upper arm muscle area (UAMA) and upper arm fat area (UAFA) references have been published (Oyhenart *et al.,* 2019) among Argentinian children and adolescents, similar to the one earlier published by Frisancho (2008) and Addo *et al*. (2017) of children and adolescents in the US.

Skinfold is a fold of skin formed by pinching or compressing 2 layers of the skin and its underlying subcutaneous layers in order to measure fat in specific part of the body. Skinfold has long been used as a measure of nutritional status (Heyward and Wagner, 2004;

Wells and Fewtrell, 2006; Addo and Himes, 2010). Skinfold thickness evaluation are inexpensive, non-invasive and simple anthropometric technique for assessing body composition, body somatotype and nutritional status (Wagner and Heyward, 1999; Goodpaster, 2002; Steinberger *et al*., 2005; Suliga, 2006; Wells and Fewtrell, 2006; Fichna and Skowrońska, 2008; L'Abée *et al*., 2010). In view of the likely striking inequalities in anthropometrics due to genetic, demographic, sex, age, socio-economic status and cultural divide and for the purpose of comparison, it is important to develop local reference values at national level that account for the perculiarities of Nigeria's socio-demographics.

Abnormal accumulation of subcutaneous adipose tissue assessed with skinfold thicknesses has been found to be related to dyslipidaemia, which increased the risk of atherosclerosis, coronary heart disease, metabolic syndrome, stroke and hypertension (Freedman *et al.,* 1999; Steinberger *et al.,* 2005; Andaki *et al.,* 2017).

Some countries have developed their reference values from national studies (Addo and Himes, 2010; Jaworski *et al.,* 2012; Kuhle *et al.,* 2016). Nigeria has no national reference values for skinfold thicknesses for children and adolescents. The few available studies in which skinfold were measured were not rigorous and not robust enough and are flawed in many respects especially in their methodological design such as sampling method, for instance use of non-representative data from regions, heterogeneity of measurement techniques and sampling and poor statistical power in some age categories (Izuora *et al.,* 2008; Senbanjo *et al*., 2014; Amoo-Tella *et al.,* 2017).

In order to address this lack of recent anthropometric data at national and sub-national levels, this cross-sectional study is designed with the primary aim to assess physical

growth, nutritional status and to provide reference percentiles for height, weight, body masss index (BMI), skinfold thicknesses, MUAC and its derivatives. Further, the summary values of lamda mu and sigma (LMS) parameters will allow for the calculation of corresponding z-scores standardized for age and sex groups. Finally, the study assesses the accuracy of MUAC as proxy screening tool for thinness and severe thinness compared to BMI-for-age z-score (BAZ) and generated appropriate MUAC cut-offs specific for age and sex for screening thinness and severe thinness among school-aged children and adolescents in Nasarawa State.

1.2 Statement of Research Problems

Nutritional status has long been used as anthropological means of identifying individuals in dire need of intervention and as indicator of the general well-being of the population. Nevertheless, there are no studies with representative samples of children and adolescents from Nasarawa state that has estimated the prevalence of undernutrition (for example, underweight, stunting and wasting)and overnutrition (that is, overweight and obesity) using the WHO reference. Previous studies that have attempted to estimate prevalence of undernutrition and/or overnutrition are marred either by their sample size (that should provide adequate statistical power for estimating prevalence of undernutrition and for generating percentile references), sampling or methodological techniques. Mid-upper arm circumference has long beenused in anthropometric assessments of nutritional status in fieldsettings, especially in emergency situations, but percentile rangesfor Nigerian children are currently unavailable.Skinfold thicknesses have long been considered importantand valid measurements of subcutaneous fat. Nevertheless,there are no current skinfold reference data for Nigerian children andadolescents.

1.3 Justification

Despite the need for regular updates of anthropometric measures in order to guarantee sensitivity and specificity of physical growth data, no study has been organised to establish the nutritional status and the centile patterns of height, weight and BMI values of children and adolescents in Nigeria with representative sample size. Heretofore, reference percentile ranges and smoothed z-scores for height, weight, BMI, skinfold thicknesses, MUAC and its derivations have not been available for representative sample of Nasarawa State children and adolescents. The new reference ranges and z-scores may greatly facilitate comparisons across ages, between sexes, among other anthropometric indicators. The present study may be considered as a first step towards opening a dialogue on the need for cross-sectional national survey to determine the nutritional status and growth patterns of children and adolescents in Nigeria and to generate local reference data that considered the peculiarities of Nigeria's socio-demographic settings.

1.4 Aim and Objectives of the Study

1.4.1 Aim

To assess the growth pattern, nutritional status and body composition of children and adolescents in Lafia and Doma, Nasarawa State Nigeria and to develop reference curves for height, weight, BMI, skinfolds thicknesses, MUAC and its derived measures.

1.4.2 Objectives

The present study was intended to achieve the following specific goals. These were to:

i. assess the nutritional status of school-aged children and adolescents according to the WHO (2007) reference;
ii. develop reference curves for height, weight and BMI of children and adolescents aged 5 – 19 years;
iii. develop reference curves for MUAC and derivedmeasures of UAMA and UAFA;
iv. develop new percentile reference curves for biceps, triceps, sub-scapular and supra-iliac(otherwise known as iliocristale) skinfold thicknesses;
v. generate values of LMS parameters that allow for the calculation of corresponding z-scores standardized for age and sex groups as a useful nutritional-status assessment tool;
vi. assess the accuracy of MUAC compared with BMI-for-age z-scores (BAZ); and
vii. identify appropriate MUAC cut-offs for screening thinness and severe thinness in children and adolescents from Nasarawa State by year and age group.

1.5 Study Hypotheses

Due to the precarious living conditions in Nasarawa state, the distribution of height, weight andBMI will be below the WHO 2007 reference, similar to patternsobserved in other sub-Sahara African countries and, consequently,there will be high prevalence of stunting, underweight andthinness and low prevalence of overweight and obesity. For the same reason, MUAC, UAMA and annulus of fat in Nasarawa State children and adolescents will consistently be lower compared to international reference.

1.6 Limitations of the Study

The study has some limitations. One of such limitations is the limited number of study participants per age and our inability to measure skinfold of some age groups. Such sample

size limitation weakens statistical power of the results especially at extreme ages. Data were collected from schools and clinics, thereby excluding out-of-schoolchildren, those absent from school in the day of data collection, or those in internally displaced persons camps. Also, permission was not granted for data collection from some schools recruited *ab initio*. We did not account for the impact of socio-demographic factors on nutritional status.

The skinfold reference data provided in this study presents the prevailing skinfold thickness of children and adolescents in Nasarawa State, Nigeria and should not be considered as standard of skinfold thickness or growth standard of children in Nigeria since participants were not recruited based on "optimal conditions" such as healthy environmental conditions rather the data should be considered as a reference for future studies both in Nigeria and sub-Saharan Africa. Needless to say, to our knowledge, the present study was one of the first in Nigeria and sub-Saharan Africa to develop centile curves for four skinfold thicknesses that adopts a methodology in keeping with current recommendations regarding sampling techniques and curve fitting by the WHO (Borghi et al., 2006). Although these curves are generated based on data from children and adolescents from Nigeria, it is believed that they can also be useful in other regional countries with similar socio-demographic and economic settings.

Unfortunately, some of the limitations of the study include its use of cross-sectional data collection and limited sample size. Longitudinal data are more appropriate for determining subcutaneous fat distribution in growing children than cross-sectional as the former has the advantage of showing changes in fat distribution during child growth and development than the latter. The flexibility that goes with Box-Cox Power transformation smoothing techniques may lead to curves with slightly different fitting based on the choice of

parameters entered by the investigator. In addition, data collection began at age 3 years, which made it impossible to capture changes in skinfold thickness among younger children, especially for children under five years.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Development of Anthropometric References

Anthropometry is the single most portable, universally applicable,inexpensive, and non-invasive method available toassess physical growth, nutritional status and body composition of children and adolescents. It is used forselecting individuals and populations for health and nutritioninterventions, as well as for monitoring their health andnutrition (Wang and Cheng, 2012).For physical growth and nutrition evaluation, accurate and valid anthropometric classificationis an essential step. Anthropometric indicatorsmay be developed based onan internal standard within a specific study, from a localgrowth reference, or from the international growth reference.Irrespective of the reference population used, ananthropometric indicator provides a measure of an individual'sgrowth status in relation to the reference median,expressed either as a percentile, a percentage of thereference median, or as a proportion of the standard deviationoften referred to as a z-score (Wang and Cheng, 2012). The use of z-scores to express anthropometric statusin relation to the international growth reference was proposedby Waterlow *et al*. (1977) to ensure that a single z-scorecut-off point would be comparable across all indicatorsand at all ages (Keller and Filmore, 1983).The use ofa referencepopulation makes it possible to compare the growth statusofchildren ofdifferent ages and makes it feasible to assessanthropometric status in population studies and in surveillanceprograms (Waterlow *et al*., 1977; Keller and Filmore, 1983).

Anthropometric charts are clinical and nutritional tools used for identifying normal and abnormal variations in various settings, such as growth monitoring, imaging and clinical

genetics.In early postnatal life, the main purpose of growth monitoring is to evaluate the adequacy of infant feeding in physiological or pathological situations (Sachs *et al.,* 2006). Later, its main purpose is to contribute to the timely detection of serious health conditions to provide optimal care and reduce morbidity and mortality (Scherdel *et al.,* 2016). Growth monitoring requires the use of growth standards or references for comparing observed values in a child with expected values among their peers.In practical terms, anthropometric values are comparedacross individuals or populations in relation to an acceptableset of reference values.Use ofa single international reference population allowscomparison ofresults among different nutrition and healthstudies and, thus, greatly assists the interpretation of results (WHO, 1995).

2.2 Infants and Children

Growth assessment is the single measurement that best definesthe health and nutritional status of children becausedisturbances in health and nutrition, regardless of their aetiology,invariablyaffect child growth. The most commonly usedanthropometric indexes for assessing child growth are weight-for-height, height-for-age and weight-for-age (WHO, 1995; Alderman 2000).

The issue of which reference population to use in assessingthe adequacy of growth during childhood has received considerableattention in the last decades. The WHO adopted thereference curves of the National Centre for Health Statistics (NCHS) for international use (Waterlow *et al*., 1977) based onthe then growing evidence that the growth patterns of well-fed,healthy preschool children from diverse ethnic backgrounds aresurprisingly similar (Habicht *et al*., 1974). Differences of genetic origin areevident for some

comparisons; however, these variations arerelatively minor compared with the large worldwide variationin growth related to health and nutrition (Martorell, 1985). A detailedaccount of the historical background of the currently usedNCHS/WHO growth charts, together with a discussion of someof the contemporary scientific issues, can be found elsewhere(de Onis and Yip, 1996).The international growth reference has served many usefulpurposes by providing a single set of growth references thatpermit comparison of growth data from different populations.However, in part because two distinct data sets were used toconstruct the reference curves, the international growth referencehas important technicallimitations that complicate theinterpretation of growth data from nutrition surveys and surveillance(WHO, 1995; Alderman 2000).

Concern has been expressed that the NCHS/WHOcurves are inappropriate for healthy, breast-fed infants. As partof the preparatory work for the Expert Committee, a WorkingGroup on Infant Growth was established to assess the growthpatterns of infants following current WHO feeding recommendations(WHO, 1995a), and the relevance of such patterns to the developmentof growth reference data. In reviewing the growth ofbreast-fed infants who live under favourable environmental conditionsin different parts of the world, the Working Groupfound significant differences between the growth patterns ofthese infants and the patterns reflected in the NCHS/WHOreference. Infants fed according to WHO recommendations andliving under conditions that favour the achievement of geneticgrowth potential grew less rapidly than, and deviated significantlyfrom, the international reference (de Onis and Habicht, 1996; WHO, 2006a, b). Concerningthe clinical and public health significance of these differences,the Working Group placed particular emphasis on the risksassociated with both the premature

introduction of complementaryfoods and their undue delay and concluded that the NCHS/WHO growth reference has limited value as a tool for the optimalnutritional management of infants (WHO, 1994; 1995a).

However, because of the significant technical draw-backs oftheNCHS/WHO growth reference, especially for population-based applications, an update or replacement in the nearfuture was recommended. Updating a reference, or developingan entirely new one, is an extremely complex, costly, andtime-consuming undertaking. The difficulties inherent in generatingstatistically sound and appropriate growth curves aremany. To be of lasting value, therefore, it is clear that the nextreference must be exceptionally well-prepared. The ExpertCommittee identified some of the desirable characteristics fordata sets to be used in the development of a new referencepopulation (Table 2.1) (WHO, 1995b). Applying the Committee's recommendation, formulation of a truly international referencebased on carefully conducted surveys covering broad populationsfrom several countries might be more acceptable thandata from a single country. This procedure may avert thepolitical difficulties that have arisen from using a single country'schild-growth pattern as a worldwide "standard" for optimalgrowth.

Table 2.1: Desirable characteristics for anthropometric data to be used in thedevelopment of a new international growth reference

No.	Characteristics
1.	Several countries from different geographical regions should beincluded. among them less-developed ones
2.	The sample should be collected from a cross-sectional study of a well-nourished and healthy population with unconstrained growth and should include at least 200 children of each sex per age group
3.	Sample sizes and procedures should be adequate
4.	Raw data should be available
5.	The age range from birth to adolescence should be covered by most dataSources
6.	For adolescents, measures of sexual maturity should be available
7.	Secular trends in growth should be small or absent because they suggestthe presence of growth inhibiting factors in a population
8.	The sampling methods should be well-defined and reproducible and the anthropometric measurements were to have been made by well-trained using well-designed, calibrated equipment
9.	The anthropometricmeasurements were to include a selection of measurementssufficient to evaluate the nutritional status of children
10.	Finally, the anthropometric data were to be availablefor anyone wishing to use them and the procedures usedfor smoothing the curves were to be adequately describedand documented

Adapted from: WHO (1995b)

2.3 Growth and Nutrition of Adolescents

While most growth and nutritional studies have been conducted on children under 5 years of age, studies on adolescence has received less attention. Adolescence is a significant period of human growth andmaturation; unique changes occur and many adult patterns areestablished during this period. In addition, the proximity ofadolescence to biological maturity and adulthood may providefinal opportunities for preventing adult health problems (Rah*et al.,* 2008). Humangrowth and maturation are continuous processes, andtransitions from childhoodinto adulthood are not abrupt (King, 2003). Incontrast with the previous age groups, which are defined bychronologic age, adolescence begins with pubescence, the earliestsigns of development of secondary sexual characteristics,and continues until morphologic and physiologic changes approximateadult status, usually near the end of the seconddecade of life (UNICEF, 2011).

Adolescent nutrition is coming of age, gaining significantattention in the past few years (Bundy *et al.*, 2017; WHO, 2017). The recent surgein population growth makes this the largest generation ofadolescents in history, most of whom live in low- andmiddle-incomecountries (Patton *et al.,* 2016). Although the first 1000 days remains a critical period of physical growth and nutritionalneed, requiring continued high global attention, there is goodreason to also focus on adolescence-generally defined asindividuals aged 10–19years (Georgiadis and Penny, 2017; Sawyer *et al.,* 2018).During the adolescent growthspurt or period of peak height velocity, the growth rate forgirls is similar to-and for boys surpassesthe rate at 2 years of age (Marshall and Tanner, 1986). Adolescence is the only time in life besides earlyinfancy when the velocity of growth increases (Spear, 2002). Duringpuberty, adolescents gain~15% of their final adult height. Byabout age 20 years, 90

– 95% of total peak bone mass is attained,45% of which is built during adolescence (Matkovic *et al.,* 1994; Lytle, 2002; Spear 2002). Weightgain during this period accounts for about half of the idealadult weight. Rapid biological and psychosocial growth anddevelopment increase nutritional needs for both boys andgirls (Das *et al.,* 2017). Finally, recent evidence has reopened the questionof whether interventions during adolescence could redresslinear growth deficits accumulated earlier in life (Prentice *et al.,* 2013; Roberts and Stein, 2017).

Interest in adolescent nutrition has generated evidencereviews (Salam *et al.,* 2016; Lassi *et al.,* 2017; Christian and Smith, 2018; Benedict *et al.,* 2021), new global guidelines (WHO, 2018), internationalmeetings (Krebs *et al.,* 2017; GAIN/WHO, 2018; SPRING, 2018a), donor commitments, and political willto institute new policies and programs (GAIN/WHO, 2018; SCAN, 2021). To effectivelychannel these efforts and resources, precise andcontext-specific evidence is required for decision–makingregarding which adolescent nutrition interventions shouldbe implemented for particular purposes and populations(SPRING, 2018b).

Anthropometric indicator prevalence estimates basedon cross-sectional survey data and the 2007 WHO GrowthReference for children and adolescents 5–19 years old (WHO, 2021)are frequently used to assess and compare the burden ofmalnutrition at a population level, including comparisonsover time and across age subgroups. Several such analyseshave been recently conducted and reviews writtenusing large–scale cross–sectionalsurvey data such as theDemographic and Health Surveys and Global School–BasedStudent Health Surveys (Akseer *et al.,* 2017; Caleyachetty *et al.,* 2018; Christian and Smith, 2018). Although

someof the articles include caveats related to the robustnessof prevalence estimates, the continued use of these data,references, and cut-offs holds substantial risk for misguidedconclusions being reached related to the magnitude anddistribution of nutritional issues in populations (Tumilowicz *et al.,* 2019).

2.4 World-wide Variation in Human Growth and the WHO Growth Standards

For decades, health-care practitioners worldwide have used national growth references mostly produced in countries with advanced economies. The WHO calculated a set of normative curves from the Multicentre Growth Reference Study (MGRS) and published international growth standards from birth to 5 years of age in 2006 and growth references for school children and adolescents aged 5 – 19 years in 2007 (WHO MGRS, 2006; WHO, 2006; de Onis *et al*., 2007; WHO, 2007) and recommended their use in all countries (de Onis *et al.,* 2012).

The WHO refers to its curves as growth standards, ortools that provide a norm or desirable target, that involves avalue judgement, and describe how children 'shouldgrow' in all countries.3–8 Standards are different fromreferences, which show how children are actuallygrowing in a given place and time. The WHO notes thatany deviations from its standards should be consideredas evidence of 'abnormal growth' (WHO, 2006, 2007). To date, over 100 countrieshave adopted the MGRS curves (Grummer-Strawn*et al.,* 2010).

However, the WHO growth charts were found to be imperfectly calibrated with the growth of contemporary children in many developed countries, especially economically advantaged countries, such as France (Scherdel*et al*., 2016). These studies were rigorous. Unfortunately, however, they focus on no more than twocountries or ethnic groups (Anzo

et al., 2002; Gokcay *et al.,* 2008; Daymont *et al.,* 2010; Juliusson *et al.,* 2011; Schienkiewitz *et al.,* 2011; Willows *et al.,* 2011; Tinggaard *et al.,* 2014; Heude *et al.,* 2019), do not compare theirdata with the MGRS data, were published before theMGRS curves (Agarwal and Agarwal, 1994; Fredrik *et al.,* 2000; Anzo *et al.,* 2002; Werner and Bodin, 2006; Gokcay *et al.,* 2008; Zaki *et al.,* 2008) or are written in local languages (Copil *et al.,* 2006; Neyzi *et al.,* 2008; Braegger *et al.,*2011).

The growth of contemporary French children was shown to be closer to the WHO growth charts than the former French national growth charts, except for the first 6 months of life (Scherdel*et al*., 2015). Further, some countries, such as the UK, decided to use the WHO growth charts for young children and national ones after age 4 years, which led to the production of growth charts with a sudden shift in curves at this age (RCPCH, 2013a, b). The consequences of such a choice on the performanceof growth monitoring around this age has not been evaluated (de Onis *et al.,* 2004).

An alternative option would be to update former national growth charts to produce more accurate national growth charts that are perfectly calibrated to the population for which they will be used (Roelants*et al.,* 2009; Júlíusson*et al.,* 2011; Saari*et al.,* 2011; Kułaga*et al.,* 2011, 2012; Karvonen*et al.,* 2012; Tinggaard*et al*.,2014; de Wilde*et al.,* 2015). The collection of massive and representative anthropometric data needed to obtain adequate calibration at the national level is time consuming and costly using classical ad-hoc cross-sectional surveys (Roelants*et al.,* 2009; Saari*et al.,* 2011; Júlíusson*et al.,* 2011; Kułaga*et al.,* 2012, 2011; Karvonen*et al.,* 2012; Tinggaard*et al*.,2014; de Wilde*et al.,* 2015). The recent digital revolution has made available nearly unlimited auxological data routinely collected by health-care professionals. For its appropriateness for use in creating new

growth charts, such data must come from settings with a large national geographical basis and from facilities that care for children from birth to adulthood, who are mostly without chronic diseases that can affect growth (Tinggaard*et al*.,2014; de Wilde*et al.,* 2015).

A much-debated topic is whether a growthchart should be local, national or international(Milani *et al*., 2012). Some authorsagree with the use of international standards(Johnston, 1986), while others argue that estimatingprevalence of malnutrition in certainpopulations and providing an accuratenutritional assessment of specific individualsmay be difficult, suggesting, when possible,constructing new reference values, using localstandards from subjects with a similar geneticcomposition (Cameron, 1986; Marrodán,2005).

In Nigeria, most health facilities adopt the WHO growth standards for children < 5 years and the WHO reference for school children and adolescent. However, the operability and implications of adopting the MGRS charts to contemporary Nigerian children and adolescents has not been elucidated. Also, since the MGRS charts were published, no national study has been conducted that compares the growth pattern of Nigerian children to those used in developing the MGRS charts nor has there been efforts to develop national reference values for height, weight, BMI, MUAC and skinfold thicknesses with nationally representative sample of Nigerian children and adolescents.

The only available national auxological data was for children < 5 years of age often conducted during national health and nutrition survey (NHNS). National data on full anthropometric assessment of children older than 60 months are lacking in Nigeria. This has made the true measure of the impact of undernutrition on school-aged children and

adolescents difficult to obtain. The NHNS does not currently include anthropometric assessment of school-aged children and adolescents; this data deficiency must be addressed to accommodate the collection of such data. Furthermore, anthropometric measurementsare greatly influenced by genetic (Hauspie, *et al.*,1982; Mueller, 1986; Hauspie,1982, 1998), sociocultural (Bielicki and Waliszko, 1991; Skuse, 1998), nutritional, environmental,and economic factors (Habicht,*et al.*,1974; Tanner, 1986;Bustos*et al.*,2001; Vercauteren, 2005; Monnier *et al*., 2011).

2.5 Growth References and Standards

Since the 1970s the WHO has published several versions of growth references, recommended forinternational use to help assess children's growth and nutritional status. Thus far, there are threewidely known and used versions: the 1978 WHO/NCHS Growth References (for children up to age10), the 1995 WHO Growth References (for children and adolescents up to age 19), and the 2006 WHOGrowth Standards (for preschool children, under 6 years of age).Most of the earlier versions are based on growth references developed and used in the US. TheUS CDC/NCHS developed growth references based on national survey data collected in the 1960sand 1970s. These NCHS Growth Charts included anthropometric measurements such as weight-for-height,weight-for-age, height-for-age, and head circumference-for-age. They were developed basedon several national surveys (namely NHES II, NHES III, and NHANES I) and a local study forinfants (the Fels Longitudinal Study). More details about the history of the WHO growth referencesare provided elsewhere (WHO, 1995; Wang *et al.*, 2006; WHO MGRS, 2006a).

2.5.1 The 1978 WHO/NCHS Growth References

In 1978, the WHO/CDC produced a normalized version of the US CDC/NCHS growth curves,showing *Z* -scores instead of absolute anthropometric values. It was called the 1978 WHO/NCHSGrowth References, and has been widely used all over the world since then. However, it has a numberof limitations (Wang *et al*., 2006). For example, one of its main limitations is about representativeness. This is because the growth reference for infants was developed based on data collected from theFels Longitudinal Study, which followed mainly formula-fed children in an area in Ohio State inmid-west of the USA. Moreover, the children were followed with large time intervals, which provided insufficientdata to describe the rapid and changing rate of growth in early infancy(Kuczmarski *et al*., 2002). Recent studies have shown that the growth pattern of breast-fed infantsdiffered from that of formula-fed infants (Victora *et al*., 1998; de Onis and Onyango, 2003). To overcomethese limitations, new growth references and standards have been developed in the US in 2000and by the WHO in 2006, respectively.

2.5.2 The 1995 WHO Growth References

In 1995, a WHO Expert Committee reviewed existing growth references and research findings, andthen re-endorsed the use of the 1978 WHO/NCHS Growth Charts. In addition, for adolescents, thecommittee recommended use of the sex- and age-specific BMI ≥ the 85th percentile and both tricepsand sub-scapular skinfold thickness ≥the 90th percentile for classifying “at risk of overweight” and “overweight” (WHO, 1995). These percentiles were developed based on the US data. Previously theWHO had not made specific recommendation for adolescents. The committee acknowledged theweaknesses of the NCHS infant growth charts, and some potential problems when using these USadolescent BMI percentiles in other populations. For example, their predictability to future healthrisk

and generalizability for children from developing countries was unknown. The committee recommendedthe use of these references on a provisional basis, until better reference data becameavailable (WHO, 1995).

2.5.3 The 2006 WHO Growth Standards for Preschool Children

On April 27, 2006, the WHO released new growth standards for children from birth to the age of 60months (5 years old) (Table 2.2). In order to establish growth standards for differentraces/ethnicities, the MGRS recruited affluent, breast-fed,and healthy infants/children whose mothers did not smoke during or after delivery from six cities inBrazil, Ghana, India, Norway, Oman and USA. This study included a longitudinal samplefollowed from birth to 24-month-old and a cross-sectional sample recruiting 18to 71-month-oldchildren. The MGRS data showed great similarities in growth across all study centres, with onlyabout 3% of the total variation in growth was contributed by race/country. Hence, the multicentredata were pooled for a more powerful sample (WHO MGRSG, 2006a). The data demonstrate thatpreschool children in different regions of the world have the same growth potential to achieve similarlevels of heights and weights when their nutrition and health care needs are met. However, this conclusionwas based on children from birth to 6 years (72 months) of age. Genetic influence on interindividualvariation in the ultimate height in adulthood cannot be ruled out (Hjelmborg*et al.*, 2006).

The WHO recommends these new standards in replace of the old versions for international useamong preschool children, although some countries still use their own growth references/standards.The 2006 WHO Growth Standards include anthropometric indicators such as length/height-for-age, weight-for-age, weight-for-length/height, BMI-for-age, head

circumference-for-age, armcircumference-for-age, sub-scapular skinfold-for-age, and triceps skinfold-for-age. Recumbentlength-for-age was used for indicator of stature from birth to age of 24 months, while standingheight-for-age from 2 to 5 years old. The WHO provides growth charts and tables of percentiles and*Z* -scores, separately for girls and boys. On the *Z* -score growth charts, the curves for 0, ±2, and ±3SD from the age specific median of certain indicator were plotted. As for the percentile charts, fivecurves for the 3rd, 15th, 50th, 85th, and 97th percentiles were shown for each indicator. In thetables, the values of indicator at 0, ±1, ±2, and ±3 SD, and for percentiles of 1st, 3rd, 5th, 15th,25th, 50th, 75th, 85th, 97th and 99th were provided for each age of month.

The 2006 WHO Growth Standards differ from the existing growth charts in many ways. They suggest "how children should grow", which is developed using a prescriptive approach, not just a descriptiveone. They show that all children can attain similar levels of healthy height and weight as long asthey have adequate feeding and health-care. A key characteristic of the new standards is that it presumedbreastfeeding as a biological norm (Wang and Chen, 2012). Furthermore, the pooled sample from the six participatingcountries creates better international standards, in contrast to the previous growth reference based onchildren from a single country. The standards can serve as tools for detecting both under-nutrition andobesity. The standards go beyond the previous references and include indicators like BMI and skinfolds (Addo *et al.,* 2017).These charts are particularly useful in monitoring childhood obesity, which is relevant to publichealth in both developed and developing countries (WHO MGRS, 2006a; WHO, 2006).

2.5.4 WHO 2007 GrowthReference for Children and Adolescents 5-19 Years Old

In 2003, an expert meeting brought together representativesfrom WHO, the United Nations University Food andNutrition Program, and the FAO to consider the feasibilityand appropriateness of developing a single internationalgrowth reference or standard to describe universal growthpatterns of children and adolescents aged 5-19 years (Butte *et al.*, 2007). Theexpert group concluded that it could not be ruled outthat some differences in linear growth across populationsreflect genetics rather than solely environmental factors(Haas and Campirano, 2006).

Therefore, the sampling frame for the developmentof an international growth standard for children >5 years oldwould have to include a multiethnic sample to capturethe variation in human growth patterns. The expert groupalso determined that a prescriptive standard using eitherhistorical or prospective growth data is possible with carefulconsideration of the population and individual selection criteria,study protocol, and statistical methods. Nevertheless,the expert group decided it would not be feasible to conducta prospective, prescriptive,multicentre study, like theMRGS,owing to the difficulty of controlling the dynamics of olderchildren's environments. Turning attention to existing datasets, they found excessive heterogeneity in study designs,socio-economic status of participating children, and other factorscritical to growth curve construction. Subsequently, theexpert group developed the 2007 WHO Growth Reference based on recommendations made in 2006 by reconstructing the 1977 United States NCHS/WHOGrowth Reference whichwas based on US children collected by the US HealthExamination Surveys from 1960 to 1975 (de Onis, 2007).

The expert group recognized the inherent limitation ofusing data based on a single population, which does notaccount for genetic differences in growth potential (Haas and Campirano, 2006; Wang *et al.,* 2006). Nevertheless, the 2007 WHO Growth Reference is animprovement on the NCHS/WHO Growth Reference in thatit includes BMI and the curves align with the 2006 WHOChild Growth Standards at 5 years and recommended adultcut-offs for overweight and obesity. Moreover, the referencepopulation of US children from 1960 to 1975 came frommostly nondeprived circumstances and were yet to be greatlyaffected by the obesity epidemic. If the reference populationwere undernourished, the "true" prevalence of a specifiedindicator of poor nutrition (for example, severe stunting or severethinness) for the study population would be underestimated.Inversely, using a reference with a positively skewed BMIdistribution to assess children worldwide would result in anunderestimation of the prevalence of child overweight andobesity and overestimation of undernutrition. For example,the International Obesity Task Force (IOTF) reference forchildren aged 2-18 years uses data from 6 different countriesand is thus more internationally representative (Cole and Lobstein, 2012; WOF, 2021), butthe IOTF reference is based on more recent data.

Usingthe IOTF reference, compared to the 2007 WHO GrowthReference, results in overall higher estimates of thinnessand lower estimates of overweight and obesity (Abarca-Gómez *et al.,* 2017; WOF, 2021).For each indicator, charts and tables for percentiles and *Z*-scoreswere provided. The percentiles charts draw the 3rd, 15th, 50th, 85th, and 97th percentile curves,while the tables provided the values of anthropometric measures for more percentiles (1st, 3rd, 5th,15th, 25th, 50th, 75th, 85th, 95th, 97th, and 99th). The WHO recommended the cut points for overweight and obesity based on the BMI-for-age*Z*-scores.

2.5.5 Standard Compared with Reference

In 1995, the WHO Expert Committee on Physical Status:the use of and interpretation of anthropometry defined areference as “a tool for grouping and analysing data thatprovides a common basis for comparing populations; noinferences should be made about the meaning of observeddifferences” (WHO, 1995). This contrasts with a standard, which“embraces the notion of a norm or desirable target, and thusinvolves a value judgement” (WHO, 1995). Operationally, a referencedescribes the growth pattern of a specific population,whereasa standard defines a recommended growth pattern thathas been associated with specified health outcomes. Agrowth reference is developed descriptively (Pelletier, 2006). Typically,a nationally representative distribution is constructed usingmild exclusion criteria to select a supposed healthy, well-nourishedpopulation, but the observed distribution issusceptible to being composed of 2 sub-distributions - ahealthy one and an unhealthy one (WHO, 1995; Pelletier, 2006).

In contrast to a growth reference,a growth standard is developed prescriptively (Garza and de Onis, 2004). The2006 WHO Child Growth Standard for children from birthto 5 years (WHO, 2021) was constructed using longitudinal and cross-sectionaldata collected prospectively through the MGRS (de Onis *et al.*, 2004). Children fromthe six participating countries (Brazil, Ghana, India, Norway, Oman and USA) were healthy, fed accordingto WHO feeding recommendations, and met other rigorouscriteria to ensure there were no significant environmentalor individual constraints on growth (de Onis *et al.,* 2004). The MGRS foundstriking similarity in linear growth between children in the6 sites, justifying pooling the data and constructing a singleinternational standard from birth to 5 years of age (de Onis, 2007). As aresult, the 2006 WHO Child Growth Standard reflects howchildren

should grow under optimal conditions and can beused to make inferences about health or nutrition (Garza and de Onis, 2004).

2.5.6 The United States 2000 Center for Disease Control Growth Charts

The US CDC/NCHS has developed several versions of growth charts since the1970s, and some of them had been recommended by the WHO for international use. In order toaddress the limitations of the previous growth charts, the CDC/NCHS released new growth charts in2000, which were developed based on data of infants and children from birth to 5 years old in theThird National Health and Nutrition Examination Survey (NHANES III) to replace the FelsLongitudinal Study, and on the other data from earlier national surveys.The growth charts consist of a series of percentile curves of selected anthropometric measures,including weight-for-age, length-for-age, weight-for-length, and head circumference-for-age frombirth to 36 months of age. For children above 2 years old, there are weight-for-age, stature-for-age,BMI-for-age, and weight-for-stature charts for children taller than 77cm (Table 2.2) (CDC, 2000;Kuczmarski *et al*., 2002).

The chartsare presented separately for 0 – 2years old and for 2 – 20years'oldchildren, thus, the issue of disjunction between length and height measurements at the age of 2 yearsis not observable on the charts.The growth charts and tables present the 3rd, 5th,10th, 25th, 50th, 75th,90th, 95th and 97th percentile curves. The 85th percentile curve is in addition provided, on the BMI-for-age and weight-for-stature growth charts for 2 - 20years old children because this is a recommendedcut point for childhood overweight. Regarding the *Z*-score for the indicators, only tablesprovide the detailed corresponding values indicator-for-age at 0, ±0.5, ±1, ±1.5, and ±2 (Wang and Chen, 2012).

2.6 Growth Parameters

Growth is the primary outcome measure of nutritional status inchildren and adolescents (Baer and Harris, 1997; Mehta *etal*., 2013). Growth should be monitored at regular intervalsthroughout childhood and adolescence and should also bemeasured every time a child presents, in any healthcare setting,for preventive, acute, or chronic care. In children less than 36months of age, measures of growth include length-for-age,weight-for-age, head circumference-for-age, and weight-for-length.In children ages 2–20 years, standing height-for-age,weight-for-age, and body mass index (BMI)-for-age are typicallycollected (Gomez *et al.,* 1955, 1956; Seoane and Latham, 1971; NCCDPHP, 2007; CDC, 2000).

Anthropometric measures of growth are typically expressedand reported in comparison with population data (Table 2.2). Traditionally,the measures are expressed as percentiles and express therank or position of a child's measurements on a standard referencecurve. Percentiles indicate the portion of the referencepopulation that lies above or below that of the child being measured.It is used to help parents understand where their child"fits" in a population of children of similar ages, heights, and/or weights. The charts are designed so that growth trends in theindividual child can be observed over time and growth problems,when detected, addressed in a timely manner (NCCDPHP, 2007).

Table 2.2: Key anthropometric measures and indicators provided in the WHO and US CDC growth references/standards

	2000 CDC growth reference		2006 WHO growth standards		2007 WHO growth reference
Applicable age range (years)	0 – 3	2 – 20	0 – 2	2 – 5	5 – 19
Length/height/stature-for-age	X		X	X	X
Weight-for-age	X		X	-	X
Weight-for-length	X	-	X	-	-
Weight-for-height/stature	-	X	-	X	-
BMI-for-age	-	X	X	X	X
Head circumference-for-age	X	-	X	-	-
Arm circumference-for-age	-	-	X[b]	X	-
Sub-scapular skinfold-for-age	-	-	X[b]	X	-
Triceps skinfold-for-age	-	-	X[b]	X	-

This table lays out the anthropometric measures included in the three sets of recent growth references/standards.
"X" indicates available measures
[b]From 3 months to 5 years (CDC, 2000; WHO, 2006; de Onis *et al*., 2007)

However,a percentile does not reveal the actual degree of deviation frompopulation norms. The percentile will always be positivebecause the bell-shaped curve, statistically, has an infinite tailon both sides.

More recently, growth charts that facilitate comparisons ofunits of standard deviation from norms for reference agegroups, *z-score* (SD) comparisons, are recommended fortracking and assessing nutritional status in children (CDC, 2000; WHO, 2008; Mehta*et al.,* 2013). A z-score is a statistical measure that tells how a single data pointcompares with normal data and, if above or below "average,"how atypical the measurement is. Growth measurements thatcross z-*score* lines indicate possible risk. Children who aregrowing and developing normally will be on or between −1and 1 *z-score*s of a given indicator. Interpretation of the significanceof *Z-score* data is based on the point at which, in thechild's pattern of growth, the change began and the child'shealth status relative to the point and progression ofchange (Waterlow*et al*., 1977; Dibley*et al*., 1987; Mehta*et al.,* 2013).

2.7 Racial/Ethnic Differences in Linear Growth Potential

The MGRS found similarity in linear growth betweenchildren<5 years of age in the 6 study sites, supporting the theoryand previous empirical findings that population differencesin HAZ among young children are predominantly a result ofdifferences in their environment (for example, nutrition, infectiousdisease burden) and not inherited traits (de Onis, 2007). Without datafrom a study like MGRS that controls for environmentaldeterminants, it is imprudent to assume that the same istrue among older children and adolescents (Haas and Campirano, 2006; Wang *et al.,* 2006), giventhat large differences exist between global populations inheights of healthy young adults (Eveleth and Tanner, 1990; Haas and

Campirano, 2006). When using the2007 WHO Growth Reference, the possibility that a givenstudy population has a different growth potential than thereference population should be considered. Several studiesfrom diverse contexts have found differences in the lineargrowth trajectory of adolescents compared to the 2007WHOGrowth Reference including the Netherlands (de Wilde *et al.*, 2015), Peru (Bustamante *et al.*, 2015),Argentina (Orden and Apezteguía, 2016), Poland (Kulaga *et al.,* 2010), and Hong Kong (So *et al.,* 2011).

2.8 Relation Between Cut-Offs and Risk of Adverse Outcomes

Adolescentstunting, thinness, and obesity have been associatedwith past, present, adult, and intergenerational outcomes.Variation in adolescent HAZ largely reflects variation ingrowth during childhood and HAZ is positively associatedwith school attendance (Omwami *et al.*, 2011; Fink and Rockers, 2014) and non-cognitivemarkers ofself-efficacy, self-esteem, and educational aspirations (Dercon and Sánchez, 2013),and negatively associated with cognitive performance (Dissanayake *et al.*, 2009; Crookston *et al.,* 2014; Fink and Rockers, 2014; Perignon *et al.,* 2014) and school performance (Acham *et al.,* 2008; Dissanayake *et al.,* 2009; Crookston *et al.,* 2014; Fink and Rockers, 2014). Theevidence of the association between maternal stunted heightandnegative birthoutcomes suchas childmortality, stunting,and underweight is well established (Monden and Smits; 2009; Subramanian *et al.*, 2009; Özaltin *et al.*, 2010; Addo *et al.*, 2013). Adolescentthinness is negatively associated with school performance(Acham *et al.*, 2008; Mukudi, 2003).

In addition, low maternal BMI in early pregnancyincreases the risk of infants being small for gestationalage (Black *et al.,* 2013), and high maternal BMI before pregnancy

isassociated with stillbirth, infant mortality, and cerebral palsyin offspring (Cnattingius and Villamor, 2016; Forthun *et al.,* 2016). Childhood and adolescent obesity areassociated with increased risk of numerous adverse healthmeasures, such as hypertension, insulin resistance, metabolicsyndrome, atherosclerosis, and non-alcoholic fatty liver disease(Calcaterra *et al.,* 2008; Daniels, 2009; Wang *et al.,* 2015). Although there is little evidence that obesityduring childhood and adolescence is an independent riskfactor for metabolic disease in adulthood (Owen *et al.,* 2009; Lloyd *et al.,* 2012), obesityduring childhood and adolescence is strongly associated withadult obesity (Guh *et al.,* 2009; Owen *et al.,* 2009; Lloyd *et al.,* 2012).

Adolescent anthropometric indicators are clearly useful indetermining the risk of various adverse outcomes. The bestcut-offs, however, are likely to vary considerably dependingon an indicator's use, as described by the WHO ExpertCommittee on Physical Status (WHO, 1995) and again by Pelletier (Pelletier, 2006).For example, the best-performing BMIZ cut-off to identifyadolescents at present risk of adverse health outcomes maybe different from that to identify future risk. Moreover,the same indicators reflect different types of health risksand have different implications depending on age and sex.Ideally, the basis for defining cut-offs should be healthand functional consequences associated with deviationsin an anthropometric indicator (Pelletier, 2006). Current adolescentanthropometric cut-offs, however, are not designed to selectindividuals or populations with specific risks (de Onis, 2007). SDsfrom the reference population median are used to classifyindividuals who are unusually low, usual, or unusually highbased on statistical probabilities (Gibson, 2005; de Onis, 2007). Although the 2007WHO Growth Reference mean, median, and SD providemetrics to assess if there is displacement or distortion of thestudy population's

anthropometric curve compared to thereference data, they provide an inadequate estimate of whois likely to suffer adverse outcomes and what those outcomesare (WHO, 1995).

Perumal *etal*. (2018) explained the misuse of the stuntingcut-off (HAZ <-2) to classify undernutrition of children<5 years and to estimate the proportion of a populationat risk of adverse outcomes. Many of the commentary'sarguments apply to adolescent anthropometric indicators.

Like child stunting, the relation between adolescent anthropometricindicators and functional impairment, signs of deficiency, or adverse health outcomes is graduatedand seemingly without notable inflection points. Thereis no single cut-off that distinguishes a well-nourishedpopulation from a malnourished one. Consequently, theprevalence of children and adolescents affected by malnutritionmay be underestimated when using a single cut-offif the entire distribution of a population is shifted downor up.

Using the same z-score cut-offs across different anthropometricindicators can be misleading because they representvery different magnitudes of nutrition problems dependingon the indicator. For example, among children <5 years old, astunting prevalence of <20% (based on a HAZ <−2) isconsidered low, whereas the same prevalence for a weight-for-height *z-score*<−2 is high and likely reflects severefood insecurity (WHO, 1995).

2.9 Indicator Cut-Offs are Misaligned Across the Lifespan

Table 2.3 summarizes cut-offs for anthropometric indicatorsused by WHO across the lifespan. The 1977 NCHS/WHOGrowth Reference data were merged with data fromthe 2006WHO Child Growth Standard using sophisticated statisticalmethods to smooth the

transition between the 2006 WHOChild Growth Standard for children <5 years and the 2007WHO Growth Reference for children and adolescents 5−19 years. The cut-offs for stunting and underweight (BAZ) forchildren under and over 5 years old are closely aligned (de Onis, 2007).WHO recommends a more conservative BAZ overweightcut-off of+2 for children<5 years old,however, so there is a jumpin prevalence at age 5 years when the cut-off is decreased to +1(de Onis, 2017).The larger problem is going from adolescent to adultreferences. For girls aged 19 year, the 2007 WHO GrowthReference stunting cut-off for children and adolescents aged5−19years (HAZ <−2) corresponds with an adult heightof <150.1 cm. The cut-off for stunted adult height amongwomen is 145.0 cm and was chosen because it is commonlyreported and represents increased obstetric risk (Garcia and Mason, 1992). The145-cm cut-off is closer to the 2007 WHO cut-off of severestunting (HAZ <-3) for adolescent girls aged 19 years (<143.5 cm). The 2007 WHOGrowth Reference BAZ values at 19 years closely align withadult BMI cut-offs for overweight and obesity but not forthinness. The BMI values for both sexes at a BAZ<-2 (17.6for boys and 16.5 for girls) are considerably lower than theadult thinness cut-off of 18.5 (Table 2.3) (WHO, 1995).

Table 2.3: Comparison of WHO indicators across the lifespan§

Indicator	Cut-off	Corresponding value at 19 years
Children <5 years		
Stunting	HAZ <−2	–
Thinness	BAZ, WHZ, or WLZ <−2	–
Overweight	BAZ, WHZ, or WLZ > +2	–
Obesity	BAZ, WHZ, or WLZ > +3	–
Girls 5 – 19 years		
Stunting	HAZ <−2	<150.1 cm
Thinness	BAZ <−2	BMI < 16.5
Overweight	BAZ > +1	BMI > 25.0
Obesity	BAZ > +2	BMI > 29.7
Boys 5 – 19 years		
Stunting	HAZ <−2	<161.9 cm
Thinness	BAZ <−2	BMI < 17.6
Overweight	BAZ > +1	BMI > 25.4
Obesity	BAZ > +2	BMI > 29.7
Adults ≥ 20 years		
Stunting (women)*	Height < 145.0 cm	–
Thinness	BMI < 18.5	–
Overweight	BMI ≥ 25.0	–
Obesity	BMI ≥ 30.0	–

§Indicators for children <5 years are based on the 2006 WHO Child Growth Standard (WHO, 2021); indicators for children and adolescents 5-19 years are based on the 2007 WHO Growth Reference (WHO, 2007); and indicators for adults ≥20 years are based on the recommendations by the 1995WHO Expert Committee (WHO, 1995). BAZ, BMI (in kg/m^2)-for-age z-score; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; WLZ,weight-for-length z-score.

*There is no commonly used cut-off for stunting among adult men. Cut-off based on Reference (Garcia and Mason, 1992).

2.10 Use of Percentiles and z-Scores in Anthropometry

Percentiles and z-scores in anthropometric measures have been widely used to help assess the nutritional status and growth status of children and adolescents, such as undernutrition (for example, underweight, stunting and wasting)and overnutrition (that is, overweight and obesity) (Tables 2.4 and 2.5). Often, percentiles (suchas the 5th, 85th, 95th, 97th, 99th percentiles) and z-scores (for example, −2 and +2) are used to classify varioushealth conditions, and sex-age-specific anthropometric measures cut-points (based on z-scores orpercentiles) are provided in tables and as smoothed curves on growth charts.For the past four decades, the World Health Organization (WHO) has recommended the use ofgrowth reference (or "growth chart"), mainly based on z−scores ofanthropometric measures, toassess children's nutritional status and growth (Wang and Chen, 2012).

Table 2.4: Comparison of percentiles and *Z*-scores in anthropometry

	Percentiles	z–scores
1. Definition	The percentage of observations (or population) that falls below the value of a variable	The number of standard deviation (SD) away from the mean, when the distribution is normal
2. Scale	Rank scale	Continuous scale (from $-\infty$ to ∞)
3. Strengths	(a) Intuitively more understandable (b) Indicating the expected prevalence	(a) Allowing comparisons across ages and sexes (b) Able to quantify the extreme values (c) Good for assessing the longitudinal changes in growth status
4. Limitations	(a) Not comparable across different anthropometries (b) Extreme values are lumped to the highest/lowest percentile (c) Not suitable for assessing longitudinal growth status	Difficult to perceive than percentiles, especially for the public
5. Under normal distribution, a percentile must correspond to a fixed z–score. The following is a list of usually used percentile–z–score conversion values.		
	0.2nd	–3
	2.3rd	–2
	2.5th	–1.96
	5th	–1.64
	15th	–1.04
	16th	–1
	50th (median)	0
	84th	+1
	85th	+1.04
	95th	+1.64
	97.5th	+1.96
	97.7th	+2
	99.8th	+3

Key definitions and scales of percentiles and z–scores, and comparison of strengths and limitations of both scales. In practical setting, users would often face the task to convert z-scores to percentiles or vice versa. Corresponding values between percentiles and z–scores are also shown (Wang and Chen, 2012).

Table 2.5: The 1995 WHO growth reference: use of percentiles and z–scores

Outcome	Anthropometric measures and cut points	Indications of growth/nutrition problems
Infants and children (<10 years)		
Stunting	HAZ <–2 z-score, or <3rd percentile	Chronic malnutrition
Wasting/thinness	WHZ <–3 z-score, or <3rd percentile	Acute malnutrition, current malnutrition
overweight	WHZ > 2 z-score	Overweight
Adolescents (≥ 10 years)		
Stunting	HAZ <–2, or <3rd percentile	Chronic malnutrition
Thinness	BMI–for–age < 5th percentile	Underweight
At risk of overweight	BMI–for–age ≥85th percentile	Overweight
Obese	BMI–for–age ≥85th percentile and Triceps and Sub–scapular skinfold thickness–for–age ≥ 90th percentiles	Obesity

Summaries of cut-points of percentiles and z-scores to define problematic growth status in children and adolescents when using anthropometric measures. The cut-points are based on statistical distribution often adopted by other growth references/standards including the recent new WHO growth standards and references
HAZ: Height- or length-for-age z -score; WHZ: Weight-for-age z -score; BMI: Body mass index.
a. According to the WHO/NCHS reference (WHO, 1995; de Onis and Yip, 1996) and the BMI percentile developed by Must *et al.,* 1991.

2.10.1 The use of z-scores

The use of z-scores is recommended for several reasons (Tables 2.4 and 2.5). First, z-scores are calculatedbased on the distribution of the reference population (both the mean and the standard deviation [SD]);thus, they reflect the reference distribution. Second, as standardized measures, z-scores are comparableacross age, sex and measure (as a measure of "dimensionless quantity"). Third, a group of z-scores canbe subject to summary statistics such as mean and SD and can be studied as a continuous variable. Inaddition, z-score values can quantify the growth status of children outside of the percentile ranges(WHO, 1995). However, the major limitation of z-scores is that they are not straightforward to explainto the public and may be of limited use in clinical settings. In statistical terms, z-scores are a special application of transformation rules. The z-score for ameasure (for example, height or BMI), indicates how far and in what direction (positive vs. negative) a measuredvalue deviates from the population mean, expressed in units of the population SD. It is adimensionless quantity derived from dividing the difference between individual value (x) and thepopulation mean (μ) by the population SD (σ). The transformed z-scores' distribution will have amean of zero and a SD of one (that is, mean = 0, SD = 1). This conversion process is called standardizingor normalizing.

$$z = \frac{x - \mu}{\sigma}$$

Z-scores are sometimes called "standard scores". The z-score transformation is especially usefulwhen seeking to compare the relative standings of different measures (for example, height vs. BMI, or themeasures of boys vs. girls) from distributions with different means and/or different SDs. Z-scoresare especially informative when the distribution to which they refer is normal (Table 2.6).

Table 2.6: WHO growth/nutritional status based on anthropometry: use of z-scores

Classification	Condition	Age: 0 – 60 months[•] Indicators and cut–off	Age: 61 months to 19 years[*] Indicator and cut–off
Based on body mass index (BMI)	Possible risk of overweight	BMI–for–age (or weight–for–height) >1SD to 2SD	
	Overweight	BMI–for–age (or weight–for–height) >2SD to 3SD	BMI–for–age >1SD (equivalent to BMI 25 kg/m^2 at 19 y)
	Obese	BMI–for–age (or weight–for–height) >3SD	BMI–for–age >2SD (equivalent to BMI 30 kg/m^2 at 19 y)
	Thin		BMI–for–age < –2 to –3 SD
	Severely thin		BMI–for–age <–3 SD
Based on weight and height	Stunted	Height–for–age <–2SD to –3SD	Height–for–age <–2SD to –3SD
	Severely stunted	Height–for–age <–3SD	Height–for–age <–3SD
	Underweight	Weight–for–age <–2SD to –3SD	Weight–for–age (up to 10y) <–2SD to –3SD
	Severely underweight	Weight–for–age <–3SD	Weight–for–age (up to 10 y) <–3SD
	Wasted	Weight–for–height <–2SD to –3SD	
	Severely wasted	Weight–for–height <–3SD	

•: WHO, 2006
*: WHO, 2007

2.10.2 The use of percentiles

A percentile is the value of a variable below which a certain percentage of observations (or population)falls, that is, the percentile refers to the position of an individual on a given reference distribution.Percentiles are easier to understand and use in practice, both by health professionals and the public.In addition, a percentile dictates the expected percentage of a population should be above or below it (Table 2.4). Often age-sex-specific percentiles are recommended to assess children's growthand nutritional status based on anthropometric measures as well as other health conditions such asblood pressure. During recent years, there is a growing consensus on using sex- and age-specificBMI percentiles as cut-offs instead of weight-for-height z-scores (WHZ) for assessing overweightand obesity as well as thinness/underweight in children over 2 years old (Kuczmarski *et al*., 2002;Wang *et al*., 2006; WHO, 2006). The widely used percentiles include the 3rd, 5th, 50th (median),85th, 95th, 97th, 99th.

2.10.3 Applications to other areas of health and diseases

Individuals can use the percentiles and z-scores of anthropometric measures in various growth standardsor references to assess children and adolescents' growth and nutritional status problems including malnutrition (for example,stunting, wasting, underweight) and overnutrition (for example, overweight and obesity). In addition, percentilesof other health measures such as blood pressure has been used to help classify elevated bloodpressure (hypertension) in young people (National High Blood Pressure EducationProgram 1996). This means that blood pressure readings are ranked according to where they fallagainst the percentage of the reference population of all children, while considering variationsin gender, height, age, and other developmental parameters. For example, in the USA,

theupdated blood pressure tables were developed based on the NHANES 1999 - 2000 data, and includedthe 50th, 90th, 95th, and 99th percentiles (NHLBI, 2004). The 50th percentile indicates the midpointof normal blood pressure range, and is additionally compared to earlier guidelines. “Prehypertension”is defined as average systolic and/or diastolic blood pressure (SBP/DBP) ≥ 90th and < 95th percentiles(previously defined as “high normal”). Hypertension is defined based on the 95th percentile, andthe 99th percentile allows more precise staging of hypertension.Table 2.8 lists examples of software programs such asANTHRO that are available for individual z-score calculation (WHO, 2011).

Table 2.7: Resources for Determining *z-score*s for Anthropometrics

CDC Growth Charts	WHO Growth Charts
STAT GrowthCharts (compatible with iPod Touch, iPhone,iPad)	STAT GrowthCharts WHO (compatible with iPod Touch, iPhone, iPad)
Epi Info NutStat (available for download): http://www.cdc.gov/growthcharts/computer_programs.htm	WHO *z-score* charts: http://www.who.int/childgrowth/standards/chart_catalogue/en/index.htm
CDC website (*z-score* data files available as tables): http://www.cdc.gov/growthcharts/zscore.htm	WHO Multicentre Growth Study website: http://www.who.int/childgrowth/software/en/ All 4 macros (SAS, S-plus, SPSS, and STATA) calculate theindicators of the attained growth standards
PediTools Home: www.peditools.org	PediTools Home: www.peditools.org

Source: WHO, 2019

2.11 Overview of Anthropometric Indicators

Anthropometric measures often contain measures of weight and height, in particular for children and adolescents.Weight and height do not indicate malnutrition directly. Besides age and sex, theyare affected by many intervening factors other than nutrient intake, in particulargenetic variation. However, even in thepresence of such natural variation, it is possibleto use physical measurements to assess the adequacy of diet and growth, inparticular in infants, school-aged children and adolescents. This is done by comparing indicators with thedistribution of the same indicator for a "healthy" reference group and identifying"extreme" or "abnormal" departures from this distribution. For example, three ofthe most commonly used anthropometric indicators for infants and children; weight-for-height, height-for-age, and weight-for-age, can be constructed by comparingindicators based on weight, height, age, and gender with reference data for"healthy" children (WHO, 1995; Alderman, 2000).

2.11.1 Weight-for-height

Weight-for-height (W/H) measures body weight relative to height and has theadvantage of not requiring age data. Normally, W/H is used as an indicator of currentnutritional status and can be useful for screening children at risk and for measuringshort-term changes in nutritional status. At the other end of the spectrum,W/H can also be used to construct indicators of obesity. Low W/H relative to achild of the same sex and age in a reference population is referred to as "thinness."Extreme cases of low W/H are commonly referred to as "wasting." Wasting may bethe consequence of starvation or severe disease (in particular, diarrhoea). Low W/Hcan also be due to chronic conditions, although height-for-age is a better indicatorfor monitoring such problems. It is important to note that a lack of evidence

ofwasting in a population does not imply the absence of current nutritional problemssuch as low height-for-age (Kuczmarski *et al*., 2002;Wang *et al*., 2006; WHO, 2006).

2.11.2 Height-for-age

Height-for-age (H/A) reflects cumulative linear growth. H/A deficits indicate pastor chronic inadequacies of nutrition and/or chronic or frequent illness, but cannotmeasure short-term changes in malnutrition. Low H/A relative to a child of thesame sex and age in the reference population is referred to as "shortness." Extremecases of low H/A, in which shortness is interpreted as pathological, are referred toas "stunting." H/A is used primarily as a population indicator rather than for individualgrowth monitoring (WHO, 1995; Wang *et al*., 2006 ; WHO MGRSG, 2006a).

2.11.3 Weight-for-age

Weight-for-age (W/A) reflects body mass relative to age. W/A is, in effect, a compositemeasure of height-for-age and weight-for-height, making interpretation difficult.Low W/A relative to a child of the same sex and age in the reference population isreferred to as "lightness," whereas the term "underweight" is commonly used torefer to severe or pathological deficits in W/A. W/A is commonly used for monitoringgrowth and to assess changes in the magnitude of malnutrition over time.However, W/A confounds the effects of short- and long-term health and nutritionproblems(WHO 1995; Wang *et al*., 2006; WHO 2006; WHO MGRSG, 2006a,b).

2.12 Consequences of Linear Growth Stunting

Stunting, or linear growth retardation (<−2.0 SD inheight-for-age Z-score), is common among indigenouspopulations of Nigerians (Senbanjo*et al*., 2011; Atawodi *et al*., 2015) and most recentestimates suggest that about 165 million children underthe age of five worldwide were growth stunted (de Onis*et al*., 2012; Black *et al*., 2013). The bulk of research ongrowth patterns in biological anthropology (Kuzawa,1998; Bogin, 1999; Walker *et al*., 2006; Bogin *et al*.,2007) draws on evolutionary life history, which explicitlygrapples with how trade-offs between overlappingdomains of growth, reproduction, and maintenance serveto enhance survival and reproduction in heterogeneousenvironments. In terms of understanding human phenotypicvariation, these developmental trade-offs connectearly growth deficits to long-term consequences includingshorter stature (Stein *et al*., 2010; Sterling *et al*.,2012) and increased risk of developing metabolic diseasesincluding cardiovascular disease and type 2 diabetes(Barker *etal*., 2002). While there is considerableevidence linking growth restriction in utero to adult outcomes,research on the associations between postnatalstunting and later-life body composition has producedmore variable results. Body fat reserves play importantroles in survival and reproduction and developmentaloscillations in body composition throughout childhoodand adolescence, and may have evolutionary consequences(Zafon, 2007; Adair, 2008; Wells, 2010).

Therefore,research examining how growth restriction or stuntingin childhood is related to body composition may deserveadditional attention.Over the past several decades, research has shownlinks between early growth stunting and later body compositionbut the direction of the association likely varieswith local context. Among some urbanizing populations,childhood stunting exists alongside rapidly rising ratesof obesity. This dual

nutritional burden is hypothesizedto stem from developmental adaptations in which metabolicadjustments early in life result in increased risk ofmetabolic disease, including obesity, later in life (Frisancho,2003; Leonard *et al*., 2009; Wilson *et al*., 2012).

Severallarge studies have identified the co-occurrence ofboth stunting and overweight or obesity in children(Popkin *et al*., 1996; Fernald and Neufeld, 2007) andevidence for metabolic trade-offs associatedwith lineargrowth stunting is mounting (Hoffmann *et al*., 2000a,b).For example, in large surveys from Russia, Brazil,China, and the Republic of South Africa, Popkin *et al*.(1996) found that stunted children had a 1.7-7.8 timesincreased risk of being overweight than their non-stuntedpeers, depending on country and householdincome. Research among Mayans in urban Mexico hasalso demonstrated associations between child stature,lean body mass, and total energy expenditure (Wilson*et al*., 2012) and that the effects of shortness and stuntingmay persist across generations (Varela-Silva *et al*.,2009; Azcorra *et al*., 2013).Several longitudinal or cohort studies have failed to findclear associations between stunting and weight or body fatduring childhood or adolescence. For example, in their longitudinalresearch among South African urban children,Cameron *et al*. (2005) found children who were stunted at2 years of age were shorter and lighter than their non-stuntedpeers at 9 years of age, but they did not identifyassociations between stunting and later BMI, body composition,or fat patterning.

Research from Guatemala (Li*et al*., 2003) and Jamaica (Walker *et al*., 2002, 2007) hasalso suggested that early growth restriction is associated withless body fat and muscularity over time. The results in thisliterature indicate that the consequences of linear growthrestriction are complex and likely depend on local environment,diet, and developmental timing. Therefore,as severalresearchers have noted (Baker *et al*., 2009; Varela-Silva *et al*., 2012),

longitudinal research in rural areas oflow-income countries is needed to better understand thefull range of consequences of growth trade-offs.

2.13 Limitations of BMI as an Indicator of Adiposity andThinness

BMI (Body mass index) is generally considered as agood indicator and used for the assessment of chronicenergy deficiency of adults, especially in developingcountries (Shetty and James, 1994; Khongsdier, 2002). It is highly correlated with fat andfat-free mass and so the protein and fat reserves of bodycan be estimated. In normal adults the ratio is approximatelyconstant, and a person with a low BMI is underweightfor his/her height.

However, there are some difficulties associated withthe sole use of BMI, for example the ratio of sittingheight to standing height or cormic index can influenceBMI (Norgan, 1995). Cormic index varies both between populationsand within populations (Norgan, 1994). So, without the correctionby cormic index as a correction factor, the sensitivityand specificity of BMI as an indicator of nutrition maybe low. Age is another factor that may alter the functionalsignificance of BMI at different ages; becauseadults tend to lose fat free mass and increase fat masswith increasing age (Rolland-Cachera *et al.,* 1991; Norgan, 1994b; Gallagher *et al.,* 1996). Oedema can also affect thesignificance of BMI. Adults may develop oedema whenseverely undernourished, which artificially increases anindividual's weight resulting in BMI appearing more normalthan the actual value (Woodruff and Duffield, 2002). Moreover, the universalcut-off of the BMI cannot be applicable across differentpopulations (Barba *et al.,* 2004). So, these inabilities limit the usefulnessof BMI as an accurate screening tool to assess adultundernutrition.

Whereas BMI is highly correlated with adiposity for mostadult population groups (and with subsequent risk ofadult mortality), the association among adolescents is morevariable (Horlick, 2001; Freedman *et al.,* 2004). BMI does not distinguish between fat-freemass (for example, bones, muscles) and fat mass (Cole, 1991; Gibson, 2005), and manydifferent proportions of these can result in the same BMIamong adolescents (Freedman *et al.*, 2004). Fat-free and fat mass during adolescencedepend on various factors including age, sex, pubertalstatus, exercise regimen, and race/ethnicity (Cole, 1986; Marshall and Tanner, 1986; Daniels *et al.,* 1997; Maynard *et al.,* 2001; Freedman *et al.*, 2004; Demerath *et al.*, 2006; Siervogel *et al.,* 2006). Studies indicate that longitudinal increases in BMI duringchildhood and adolescence are largely attributable to fat-freemass, particularly among adolescent boys (Guo *et al.*, 1997; Maynard *et al.,* 2001; Freedman *et al.,* 2004; Demerath *et al.*, 2006).

The accuracy of BMI as a surrogate measure of adiposity alsovaries according to total body weight, with BMI performingwell among heavy children and adolescents but not amongthose who are lighter (Freedman *et al.*, 2004; Demerath *et al.*, 2006). Waist-to-height ratio hasbeen shown to be better than BMI at predicting adiposity inchildren and adolescents and could be a superior marker ofadiposity-related morbidity (Brambilla *et al.*, 2013).Body proportions, build, and fat distribution influence theinterpretation of BMI and vary substantially across differentracial/ethnic groups (Heymsfield *et al.,* 2015). Leg length relative to height affectsBMI values and potentially distorts classifications of thinnessand fatness based on BMI (Norgan, 1994a; Norgan, 1994b; Bogin and Beydoun, 2007).

Populations that have relativelylong legs for their height have lower BMI values whichcould lead to underestimates of overweight and obesity, andoverestimates of thinness

(the converse is found for greaterBMI associatedwith relatively shorter leg length). Significantvariation in sitting height ratio is found across ethnic groups(WHO, 1995). Slenderness of limbs measured with wrist and kneewidth, and slenderness of the trunk measured with pelvicbreadth and shoulder breadth, also affect interpretation ofBMI (Deurenberg *et al.,* 1999). Populations with more slender builds tend tohave a higher percentage of body fat for the same BMIas those with less slender builds (Deurenberg *et al.,* 1999; Deurenberg *et al.,* 2002; Rush *et al.,* 2009). BMI has beenfound to systematically underestimate adiposity in SouthAsian children (Nightingale *et al.,* 2011).

When using the NCHS/WHO GrowthReference (de Onis *et al.,* 2001) and 2007 WHO Growth Reference (So *et al.,* 2011), ahigh prevalence of thinness unlikely reflects the true levels ofacute malnutrition that have been found in some samples ofadolescents fromrelatively healthy and high-socio-economic statusAsian populations. The apparent overestimation ofthinness is likely due to differences in body build betweenthe study and reference populations. Body fat distributionalso varies across populations. For example, South Asianshave a more centralized distribution of body fat whichcoincides with increased risk of diabetes, hypertension, andcardiovascular disease compared to Europeans at the sameBMI values (McKeigue *et al.,* 1988; Rush *et al.,* 2009; Wen *et al.,* 2009).

2.14 Mid-Upper Arm Circumference

It is ameasure of the circumference of the upper arm at themidpoint between the olecranon and acromion processes(Gibson, 2005). The use of MUAC has improves the ability of nutritional anthropologists to screen and assess for acute malnutrition among children and adolescents. Increasingly, MUAC is also being used to assess nutritional status and

determine eligibility for nutrition support among adolescents and adults in low-resource settings, especially among pregnant women and people living with HIV who are eligible for antiretroviral therapy (Tumilowicz 2010; Bahwere *et al*., 2011; Ververs, 2013). Measurement of MUAC requires minimal equipment and calculations as compared to weight and height measurements for calculation of BMI or other anthropometric measurements, such as skinfold thicknesses.

The assessment of anthropometric measures is a rapid, safe,inexpensive, and effective method to screen for malnutrition inchildren and adolescents (AAPCN, 2013). In most settings, measurements of height and weightare sufficient for nutritional status assessment. The measurementof mid-upper arm circumference (MUAC) has been used in fieldsettings to rapidly identify young children and adolescents with undernutritionwho are at elevated risk of near-term mortality, especially underemergency situations such as famine or refugee crises (WHO, 2013).The MUAC, together with the triceps skinfold thickness canbe used to estimate skeletal muscle and subcutaneous fatstores (Frisancho, 1981).

Recently, the Academy of Nutrition and Dietetics consensusreport on the nutritional assessment of critically ill childrenrecommended the use of MUAC to assess nutritional status inbedbound children when measurements of weight and lengthor height were not feasible (Becker *et al.,* 2014). Though worldwide referenceranges with standard deviations are not available for older childrenand adolescents, Frisancho (1981) provides percentile guidelinesfor ages 1–79 years. However, only limited referencedata for MUAC are available for children >5 years of age,and these data were not established with the use of contemporarystatistical approaches that provide smoothed referencepercentiles (Frisancho, 1981).

In children aged 2–20 years, the CDC 2000 BMI reference percentilesare most commonly used to screen for underweight,overweight, and obesity. The CDC 2000 BMI charts were basedon>32,600 observations of children throughout the UnitedStates that were measured between 1963 and 1994; children>6 years of age who were measured between 1988 and 1994 wereexcluded because of the rising prevalence of obesity (Kuczmarski *et al.*, 2002). Morerecently, Addo and Himes (Addo and Himes, 2010) published references for skinfoldthicknesses at TSFT and sub-scapular skinfold thicknesssites to aid in the interpretation of subcutaneous fat measureswith the use of a nearly identical set of children who were notexposed to the more obesogenic environment of the previousdecades.

The MUAC has been correlated to BMIin children (Schweizer and Gerver, 2005; Martin *et al.*, 2009) and adults (Powell-Tuck and Hennessy, 2003) and has shown to be more sensitiveto changes in muscle and fat mass than BMI in adults (Powell-Tuck and Hennessy, 2003). MUAC measurements should be part of the full anthropometricassessment in all patients and are particularly importantin those whose weight may be affected by lower extremity oedema, ascites, or steroids, as weight trends alone are unreliablein relation to fluid status. When serial z-scores areunavailable, serial MUAC measurements can be used to monitorchanges in body composition by using the child as his orher own control. MUAC has been indicated as a more sensitiveprognostic indicator for mortality than weight-for-heightparameters in malnourished children (Briend *et al.*, 2012; Rasmussen *et al.*, 2012). It is advisableto have trained individuals consistently perform thesemeasurements for the best long-term comparison of data.

2.15 Validity of MUAC as BMI Alternate Screening Tool for Undernutrition

The use of anthropometry as an indicator of nutritionaland health status of adults is well established and stronglyrecommended by the WHO(1995). The BMI is an indicator ofoverall adiposity (fatness) or energy reserve in the humanbody. Although adult nutritional status can be evaluated inmany ways, BMI is the most widely used because it isinexpensive, non-invasive and thus suitable for large-scalepopulation surveys(Lohman *et al.,* 1988; Ferro-Luzzi *et al.,* 1992; James *et al.,* 1994). It is not only a sensitive indicatorof nutritional status but also of the socio-economic conditionof the population, especially the adolescent populationsin developing countries(Ferro-Luzzi *et al.,* 1992; Shetty and James; 1994; Nube *et al.,*1998; Khongsdier, 2002). BMI<18·5 kg/m^2 is widelyused as a practical measure of chronic energy deficiency(CED), defined as a state of 'steady underweight' in whichan individual is in energy balance irrespective of a loss ofbody weight or energy stores(Ferro-Luzzy *et al.,*1992; Khongsdier, 2005). Such a 'steady' underweighthas been associated with morbidity and otherphysiological and functional impairments(James *et al.,* 1988; Nube *et al.,* 1998).

Low BMIwas shown to be associated with increased morbidity andmortality in field settings and in several large anthropometric studies(Whitlock *et al.,* 2009; Kelly *et al.,* 2010; Aune *et al.,* 2016; Di Angelantonio *et al.,* 2016; Sun *et al.,* 2016). Although in general, height andweight appear to be simple measures, procurement,maintenance and calibration of the measuring instrumentsare necessary. The calculation of BMI requires literacy andnumeracy skills to a certain extent. In many field settings,although warranted, it could be difficult to obtain accurateheight and weight measurements, particularly in situationswhere time and resources are scarce.Another simple anthropometric measure, the

MUAC, can also be efficiently used todetermine poor nutritional status in adults(James *et al.,* 1994; Dorlencourt *et al.,* 2000; Khadivzadeh, 2002; Bose *et al.,* 2006).

Practically, it is a simpler measure than BMI,requiring minimum equipment (that is, only a standardizedtape), and was shown to predict morbidity and mortalityas accurately as a deficit in weight in young children(Briend *et al.,* 1989).Low MUAC was also associated with increased risk ofadverse health outcomes including mortality in HIVinfectedpatients(Gustafson *et al.,* 2007; Liu *et al.,* 2011; Oliveira *et al.,* 2012) and the elderly(Allard *et al.,* 2004; Wijnhoven *et al.,* 2012), and withmorbidity in other populations(Chakraborty *et al.,* 2009; Singla *et al.,* 2010; Lemmer *et al.,* 2011). It was recommendedas a substitute for BMI when rapid screening of an adultpopulation was required(James *et al.,* 1994). Especially when individualstend to have smaller amounts of subcutaneous fat, changesin MUAC are more likely to reflect changes in musclemass with a higher precision(Gibson, 2005). In such conditions, MUACmeasurements can be useful as an indicator of protein–energy malnutrition or a state of starvation. It is a usefulnutritional indicator during pregnancy in particular, as BMIreflects the body mass of the mother including the foetus atthis time(Fakier *et al.,* 2017). MUAC is also a convenient measure in hospitalizedpatients who cannot stand erect(Benítez *et al.,* 2016).

The measurementof MUAC offers several advantages. It can betaken with a simple tape measure and does not requireany other calculation. It also requires neither highlytrained personnel nor expensive or delicate equipment.Several previous investigations showed the interrelationshipsof socio-economic status, BMI, CED andmorbidity among different populations(Campbell and Ulijaszek, 1994; Delpeuch *et al.,* 1994; Naidu and Rao, 1994;

Clausen *et al.*, 1996; Ahmed *et al.*, 1998; Reddy, 1998; Griffiths and Bentley, 2001; Pryer *et al.*, 2003; Monteiro *et al.*, 2004; Khongsdier, 2005; Mahmud *et al.*, 2006). Numerousstudies found that MUAC was highly correlated with BMIin adult populations(Bose, 1996; Collins *et al.*, 1996; Bose *et al.*, 2007; Martin *et al.*, 2009; Mazicioglu *et al.*, 2010; Singla *et al.*, 2010). However, there exist distinctethnic differences in the pattern of body fat deposition(Bose, 2001)and the relationship between overall adiposity (measuredas BMI) and regional adiposity (measured by bodycircumferences like MUAC and skinfolds) varies acrossethnic groups(Bose, 2001; Tang *et al.*, 2017). At same level of BMI, there weresignificant ethnic differences in regional adiposity andbody composition measures, such as percentage bodyfat(Deurenberg *et al.*, 1998; Deurenberg *et al.*, 2002).

Similarly, although MUAC<23 cm has beenrecommended to identify the state of undernutrition(James *et al.*, 1994), thisvalue may not be the most appropriate cut-off point in allethnic groups and populations even within the samecountry. For instance, a study from Nigeria(Olukoya, 1990) reportedthat an MUAC cut-off point of 23 cm was optimal for thenorth while a 24 cm cut-off point was moreappropriate for the south. Thus, there is a need to establishethnic- and/or region-specific cut-off points of MUAC.However, the efforts made to find appropriate cut-offvalues of MUAC to correspond with CED status (BMI<18·5 kg/m^2) are limited, especially in Nigeria. In two suchstudies in India, MUAC was shown to be a suitable and simpleralternative to BMI in identification of CED and reportedmorbidity status among the Oraon tribal people(Chakraborty *et al.*, 2011) andadult male non-tribal slum dwellers(Chakraborty *et al.*, 2009) in the eastern partof India. These studies nevertheless emphasized thenecessity for further validation studies with larger

samplesizes before this cut-off point can be recommended for useamong these populations. Similar studies are needed alsoamong children and adolescents in Nigeria.

2.16 Comparison of MUAC and Weight-For-Height Z-Score for Assessing Acute Malnutrition

A weight-for-length z-score or weight-for-height z-score(WHZ) has been used for years, particularly in the field of nutritional anthropology to assess severe wasting or severe acute malnutrition (SAM)and moderate wasting or moderate acute malnutrition (MAM).The reliable measurement of a WHZ is difficult and oftenchallenging especially for inexperienced staff in the field. Thealternate use of the simpler measurement of MUAC has a long history (Jelliffe, 1966). This measurementrequires simple, low-cost, readily available equipment and iseasy to perform even on the most debilitated individuals. Forchildren aged between 6 and 60 months, the recommended cut-offsare from 115 to <125 mm for classifying moderate wastingor MAM and <115 mm for diagnosing severe wasting orSAM (WHO/UNICEF, 2007). The use of MUAC has been justified as the criticaltool that enables the implementation of a community-basedmanagement of acute malnutrition (CMAM). Thus, its use isincreasingly preferred in practice for large-scale programs becauseit can be reliably implemented at the community level byappropriately trained health workers. The use of MUAC as asingle diagnostic criterion has been closely related to risk ofdying (Myatt *et al.,* 2006).

When comparing the WHZ with MUAC,~ 40% of childrenwho were identified as SAM by one indicator were also similarlyidentified by the other (WHO/UNICEF, 2009). However, there has been discussionabout the generalizability of the cut-offs that have been selectedfor MUAC. Recent studies have shown that linear increase in MUACwith age

during childhood introduces uncertainties(Fiorentino *et al.*, 2016; Addo *et al.*, 2017). Addo *et al*.(2017) studied 32,952 US children aged 1–20 y and showed thatthe median MUAC at 1 year of age in boys and girls were 155and 158 mm, respectively, and, at 5 years of age, were 174 and175 mm, respectively. This finding suggests that a single cut-offfor MUAC for all ages <5 years would introduce imprecision inthe classification of their nutritional status. This possibilityraises the concern that the application of the currently recommendedsingle cut-off for MUAC at all ages may fail to identify anunknown number of children at risk of SAM or MAM, therebyincreasing the risk of missing potentially preventable morbidityand mortality. In such an instance, suitable cut-offs for MUAC indifferent age groups could be more useful.

2.17 Methods of BodyComposition Assessment

Body composition may be assessedaccurately using underwater weighing,DEXA, isotope-labelled water dilution, anddevices measuring total body electricalconductivity. However, these methodsrequire expensive equipment, can betime-consuming, and could involvedifficulties in transport, which limits theiruse in field and other settings (Zemel *et al.*, 1997; Wells and Fewtrell, 2006; Gurka *et al.*, 2010).Skinfold callipers are used to measure fatin a fold between 2 layers of skin onspecific body sites. Skinfold measurementscorrelate well with other measures of bodyfatness and are used widely to assessnutritional status in research and clinicalsettings (Heyward and Wagner, 2004; Wells and Fewtrell, 2006; Addo and Himes, 2010). Skinfold measurements arefast and easy to obtain in field settings, hospitals,or at home. In addition, the cost involvedis much less compared with that for othermethods of body composition assessment.BIA measurements

are also quick and easyto perform and less invasive, but accurateBIA equipment is more expensive thanskinfold calipers (Wells and Fewtrell, 2006; Gurka *et al.,* 2010).

2.18 Skinfold Anthropometry

Double thicknesses of skin and subcutaneous fat measured asskinfold thicknesses have a long history in nutrition-related research(Himes, 1980; Garn, 1991). Accordingly, skinfold thicknesses have been used inmyriad studies of nutritional status, body composition, and relativesubcutaneous fat distribution (Bedogni *et al.,* 2003; Steinberger *et al*., 2005; Jehn *et al*., 2006; Freedman *et al*., 2009). Because the thicknessesof subcutaneous fat are very specific to adipose tissue and can bemeasured noninvasively, skinfold thickness remains an importantand valid anthropometric indicator of regional and total bodyfatness, especially in research settings (Bedogni *et al.,* 2003; Bellisari and Roche, 2005).

Skinfold thicknesses evaluation, due to its low cost and non-invasiveprocedure, is one of the most widely used anthropometricmethods for assessment of nutritional status duringgrowth and maturation period (Goodpaster, 2002; Suliga, 2006; Wells and Fewtrell, 2006; Fichna and Skowrońska, 2008). Excess fat, asassessed using skinfold thicknesses, is associated with abnormalconcentrations of triglycerides, increased low-densitylipoprotein cholesterol, reduced high-density lipoprotein cholesterol,and insulin resistance; all factors markedly increasingrisk for hypertension, metabolic syndrome, and cardiovasculardisease (Freedman *et al.,* 1999; Steinberger *et al.,* 2009).

Skinfold measurements have low precision error butshould be done by well-trained personnel (Wagner and Heyward, 1999). In practice,the magnitude of precision error largely depends on theskills of examiner conducting examinations, however islow

compared to variability observed between subject (Wang *et al.*, 2000; Wells and Fewtrell, 2006). Skinfold thickness assessments are also utilized toidentify individual body somatotype, enabling estimationsof body density and lean body mass (Suliga, 2006; Wells and Fewtrell, 2006; L'Abée *et al*., 2010).

Reliable determination of references (medians and percentiles)for a given skinfold thicknesses requires a large set ofhealthy subjects (Addo and Himes, 2010). Previous methodologies used empiricalpercentiles according to sex and age groups. Recently, thereference values based on smoothed curves across the agegroups are favoured. The most preferred method to establishreferences is LMS method. Box–Cox transformation allowstransformation of data to normality by a suitable power transformation.Standardized Z-scores can be calculated from transformeddata (Cole, 1990, 1992).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The present cross-sectional study was conducted in Nasarawa State Nigeria. The State is geographically located in the North Central Nigeria ($8^{o}32'N$ $8^{o}18'E/8.533^{o}N$ $8.3^{o}E$), bounded in the East by Taraba and Plateau States, West by the Nigeria capital, Abuja, in the north by Kaduna State and by Kogi and Benue States in the South. With a population of over 1,869,377 million (NPC, 2006), its land mass is 27,117 km^2. The State has 13 Local Government Areas (LGAs). The present study was conducted in two of these LGAs; Lafia and Doma making up 15%. These locations were randomly selected by lot. Between September 2018 and December 2019, height, weight, age, sex and demography for children and adolescents aged 0 – 19 years were collected from these two LGAs.

3.2 Study Population

Participants in Doma (considered as rural setting in this study) were relatively homogenous based on ethnicity, culture and socio-economically while those from Lafia (considered as urban setting in this study) were relatively mixed culturally, socio-economically and well-off than those from Doma. Parents of most participants in Doma were farmers, while those from Lafia were largely into other occupations other than farming; such as civil servants, professionals and artisans.

3.2.1 Inclusion Criteria

i. Only subjects aged 1 month to 19 years were included;

ii. Subjects must reports their date of birth and sex;

iii. Only schools whose authority gave consent to participate in the study were sampled; and

iv. Subject must be apparently healthy with no chronic disease that might affect growth and no physical disability or psychological disorder.

3.2.2 Exclusion Criteria

i. Children older than 19 years old;

ii. Individuals who do not know their date of birth or failed to indicate their sex;

iii. Children who reported unreasonable or dubious dates of birth;

iv. Individuals whose measurements for height or BMI were flagged as being potential outliers per Tukey's far-outside rule of ~±5 SDs (Hoaglin *et al.,* 1983) or by WHO Macro specific for age and sex; and

v. Schools for special education, where children do not meet the criteria of apparent good health were excluded from the study.

3.2.3 Informed Consent

Parental permission was requested for each child less than 18 years old by signing informed written consent (Appendix II).

3.2.4 Ethical Consideration

The study design was reviewed and approved by Ahmadu Bello University Ethics Committee on Use of Human Subjects for Research (Appendix III).

3.2.5 Sample Size Determination

The required sample size for the whole study was calculated by the formula:

$$N = \frac{Z^2 p(1-p)}{d^2} = \frac{2.58^2 \times 0.5 \times (1-0.5)}{0.015^2} = 7{,}396 \qquad \text{(Daniel, 1999)}$$

Where N = desired sample size, z = standard deviation score (z = 2.58 at 99% confidence interval) for a particular confidence interval, *P* = expected prevalence or proportion, d = precision. For a prevalence of 50%, the precision was set at 1.5%. A total of 7,321 (that is 98.99%, that is, at an attrition rate of 1.01%) of the desired samples were collected.Schools sampled were randomly selected per local government.

3.3 Sampling Techniques

Study participants were randomly selected using two-stage sampling. Primary units (schools) were sampled from list of all schools in Lafia and Doma sampling frame; sampling was stratified by region – urban/rural area. At second stage, all infants, children and adolescents in the age range within the sampled schools and clinics whose authorities consented to participate in the study comprised the sampling frame. infants, children and adolescents were selected for the study by stratified random sampling, the stratification variables being schools, classes and age groups. Systematic sampling technique was used to select schools in the study locations. The schools were numbered after being arranged in an alphabetic order and schools with even numbers were selected and adopted as the nth interval for subsequent selections.

In all, data were collected from 25 schools (nursery, primary, junior and senior secondary schools) in Lafia and Doma. Management of five schools, predominantly private, declined participation to the study citing interference to academic activities while boarding schools, special needs schools (schools for physically challenged persons) were not sampled. The

number of schools and enrolment of some of these schools are presented in Table 3.1. Values outside parenthesis represent number of schools whereas, those in the parenthesis represent their enrolment. Values standing alone (with no parenthesis), represent enrolments.

Table 3.1: Demographics of study participants

	Lafia†			Doma‡		
	Boys	Girls	Total	Boys	Girls	Total
Public Primary Schools	29,984	23,904	185 (53,888)	7,895	6,691	31 (14,586)
Private Primary Schools	1,883	1,886	109 (3,769)	38	38	38§
Public JSS	7,707	6,388	66 (14,095)	310	212	4 (522)
Public SSS	6,524	4,298	37 (10,822)	3,549	2,704	27 (6,253)
Private Secondary Schools	-	-	-	1,851	1,065	15 (2,916)
Private JSS	1,997	2,089	45 (4,086)	-	-	-
Private SSS	1,676	1,835	44 (3,511)	-	-	-
Public boarding schools	-	-	-	269	621	3 (890)
Private boarding schools	-	-	-	447	256	3 (703)
Public single-sex schools	-	-	-	-	413	1 (413)
Private single-sex schools	-	-	-	220	-	1 (220)
Private nursery schools	-	-	35	-	-	-
Public nursery schools	3,209	2,709	42 (5,918)	-	-	-

Source:

†Nasarawa State Universal Basic Education Board (NSUBEB), Ministry of Education, Science and Technology and
Nasarawa State Ministry of Education, Science and Technology, Lafia

‡Doma Local government education authority (LGEA), Area Education Quality Evaluation Office, Nasarawa State Ministry of Education, Science and Technology

§No record of enrolment available

For infants between 1 to 12 months old, measurements were taken during routine immunization while information about the child are abstracted from the Child Health Card and via interviewing the mother/caregiver. For infants above 12 to 24 months, information about the child are obtained from records kept by the management of the creche. Children 2 to 4 years are sampled in nursery schools. Records and measurements of children 5 to 10 years were done at primary schools while those aged 11 to 19 years were performed at Junior and Senior Secondary Schools. For those < 3 years old, supine length was measured using a length board while stadiometer was used for those 3 years and above.

3.4 Anthropometry

All anthropometric measurements were taken according to procedures described by (Lohman *et al.,* 1988) and by trained research assistants. Standing height was measured accurate to 0.1 cm with the aid of Harpenden infantometer for infants < 3 years and by Harpenden stadiometer for subjects 3 to 19 years old. Weight was measured to the approximately to the nearest one-tenth kilogram with a calibrated weighing scale, FitScan BC-585F (Tanita Corp., Tokyo, Japan). Body mass index (BMI) was calculated by dividing body mass in kilogram by squared of the body height in metres.

3.5 Growth and Nutritional Status

Comparison and assessment of growth was made in terms of age-specific and sex-specific z-scores of height while that for nutritional status was made in terms of age-specific and sex-specific z-scores of BMI in accordance with the guidelines published by the 2007 WHO growth reference for school-age children and adolescents (de Onis *et al*., 2007). Here, height-for-age z-score <-3, <-2 and $>+2$ respectively were used as cut-points for

classifying participants as severe stunting, stunting and tall stature. Stunting is an indicator of chronic undernutrition due to lack of assess to adequate nutrition over a long period of time. Furthermore, the WHO recommended cut-offs for severe thinness, thinness, overweight and obese based on BMI-for-age z-scores. Subjects with BMI-for-age <-3, <-2, $>+1$ and $>+2$ were considered as severe thinness, thinness, overweight and obese respectively (WHO MGRSG, 2006). Sex-age-specific mean ± standard deviations, 95% confidence intervals of z-scores and prevalence (%) were computed. One sample *t*-test was used to test for deviation of mean z-score from zero while independent sample *t*-test was used to test for difference in mean z-scores between boys and girls.

3.6 Influence of Socio-demographics on Nutritional Status

The WHO 2007 SPSS macro was used to determine the nutritional status of children age 5 – 19 years old. The macro classified children into moderate stunting (HAZ <-2), severe stunting (HAZ <-3), moderate thinness (BAZ <-2) and severe thinness (BAZ <-3). Because each of these nutritional statuses is presented as a dichotomous variable, logistic regression was used to find the best fitting model that describes the relationship between the response variable (stunting and thinness) and the predictor variables (socio-demographics). Specifically, multiple logistic regression was used to observe the association between the response variables and socio-demographics (parents' educational background and ethnic decent). The underlying multiple logistic regression model, corresponding to each variable is:

$$\log [P/(1-P)] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9$$

where P = the probability of moderate stunting (HAZ <−2 coded 1), severe stunting (HAZ <−3 coded 1), moderate thinness (BAZ <−2 coded 1) or severe thinness (BAZ <−3 coded 1).

1 − P = the probability of not-stunted (coded 0)or not-thin (coded 0).

When father's level of education is the predictor variable;

X_1 = Primary school (1 if yes, 0 if no)

X_2 = Secondary school (1 if yes, 0 if no)

X_3 = Tertiary education (1 if yes, 0 if no)

When mother's level of education is the predictor variable;

X_4 = Primary school (1 if yes, 0 if no)

X_5 = Secondary school (1 if yes, 0 if no)

X_6 = Tertiary education (1 if yes, 0 if no)

When ethnic decent is the predictor variable;

X_7 = Alago (1 if yes, 0 if no)

X_8 = Eggon (1 if yes, 0 if no)

X_9 = Hausa/Fulani (1 if yes, 0 if no)

β_0 = intercept term

β_i= unknown logistic regression coefficients (i= 1, 2, 3, …, 9). The parameter βi refers to the effect of X_i on the logodds such that Y = 1, controlling the other X_i. No formal education background was used as the reference category, whereas other ethnicity other than Alago, Eggon or Hausa/Fulani was used as the reference category. There is animportant assumption in multiple regression, either linear orlogistic, that there should be no multicollinearity problem (dependent to each other) among the independent variables. Multicollinearity was tested via variance inflation factor (VIF).

Finally, stepwise logistic regression analysis was used tochoose the most influential socio-demographicvariables for nutritional status. Stepwise logistic regressionanalysis is a technique for selecting influential variables inmultiple regression models (Chatterjee and Hadi, 2006). Instepwise logistic regression analysis both methods, forwardLR and backward LR, compute the final step by subsequentlyadding (forward LR) or taking away (backward LR)variables. Both methods stop the iterative process once aprocess step is reached which no longer improves resultssignificantly compared to the last step taken. Variables are dropped onthe basis of their contribution to the reduction of error sumof squares. The contribution of individual variable for eachstep was checked by the Wald statistic. The forward LR was used because only variables with significant contributions to the model were retained.

3.7 Derived Measures

MUAC was measured to the nearest 0.1 cm using a flexible tape measure on the right arm, midway between the acromion and olecranon processes of the ulna, and triceps skinfold was measured to the nearest 0.5 mm using a Lange caliper. MUAC was collected in duplicate and triceps skinfold in triplicate and their average constitute the analytic values.

The above measures were used to UAMA, UAFA and upper arm area (UAA) as follow:

UAMA (cm^2) = $(MUAC - \pi \times \text{triceps skinfold})^2 \div 4\pi$ ($\pi = 3.1416$) (Frisancho, 1990)

UAA (cm^2) = $\pi D^2 \div 4$ (Frisancho, 1981)

Where D = upper arm girth, defined as

$MUAC \div \pi$ (Becker *et al.,* 2014)

UAFA was therefore calculated as the difference between UAA and the UAMA

UAFA (cm^2) = UAA – UAMA (Frisancho, 1990)

Analyses were performed on MUAC and triceps skinfold data collected from prenursery, nursery, primary, junior and senior secondary schools from September 2018 and December 2019. The 3rd, 10th, 25th, 50th, 70th, 90th and 97th percentiles for MUAC, UAMA and UAFA of children and adolescents were graphically represented.

The WHO 2007 growth reference was used to investigate the independent effects of BMI status on MUAC during growth by generating reference values for various categories of nutritional status using BAZ; severe thinness (<−3 z-score) and moderate thinness (< −2 z-score). The BAZ-scores were generated for children and adolescents aged 5 – 19 years using the WHO 2007 SPSS macros. The application automatically generates variables for normally distributed data but flags outlying values. The outlying values are excluded from further analyses. To further increase the quality of the data, sex and age-specific boxplots and Shapiro-Wilk test were used to test normality of the data.The reference ranges for MUAC, UAMA and UAFA for US children and adolescents published by Addo *et al.* (2017) were used for comparisons. Here the MUAC, UAMA and UAFA distributions by age are compared focusing on centile curves for median; 3rd and 97th centiles were used as extreme centiles.

3.8 Determination of Participants' Age

To determine chronological (decimal) age, participants were asked to enter date of birth as recorded in their birth certificate. Those without birth certificate were asked to inquire from

their parents. For children in nursery or primary schools, date of birth was recorded by their parents or caregiver. To calculate chronological age of each child, SPSS date and time wizard was used to calculate the difference between date of birth and date of investigation (expressed in months).

3.9 Measurement Techniques and Equipment

The equipment that was used to take the measurements include anthropometer (GPM Swiss made), sliding calliper, spreading calliper, Lange skinfold calliper, steel tape and portable weighing machine (LIBRA). All measurements were taken following the recommendation of the IBP (International Biological Programme, 1969), except bicondylar humerus which was taken following the recommendation of Malina and Bouchard(1991). The principal investigator trained all measurers before they were engaged in taking the final measurements from the subjects. The following anthropometric measurements were collected from each subject:

***i. Standing height* (*HT*)**

This was taken with a stadiometer. Height was taken with the subject standing straight, against a stadiometer. With the head oriented in the Frankfort plane (the upper border of the ear opening and the lower border of the eye socket on a horizontal line) and the heels together. At the time of taking measurement, each subject was asked to stretch upward and to take and hold a full breath. Infantometer was used to measure the length of infants < 3 years' old.

***ii. Sitting height* (*SHT*)**

Each subject was asked to sit on a measuring box, with hands in resting on their thighs. Subject was then asked to take a deep breath while keeping the head in the Frankfort plane,

a gentle upward lift was applied on the subject's mastoid processes. The head board was then placed firmly down on the vertex, crushing the hair as much as possible.

***iii. Body Weight* (*BW*)**

Subjects were asked to wear minimal clothing, then instructed to stand in the centre of the scale platform. Weight was then recorded to the nearest tenth kilogram.

***iv. Biepicondylar Breadth of the Humerus, Right* (*BBH*)**

This was measured as the width between the medial and lateral epicondyles of the humerus, with the shoulder and elbow flexed to 90^{o}. The caliper was applied at an angle approximately bisecting the angle of the elbow. Firm pressure was placed on the crossbars in order to compress the subcutaneous tissue.

***v. Biepicondylar Breadth of the Femur, Right* (*BBF*)**

Each subject was asked to sit with knee bent at right angle. Measurement of the greatest distance between the lateral and medial epicondyles of the femur was taken (firm pressure was applied on the crossbars in order to compress the subcutaneous tissue).

***vi. Calf Girth, Right* (*CG*)**

Each subject was asked to stand with feet slightly apart. Tape was be placed around the calf and measurement of the maximum circumference taken.

vii. Skinfold Thicknesses

Skinfold thicknesses were taken with Harpenden Skinfold Calliper (graduation 0.2 mm, range 80 mm, model: HSB-BI). Four skinfolds (biceps, triceps, sub-scapular and supra-iliac) were measured for all participants. All skinfolds were measured to the nearest 1 mm with the subject in an upright position. The skinfold thickness for each site was pinched to raise two layers of skin and the subcutaneous adiposity excluding the muscle.

viii. ***Biceps Skinfold* (*BSF*)**

The subject is asked to assume a relaxed standing position with the left arm hanging by the side. The right arm will be made to relax with the shoulder joints slightly eternally rotated and elbow extended by the side of the body. The skinfold is parallel to the long axis of the arm.

ix. ***Triceps Skinfold* (*TSF*)**

With the subject's arm hanging loosely in the anatomical position, a fold of skin will be raised at the back of the arm at a level halfway on a line connecting the acromion and the olecranon processes.

***x. Sub-scapular Skinfold* (*SSF*)**

The sub-scapular skinfold was raised on a line from the inferior angle of the scapula in a direction that is obliquely downwards and laterally at 45^{o}.

xi. Supra-iliacSkinfold

Depending on the size of the subject, the supra-iliacskinfold was raised 5-7 cm above the anterior superior iliac spine on a line to the anterior axillary border and on a diagonal line going downwards and medially at 45^{o}.

***xii. Total Arm Length* (*TAL*)**

The subject is asked to stand erect with feet together and the right arm flexed 90^{o} at the elbow with the palm facing up. The measurer is positioned behind the subject. The most upper edge of the posterior border of the acromion process of the scapula is located and marked. With the zero end of the measuring tape held in this mark, the tape is extended down at the posterior surface of the arm to the tip of the olecranon process, and the reading is then read.

***xiii. Head Length* (*HL*)**

The maximum length of the head in the midsagittal plane and is measured with a spreading caliper. The subject sits looking straight ahead. One tip of the caliper is placed on the Glabella landmark between the brow ridges and the other tip is moved up and down the back of the head until a maximum measurement is obtained. Light pressure is exerted on Glabella and enough pressure is exerted at the back of the head to compress the hair.

xiv. Head Breadth (HB)

The maximum horizontal breadth of the head above the level of the ears is measured with a spreading caliper. The subject sits looking straight ahead. Enough pressure is exerted to obtain contact between the caliper and the skin.

xv. Head Circumference (HC)

The subject is asked to assume a relaxed sitting or standing position with the arms hanging by the sides and the head in the Frankfort plane. The circumference of the head is obtained at the level immediately above the glabella with the tape perpendicular to the long axis of the head. The tape will be pulled tight to compress the hair. Use will be made of the middle fingers at the sides of the head will be made to prevent the tape from slipping over the head.

3.10 Reliability of the Anthropometric Measurements

All measurements were collected by the same measurer to eliminate the problem of interobserver error. Intraobserver reliability data was be determined by performing a measurement reliability study. This was done by measuring and remeasuring a small sample of subjects and then remeasuring every 10^{th} subject (n = 30). Technical error of measurement (TEM) (Muller and Marotell, 1988), coefficient of relative variation (CRV) (Jamison and Ward, 1993), and reliability (R) (Fleiss, 1986) was determined for each anthropometric measure.

$$R = \left(\frac{\Sigma D^2}{2n}\right)$$

$$\sigma_e = \sqrt{\left(\frac{\Sigma D^2}{2n}\right)}$$

“R” refers to reliability. Reliability can be defined as the proportion of the variance of an observation due to between subject variance in error free scores.

“D” refers to the difference between the measurements taken

“n’ refers to the sample size

"σ_e” refers to technical error of measurement and will be determined by taking the square root of reliability

“CRV” refers to coefficient of variation. The CV will be calculated as the ratio of the TEM to the size of the measurement and was be reported as a percentage (%) (Jamison and Ward, 1993).

3.11 Data Analyses

All analyses were conducted with the use of IBM Statistical Package for Social Sciences (IBM SPSS Incorp., IL., Chicago, USA) for Windows version 26 and MedCalc Statistical Software version 18.11.6 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2019). All tests were two-tailed and a test probability of 5% or lesswas considered statistically significant. Height, weight and BMI were transformed to z-scores through the use of WHO SPSS macro package based on the WHO (2007) height-for-age, weight-for-age and BMI-for-age curves separated by sex and age. Height-for-age z-scores were categorizedbased on the WHO stunting cut-offs (Moderate stunting: HAZ <– 2; Severe stunting: HAZ <– 3; Tall stature: HAZ >2) (WHO, 2007a).

The BMI-for-age z-scores were also categorizedbased on the WHO BMI cut-offs for under andovernutrition (Severe thinness: BAZ <−3; Moderate thinness: BAZ <−2; Overweight: BAZ >1; Obese: BAZ>2) (WHO, 2007b). Deviation from the expectedmean of zero was tested with a one sample *t*-test within agegroups, and differences in mean z-scores between boys andgirls with a two-sample *t*-test. The LMS method (Cole, 1990) was used to generate smoothed-percentilevalues and curves fitted across age and sex separately for height, weight, BMI, MUAC, UAMA, UAFA and for each skinfold thickness. This semi-parametric method allows data tobe normalised, and to estimate extreme percentiles (Borghi*et al*., 2006). The LMS method allows departure from normal distribution by using a Box-Cox transformation to correct for skewness at each distinct age *t*. The method generates three smooth curves: L (t) for the Box-Cox power to correct skewness, M (t) for the median and S (t) for the coefficient of variation. Natural cubic splines with maximum penalized deviance (penalized log likelihood) were used to create the three smooth curves by non-linear regression. The degree ofsmoothing is determined by assigning a number of equivalentdegrees of freedom (edf) for each curve.

Variety of statistical and visual diagnostic tools were used to guide the choice of final model. These tools included Worm plots (van Buuren and Fredriks, 2001)to evaluate goodness of fit, grid test (Healey *et al.*, 1988), which compares observed to expected frequencies between centile bands with a chi-square test and Q-test for fit to assess the global goodness-of-fit of the final models (Pan and Cole, 2004). Seven percentile values were computed (3rd, 10th, 25th,50th, 70th, 90thand 97th) within 6-month age groups. Percentitles were graphically compared with theWHO (2007) reference.MUACcut-offs for screening thinness and severe thinness andyear-wise MUAC cut-offsweredetermined using

BAZ <−2and BAZ <−3, respectively,as the gold standard.Diagnostic accuracy of MUAC compared with BAZ wasassessed using sensitivity (SN), specificity (SP), negativepredictive value (NPV) and positive predictive value(PPV), whose values were calculated using the proportionof true positives (TP), false positives (FP), true negatives(TN) and false negatives (FN) using a 2 × 2 table as shownbelow:

Thin according to MUACcut-offs	Thin accordingto BAZ		Total
Yes	TP	FP	TP + FP
No	FN	TN	FN + TN
Total	TP + FN	FP + TN	N

The SN measures the percentage of true positives (thin/severelythin) calculated as TP/(TP + FN); SP measuresthe percentage of true negatives (not thin/severely thin) calculated as TN/(TN + FP); NPV indicates how likely a subject is to not be thin if the test is negative,calculated as TN/(TN + FN); and PPV indicates howlikely a subject is to be thin if the test is positive,calculated as TP/(TP + FP). FP (%) is calculated asFP/(FP + TP) and FN (%) is calculated as FN/(FN + TN).

Unlike SN and SP, the NPV and PPV are largely dependenton disease prevalence in an examined population. Valuesof SN, SP, PPV and NPV were calculated for MUAC cut-offspoints against BAZ <−2 and BAZ <−3.Receiver-operating characteristic (ROC) curve analysiswas undertaken to determine the area under the curve(AUC), along with its 95 % CI, to establish the optimalcut-off values of MUAC to identify thinness and severe thinness.The shape of the ROC curve and the AUC determinehow high is the discriminative power of a test. The AUC canhave any value between 0 and 1 and it is a good indicator ofthe goodness of the test. The categories used to summarizeaccuracy of AUC in ROC curve analysis are as follows:excellent (0·9–1·0), good (0·8–0·9), fair (0·7–

0·8), poor(0·6–0·7) and fail (0·5–0·1). A test with AUC ≥ 0·85 is consideredan accurate test(Kumar and Indrayan, 2011). Although AUC gives an overallpicture of the behaviour of a diagnostic test across all cut-offvalues, there remains a necessity to ascertain the specificcut-off value that could be used for screening andfor this purpose Youden's index (YI) is used(NCSS, 2016).

The YIis equivalent to the AUC subtended by a single operatingpoint in the ROC curve(Schistermane*t al.*, 2005). The YI is calculated by deducting1 from the sum of the test's SN and SP expressed not as apercentage but as part of a whole number: (SN + SP) − 1. Itis one of the oldest measures for diagnostic accuracy, beingused for the evaluation of overall discriminative power of adiagnostic procedure and for comparison of this test withother tests(Unal, 2017). For a test with poor diagnostic accuracy,YI equals 0, and in a perfect test YI equals 1. The YI wascalculated using MedCalc software.

CHAPTER FOUR

4.0 RESULTS

Bearing in mind that there is no national reference that the current study can be compared to, data for the new reference curves are generated based on careful measurements of anthropometrics with minimal erroneous measurements. Training of research assistant was performed prior to the commencement of the study and comprised repetitive measurements of the same participants by the researcher until the measurement procedures were standardized. Therefore, high quality measurement is a sine qua non for high intra-observer reliability and reliability of the study outcomes. It is hoped that other investigators in Nigeria willing to conduct similar studies will toe the line of high-quality control during data collection.

4.1 Absolute Values of Anthropometric Measures

Descriptive statistics for height, weight, BMI and five skinfold thicknesses (biceps, triceps, sub-scapular, supra-iliac and medial calf skinfolds) are provided in Tables 4.1 and 4.2. As expected, the mean height, weightand BMI increased significantly with age. Girls had amean height significantly higher at 3, 11–15 years, and boys have higher mean height at ages2, 4, 6, 7, 17 and 18. For the most part, themean values of weightand MUAC did not differ significantly betweenthe sexes across age. Further, girls have a mean BMI significantly higher at 5 – 9 years whereas, boys have a mean BMI significantly higher at 12 – 16 years.

Table 4.1: Descriptive statistics (mean± standard deviation) for a sample N = 7,321 boys and girls from rural and urban Nasarawa State separated by age and sex

	Boys (n = 3,575)				Girls (n = 3,746)			
	Height (cm)	Weight (kg)	BMI (kg/m^2)	MUAC (cm)	Height (cm)	Weight (kg)	BMI (kg/m^2)	MUAC (cm)
Age (y)	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
1 (n = 68 B, 54 G)	63.78 ± 10.29	7.48 ± 1.82	17.74 ± 2.30	14.85 ± 1.66	66.17 ± 9.98	7.59 ± 2.40	17.15 ± 2.91	14.55 ± 1.54
2 (n = 19 B, 27 G)	73.89 ± 8.54	10.38 ± 1.12	19.48 ± 3.62	15.37 ± 1.38	71.85 ± 10.28	10.01 ± 2.57	19.60 ± 4.15	14.59 ± 1.82
3 (n = 30 B, 38 G)	81.60 ± 11.20[a]	12.12 ± 1.56	18.83 ± 4.09[c]	14.88 ± 1.28	91.95 ± 20.51	13.63 ± 4.69	16.24 ± 3.12	15.30 ± 1.89
4 (n = 40 B, 52 G)	96.68 ± 12.84	14.34 ± 2.57	15.61 ± 2.81	15.46 ± 1.33	94.13 ± 18.18	14.91 ± 3.66	18.81 ± 15.34	15.71 ± 1.32
5 (n = 99 B, 108 G)	107.59 ± 10.17	16.08 ± 3.01[b]	13.91 ± 2.17[c]	15.66 ± 1.19	109.63 ± 8.34	17.61 ± 2.89	14.71 ± 2.20	15.76 ± 1.22
6 (n = 213 B, 235 G)	114.93 ± 7.69	18.20 ± 2.83	13.76 ± 1.49[c]	16.15 ± 1.61	114.24 ± 6.90	18.50 ± 2.81	14.18 ± 1.86	16.27 ± 1.48
7 (n = 190 B, 202 G)	121.48 ± 8.40	20.11 ± 3.50	13.58 ± 1.50[c]	16.61 ± 1.80	120.67 ± 6.90	20.75 ± 3.68	14.18 ± 1.68	16.59 ± 1.34
8 (n = 273 B, 198 G)	126.55 ± 7.70	22.68 ± 3.55[b]	14.18 ± 1.96[c]	17.26 ± 1.59[d]	127.83 ± 7.08	22.04 ± 3.42	14.48 ± 1.64	16.84 ± 1.71
9 (n = 348 B, 294 G)	129.61 ± 7.58	23.29 ± 3.63[b]	13.90 ± 2.14[c]	17.65 ± 1.50	130.49 ± 7.24	24.33 ± 4.19	14.76 ± 1.91	17.47 ± 1.65
10 (n = 318 B, 322 G)	134.04 ± 8.28	25.56 ± 4.35	14.19 ± 1.83	18.46 ± 2.81[d]	135.20 ± 8.80	25.75 ± 4.29	14.88 ± 1.87	18.04 ± 1.75
11 (n = 310 B, 321 G)	137.93 ± 8.71[a]	28.31 ± 4.71	14.88 ± 2.09	19.16 ± 2.73[d]	139.80 ± 8.55	28.83 ± 4.86	14.94 ± 2.10	18.72 ± 1.83
12 (n = 318 B, 308 G)	142.80 ± 7.80[a]	32.96 ± 6.21	16.27 ± 3.45[c]	20.37 ± 2.97[d]	144.30 ± 8.16	32.13 ± 4.72	15.45 ± 2.03	19.67 ± 1.95
13 (n = 314 B, 359 G)	146.74 ± 8.82[a]	35.64 ± 6.95	16.50 ± 2.65[c]	21.14 ± 2.80	148.47 ± 8.46	35.65 ± 7.06	16.08 ± 2.32	20.86 ± 4.53
14 (n = 297 B, 315 G)	150.41 ± 9.19[a]	39.19 ± 8.35	17.33 ± 3.60[c]	21.77 ± 2.72	152.31 ± 8.72	38.55 ± 8.01	16.51 ± 2.53	21.36 ± 3.06

15 (n = 279 B, 295 G)	154.32 ± 8.59[a]	41.16 ± 8.53	17.24 ± 3.14[c]	22.24 ± 2.54	156.98 ± 6.38	41.19 ± 7.81	16.67 ± 2.79	22.44 ± 5.12
16 (n = 188 B, 258 G)	159.09 ± 8.49	45.16 ± 7.64	17.84 ± 2.71[c]	23.40 ± 3.41[d]	159.54 ± 7.70	43.91 ± 8.36	17.16 ± 2.56	22.84 ± 2.41
17 (n = 142 B, 176 G)	163.50 ± 8.95	47.43 ± 6.94	17.76 ± 2.43	24.07 ± 2.58	162.29 ± 6.31	48.61 ± 6.90	18.45 ± 2.36	24.06 ± 2.56
18 (n = 102 B, 143 G)	164.79 ± 7.84	50.59 ± 6.57	18.70 ± 2.61	25.06 ± 2.33[d]	163.06 ± 7.92	49.72 ± 7.58	18.67 ± 2.36	24.39 ± 2.57
19 (n = 27 B, 41 G)	165.17 ± 7.74	49.30 ± 5.76[b]	18.13 ± 2.31[c]	24.45 ± 3.13	167.18 ± 6.02	54.06 ± 7.30	19.34 ± 2.43	25.23 ± 2.52

Results of unpaired sample *t*-test. Superscripts indicates significant difference in corresponding height, weight, BMI or MUAC between boys and girls.

Table 4.2:Means of skinfold thicknesses ± standard deviation for boys and girls from rural and urban Nasarawa Stateseparated by age and sex

	Boys					Girls				
	BSF (mm)	TSF (mm)	SSF (mm)	SISF (mm)	MSF (mm)	BSF (mm)	TSF (mm)	SSF (mm)	SISF (mm)	MSF (mm)
Age (y)	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
3	4.57 ± 0.79	7.71 ± 1.50[b]	6.43 ± 1.13[c]	5.71 ± 2.06	7.00 ± 2.24	4.13 ± 1.46	6.07 ± 1.44	5.33 ± 0.82	4.87 ± 1.30	5.27 ± 1.94
4	3.74 ± 1.51	6.38 ± 1.60	5.33 ± 1.39	5.29 ± 1.74	5.17 ± 2.10	4.10 ± 1.11	5.81 ± 1.62	4.81 ± 0.95	4.87 ± 1.38	5.13 ± 1.43
5	4.12 ± 1.17	6.19 ± 1.59	5.50 ± 1.37	5.45 ± 1.52[d]	6.30 ± 1.76[e]	3.99 ± 1.08	5.81 ± 1.51	5.27 ± 1.07	4.80 ± 1.20	5.14 ± 1.38
6	3.88 ± 1.16	5.81 ± 1.64	5.56 ± 1.56	5.35 ± 1.56	6.42 ± 1.69[e]	3.95 ± 1.28	5.91 ± 1.53	5.43 ± 1.35	5.12 ± 1.50	5.08 ± 1.55
7	3.80 ± 1.21	5.77 ± 1.47[b]	5.67 ± 1.64[c]	5.49 ± 1.92[d]	6.36 ± 2.16[e]	3.65 ± 1.00	5.36 ± 1.21	5.12 ± 1.04	4.91 ± 1.31	5.01 ± 1.35
8	3.79 ± 1.09[a]	5.88 ± 1.76[b]	5.78 ± 1.71[c]	5.67 ± 2.01[d]	6.77 ± 2.13[e]	3.57 ± 0.96	5.28 ± 1.18	5.21 ± 1.13	4.89 ± 1.28	4.98 ± 1.31
9	3.93 ± 1.18[a]	5.99 ± 1.88[b]	5.96 ± 2.06[c]	5.81 ± 2.13[d]	7.16 ± 2.22[e]	3.71 ± 1.22	5.47 ± 1.53	5.41 ± 1.49	5.24 ± 1.71	5.12 ± 1.63
10	4.09 ± 1.72[a]	6.23 ± 2.31[b]	6.51 ± 2.25[c]	6.41 ± 2.76[d]	7.68 ± 2.89[e]	3.76 ± 1.18	5.70 ± 1.81	5.65 ± 1.39	5.60 ± 2.08	5.39 ± 1.94
11	4.00 ± 1.49	6.60 ± 2.30[b]	6.96 ± 2.90[c]	6.80 ± 2.96[d]	8.49 ± 2.95[e]	3.87 ± 1.31	5.87 ± 2.15	5.83 ± 1.62	5.61 ± 2.34	5.47 ± 1.87
12	4.52 ± 2.26[a]	7.34 ± 4.17[b]	7.60 ± 3.36[c]	7.20 ± 3.16[d]	8.71 ± 3.38[e]	4.08 ± 1.66	6.21 ± 2.61	6.31 ± 2.52	6.26 ± 3.18	5.81 ± 2.06
13	4.65 ± 2.10	7.25 ± 2.93	7.94 ± 3.21[c]	7.93 ± 3.67[d]	8.81 ± 3.30[e]	4.56 ± 2.11	7.30 ± 3.70	6.81 ± 2.95	7.08 ± 3.80	5.87 ± 1.91
14	4.88 ± 2.33	7.39 ± 3.21	7.91 ± 3.09	7.72 ± 3.27	9.04 ± 3.35[e]	4.82 ± 2.27	7.81 ± 4.33	7.57 ± 3.65	8.15 ± 4.73	5.68 ± 1.91
15	5.12 ± 2.62	7.68 ± 3.13[b]	8.18 ± 3.33	8.08 ± 3.51[d]	9.31 ± 3.62[e]	5.16 ± 2.29	8.94 ± 4.68	8.33 ± 3.57	9.07 ± 4.59	5.94 ± 1.94
16	4.93 ± 2.18[a]	7.37 ± 3.02[b]	8.29 ± 3.30[c]	7.76 ± 3.02[d]	9.65 ± 4.06	5.43 ± 2.39	9.71 ± 5.21	9.29 ± 4.13	9.77 ± 4.72	6.42 ± 2.54
17	4.86 ± 2.42[a]	7.39 ± 3.28[b]	8.64 ± 2.86[c]	8.35 ± 3.22[d]	10.20 ± 4.42	6.36 ± 3.15	10.44 ± 5.70	10.48 ± 4.43	11.50 ± 5.84	6.84 ± 2.67
18	5.14 ± 3.23	7.59 ± 3.87[b]	10.17 ± 3.67	9.03 ± 4.14	12.08 ± 5.63[e]	6.71 ± 3.72	8.88 ± 5.37	9.39 ± 4.75	9.42 ± 4.95	6.74 ± 2.70
19	4.67 ± 2.09	8.00 ± 3.74	9.22 ± 3.13	8.74 ± 2.85	9.38 ± 2.43[e]	6.69 ± 1.84	8.22 ± 4.96	9.54 ± 3.68	9.00 ± 3.95	6.87 ± 2.69

Results of unpaired sample *t*-test. Superscripts indicates significant difference in corresponding skinfold between boys and girls. Skinfold thicknesses were not collected for children <3 years old.

BSF, biceps skinfold; TSF, triceps skinfold; SSF, sub-scapular skinfold; SISF, supra-iliac skinfold, MSF, medial calf skinfold

4.2 Nutritional Status

The prevalence of severe (<−3 z-score) and moderate (<−2 z-score) form of height deficit for age (stunting) and fairly tall status (> 2 z-score) for boys and girls were presented in Table 4.3. When compared with WHO (2007) reference data, the mean height was significantly lower in all boys and girls but for boys at age 5 and girls at ages 5, 7 and 19 years. The mean height of boys aged 10, 11 and 12 were significantly higher than those of girls whereas, the mean height of girls aged 5, 13, 16 and 17 were significantly higher than those of boys. Table 4.3 also shows that the overall prevalence of stunting in the study was 19.5% (18.6 – 20.5%), while the overall prevalence of severe stunting was 6.0% (5.5 – 6.6)%. Further, the prevalence of stunting was higher in boys 21.1% (19.7 − 22.5)% than in girls 18.0% (16.7 − 19.3)%. The prevalence of severe stunting on the other hand was similar in boys 6.1% (5.4 − 7.0)% and girls 5.9% (5.2 − 6.8%). The prevalence of stunting was slightly higher in girls at lower ages to age 13 except at ages 7 and 8 in which boys have higher prevalence than girls. Boys however, have higher prevalence of stunting from age 13 to 19.

Undernutrition among the participants in terms of BMI deficit for age; severe thinness (<−3 z-score), moderate thinness (<−2 z-score), overweight (> 1 z-score) and obesity (> 2 z-score) were presented in Table 4.4. When compared to the WHO 2007 reference data, there was significant lower mean BMI z-scores for all age in both boys and girls. The overall mean for boys 1.60 ± 0.98 kg/m^2 (1.64, −1.55)% was lower compared to that of girls −1.30 ± 1.38 kg/m^2 (−1.35, −1.26)%. It was also observed that there were significant difference in mean BMI between boys and girls at ages 5, 6, 13 and 14 years. From the Table, the overall prevalence of severe thinness, moderate thinness, overweight and obesity

were 14.5% (13.7, 15.3)%, 32.8% (30.8, 34.4)%, 3% (-2.65, 3.47)% and 0.8% (0.61, 1.04)% respectively. Prevalence of severe and moderate thinness were higher in boys than in girls. The prevalence of severe and moderate thinness in boys were 16.6% (15.4, 17.9)% and 36.1% (34.45, 37.7)% whereas in girls were 12.4% (11.37, 13.6)% and 29.5% (28.05, 31.1)% respectively. In contrast, prevalence of overweight and obesity were relatively higher in girls by 4% when compared to boys. Although there was no clear consistent pattern in observed difference of mean and prevalence based on age/sex.

4.2.1 Age and sex difference in pattern of growth

Age- and sex-specific smoothed centiles and corresponding L, M and S parameters for height, weight and BMI were presented in Tables 4.5 – 4.7 as well as selected corresponding Figures 4.1 and 4.2 for height and BMI were also presented for better appreciation. The percentile curves for height and BMI modelled using the L, M and S technique were compared with the WHO (2007) data. Percentile curves (3rd, 50th and 97th) for height and BMI were developed for participants in the present study. Except at age < 1 year, estimates were presented at interval of 6-months from 1 to 19 years. The proposed percentiles generated were P3, P10, P25, P50, P70, P90 and P97. The equivalent degrees of freedom (edf) for the Box-Cox power transformation to remove skewness (L), median (M) and coefficient of variation (S) of height, weight and BMI were shown on their respective tables.

4.2.2 Height-for-age

The reference curves of both boys and girls were modelled without skewness by setting edf for power (L) as constant 1. There was a steady increase in height with age for both boys'

and girls' centile curves. When compared to WHO (2007) growth charts, all height centile curves for Nigerian children and adolescents were distinctly below those of the WHO growth charts across all ages and in both sexes (Figures 4.1a and b). Third and median height for Nigerian children were consistently below those of WHO (2007) growth charts across all ages. The 97th percentile for Nigerian children approximates that of the WHO reference especially from ages 6 – 12 years in boys and ages 5 – 17 years in girls.

4.2.3 Weight-for-age

With regards to weight, Table 4.6 shows the gender- and age-specific percentile distribution and L, M and S parameters. The distribution of smoothed weight-for-age in boys was negatively skewed at ages 1 – 4 years and ages 11 – 19 years, as a result a positive Box-Cox power transformation was required to normalize the data while removing the skewness from the distribution. In girls however, the distribution of the smoothed weight-for-age was negatively skewed across all ages and a positive Box-Cox transformation was used to normalize the distribution of the data and to remove skewness from the distribution. In all cases, weight increased progressively with chronological age.

4.2.4 BMI-for-age

Table 4.7 shows the percentile distribution for BMI by age and sex whereas Figures 4.2c and d show the graphical comparisons of BMI percentiles between the study population and those of WHO (2007) reference data. The distribution of the smoothed BMI-for-age for both sexes were positively skewed, as such, a negative power was used to remove the skewness from the distribution. The three BMI centiles for both boys and girls revealed that Nigerian children and adolescents are lighter compared to their counterparts in the WHO

(2007) reference data. Comparison of the three percentile curves from the present study to that of the WHO reference shows evident discrepancies at all ages for both sexes, that is, all BMI charts for our sample population were distinctly below the WHO reference data. At ages 5 and 6 years, the 97th percentile for male and female children was higher than that of the WHO, however, at age ~ 6.5 years, the two curves decussate with the curve for Nigerian children tracking below that of the WHO (2007) data. The age-related decussation between the two graphs for Nigerian children and WHO (2007) reference data was not accounted for, but it did not follow the forms of an empiric higher centile and did not occur due to defect of smoothing.

Table 4.3 Distribution of stunting (moderate and severe based on < -2 *Z* and < -3 *Z-score*, respectively) and tall stature (> 2 *Z-score*) according to the WHO (2007) reference in boys and girls from Nigeria

	Boys					Girls					
			Prevalence					Prevalence			
Age, y	Mean ± SD†	95% CI[§]	< –3 SD	< –2 SD	> 2 SD	Mean ± SD‡	95% CI[§]	< –3 SD	< –2 SD	> 2 SD	*P*[*]
5	0.15 ± 1.57	–0.13, 0.43	0.8%	4.0%	16.9%	0.18 ± 1.32	–0.06, 0.42	0.8%	7.6%	7.6%	**0.033**
6	–0.34 ± 1.38	–0.53, –0.15	1.5%	11.2%	5.4%	–0.49 ± 1.31	–0.68, –0.30	1.1%	12.0%	4.9%	0.387
7	–0.26 ± 1.45	–0.45, –0.07	1.3%	11.2%	5.8%	–0.13 ± 1.32	–0.32, 0.06	1.0%	6.3%	6.8%	0.412
8	–0.32 ± 1.20	–0.46, –0.17	1.1%	8.4%	3.4%	–0.31 ± 1.17	–0.46, –0.16	0.0%	4.2%	4.6%	0.635
9	–0.54 ± 1.06	–0.66, –0.42	0.9%	7.3%	2.2%	–0.71 ± 1.11	–0.84, –0.59	2.5%	9.0%	0.9%	0.250
10	–0.59 ± 1.23	–0.72, –0.46	2.1%	10.2%	3.0%	–0.83 ± 1.33	–0.97, –0.68	5.7%	20.2%	2.4%	**0.026**
11	–0.72 ± 1.13	–0.85, –0.59	2.3%	12.6%	1.6%	–1.10 ± 1.29	–1.25, –0.95	8.2%	24.8%	0.4%	**<0.010**
12	–1.06 ± 0.99	–1.17, –0.96	2.7%	16.5%	0.3%	–1.41 ± 1.43	–1.56, –1.25	17.2%	31.3%	0.0%	**<0.001**
13	–1.47 ± 1.07	–1.59, –1.35	6.7%	30.0%	0.0%	–1.41 ± 1.45	–1.56, –1.26	18.1%	33.3%	0.3%	**0.001**
14	–1.78 ± 1.20	–1.92, –1.64	17.9%	44.2%	0.0%	–1.22 ± 1.31	–1.36, –1.07	12.7%	25.7%	0.0%	<0.197
15	–1.69 ± 1.05	–1.83, –1.56	9.2%	36.2%	0.0%	–0.81 ± 1.16	–0.94, –0.69	4.8%	15.0%	0.0%	<0.103
16	–1.76 ± 1.44	–1.96, –1.57	16.2%	37.7%	0.0%	–0.58 ± 1.08	–0.72, –0.44	1.3%	7.6%	0.4%	**<0.001**
17	–1.36 ± 1.28	–1.58, –1.13	9.4%	25.0%	0.0%	–0.47 ± 0.95	–0.62, –0.31	1.3%	4.7%	0.7%	**<0.016**
18	–1.28 ± 1.06	–1.48, –1.09	5.1%	23.1%	0.0%	–0.62 ± 0.98	–0.84, –0.41	0.0%	8.5%	0.0%	<0.654
19	–1.22 ± 1.00	–1.58, –0.86	3.1%	21.9%	0.0%	–0.38 ± 1.12	–1.06, 0.30	0.0%	15.4%	0.0%	<0.383
Total	–0.94 ± 1.33	–0.99, –0.90	6.1%	21.1%	2.2%	–0.82 ± 1.33	–0.87, –0.78	5.9%	18.0%	1.6%	

†One sample t-test revealed significant difference (at $P<0.001$) in mean z-score from 0 except at age 5 in which $P > 0.05$, $P < 0.05$ at ages 6 and 8.
‡One sample t-test revealed significant difference (at $P<0.001$) in mean z-score from 0 except at ages 5, 7 and 19 in which $P > 0.05$.
[§]95% confidence interval for mean
[*]*P-values* for independent sample t-test for sexual dimorphism in mean z-scores between boys and girls. Significant difference is expressed in boldface.

Table 4.4 Distribution of BMI z-scores and prevalence (%) of severe thinness (<-3 z-score), moderate thinness (<-2 z-score), overweight (> 1 z-score) and obesity (> 2 z-score) according to the WHO (2007) reference in boys and girls from Nigeria

	Boys						Girls						
			Prevalence						Prevalence				
Age, y	Mean ± SD†	95% CI[§]	<–3 SD	<–2 SD	> 1 SD	>2 SD	Mean ± SD‡	95% CI[§]	<–3 SD	<–2 SD	> 1 SD	> 2 SD	*P*[*]
5	–1.19 ± 1.75	–1.51, –0.88	14.9%	29.8%	6.6%	5.0%	–1.26 ± 1.26	–1.49, –1.03	9.4%	25.6%	1.7%	0.9%	**0.006**
6	–1.15 ± 1.44	–1.35, –0.95	11.2%	27.3%	5.9%	3.9%	–1.24 ± 1.36	–1.44, –1.04	12.6%	25.1%	4.4%	0.5%	0.564
7	–1.38 ± 1.38	–1.57, –1.20	14.7%	28.6%	1.4%	0.9%	–1.47 ± 1.13	–1.63, –1.31	10.9%	31.8%	0.5%	0.0%	**0.020**
8	–1.73 ± 1.38	–1.90, –1.56	19.2%	39.6%	0.4%	0.0%	–1.30 ± 1.43	–1.49, –1.12	13.0%	30.3%	6.3%	1.7%	0.983
9	–1.53 ± 1.40	–1.69, –1.38	15.6%	33.4%	2.0%	0.3%	–1.60 ± 1.48	–1.76, –1.44	17.4%	39.6%	3.8%	0.9%	0.193
10	–1.68 ± 1.36	–1.83, –1.53	18.3%	38.7%	1.8%	0.0%	–1.87 ± 1.32	–2.01, –1.72	21.6%	43.6%	1.2%	0.3%	0.546
11	–1.48 ± 1.41	–1.64, –1.32	16.8%	32.7%	3.0%	0.0%	–1.60 ± 1.28	–1.75, –1.45	14.4%	35.6%	0.7%	0.0%	0.113
12	–1.59 ± 1.32	–1.73, –1.44	15.9%	31.5%	1.2%%	0.0%	–0.98 ± 1.46	–1.15, –0.82	8.5%	24.8%	11.0%	2.8%	0.061
13	–1.70 ± 1.32	–1.84, –1.55	18.1%	40.9%	2.2%%	0.3%	–1.09 ± 1.44	–1.24, –0.94	10.4%	27.0%	4.6%	1.6%	**0.048**
14	–1.81 ± 1.32	–1.97, –1.65	21.6%	41.6%	1.5%	0.0%	–1.08 ± 1.51	–1.25, –0.92	12.2%	28.0%	7.4%	2.3%	**0.047**
15	–1.95 ± 1.39	–2.13, –1.77	22.2%	48.9%	1.8%	0.0%	–1.29 ± 1.33	–1.44, –1.15	12.3%	28.5%	2.8%	0.0%	0.369
16	–1.77 ± 1.16	–1.93, –1.61	15.1%	39.5%	1.0%	0.5%	–1.10 ± 1.21	–1.26, –0.94	9.8%	18.7%	2.2%	0.0%	0.556
17	–1.55 ± 1.27	–1.78, –1.33	11.7%	35.2%	2.3%	2.3%	–1.10 ± 1.11	–1.28, –0.92	6.7%	20.1%	1.3%	0.0%	0.441
18	–1.54 ± 1.08	–1.74, –1.34	8.6%	32.8%	0.0%	0.0%	–0.74 ± 0.97	–0.95, –0.52	1.2%	8.5%	2.4%	0.0%	0.352
19	–1.25 ± 0.98	–1.61, –0.90	6.3%	21.9%	0.0%	0.0%	–0.90 ± 1.08	–1.56, –0.25	0.0%	30.8%	0.0%	0.0%	0.406
Total	–1.60 ± 1.37	–1.64, –1.55	16.6%	36.1%	2.1%	0.7%	–1.30 ± 1.38	–1.35, –1.26	12.4%	29.5%	4.0%	0.9%	

†One sample t-test revealed significant difference (at $P<0.001$) in mean z-score from 0 per sex and age for both boys and girls.

[§]95% confidence interval for mean z-score

[*]*P-values* for independent sample t-test for sexual dimorphism in mean z-scores between boys and girls. Significant difference is expressed in boldface.

Table 4.5: Age- and sex-specific reference percentiles for height in children and adolescents aged 1 – 19 years[1]

	Height (cm)																	
	Males									Females								
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	(M)	75th	90th	97th
1.00 – 1.49	1	0.1036	49.65	53.85	58.09	62.3796	66.71	71.07	75.47	1	0.1107	47.22	52.59	57.60	62.3289	66.82	71.11	75.23
1.50 – 1.99	1	0.1020	53.37	57.80	62.27	66.7906	71.35	75.95	80.59	1	0.1088	50.86	56.48	61.74	66.7080	71.43	75.95	80.29
2.00 – 2.49	1	0.1004	57.10	61.75	66.44	71.1831	75.97	80.79	85.66	1	0.1068	54.51	60.38	65.87	71.0694	76.01	80.75	85.29
2.50 – 2.99	1	0.0987	60.84	65.69	70.60	75.5471	80.54	85.58	90.66	1	0.1049	58.19	64.28	69.99	75.4038	80.56	85.49	90.24
3.00 – 3.49	1	0.0971	64.57	69.62	74.72	79.8722	85.07	90.31	95.59	1	0.1030	61.88	68.17	74.09	79.7013	85.05	90.17	95.10
3.50 – 3.99	1	0.0955	68.29	73.52	78.81	84.1478	89.53	94.96	100.43	1	0.1010	65.56	72.05	78.16	83.9515	89.48	94.78	99.89
4.00 – 4.49	1	0.0939	71.98	77.39	82.85	88.3630	93.92	99.52	105.17	1	0.0991	69.24	75.90	82.18	88.1440	93.84	99.31	104.57
4.50 – 4.99	1	0.0923	75.65	81.21	86.84	92.5065	98.23	103.99	109.80	1	0.0971	72.91	79.72	86.15	92.2680	98.12	103.73	109.14
5.00 – 5.49	1	0.0907	79.27	84.98	90.75	96.5666	102.43	108.34	114.30	1	0.0952	76.54	83.49	90.06	96.3126	102.30	108.05	113.60
5.50 – 5.99	1	0.0891	82.84	88.68	94.58	100.5312	106.53	112.57	118.66	1	0.0932	80.14	87.20	93.89	100.2662	106.37	112.24	117.91
6.00 – 6.49	1	0.0875	86.34	92.30	98.32	104.3887	110.50	116.67	122.87	1	0.0913	83.69	90.85	97.64	104.1178	110.33	116.31	122.08
6.50 – 6.99	1	0.0859	89.77	95.84	101.96	108.1299	114.35	120.61	126.92	1	0.0894	87.18	94.42	101.29	107.8580	114.16	120.22	126.09
7.00 – 7.49	1	0.0843	93.12	99.28	105.49	111.7470	118.05	124.41	130.80	1	0.0874	90.61	97.91	104.85	111.4788	117.85	123.99	129.93
7.50 – 7.99	1	0.0827	96.39	102.62	108.90	115.2360	121.62	128.04	134.51	1	0.0855	93.97	101.30	108.29	114.9749	121.40	127.60	133.60
8.00 – 8.49	1	0.0811	99.57	105.86	112.20	118.5948	125.03	131.52	138.04	1	0.0835	97.25	104.61	111.62	118.3427	124.81	131.06	137.10
8.50 – 8.99	1	0.0795	102.66	109.00	115.39	121.8238	128.31	134.83	141.40	1	0.0816	100.45	107.81	114.84	121.5808	128.07	134.35	140.42
9.00 – 9.49	1	0.0779	105.67	112.04	118.46	124.9250	131.44	138.00	144.59	1	0.0796	103.57	110.92	117.94	124.6896	131.19	137.48	143.58
9.50 – 9.99	1	0.0763	108.59	114.98	121.42	127.9029	134.43	141.01	147.62	1	0.0777	106.61	113.93	120.94	127.6718	134.17	140.46	146.56
10.00 – 10.49	1	0.0747	111.43	117.83	124.27	130.7634	137.30	143.88	150.50	1	0.0757	109.57	116.85	123.82	130.5312	137.01	143.29	149.38
10.50 – 10.99	1	0.0731	114.19	120.58	127.03	133.5135	140.04	146.62	153.23	1	0.0738	112.46	119.67	126.60	133.2727	139.72	145.97	152.04
11.00 – 11.49	1	0.0715	116.88	123.26	129.69	136.1613	142.67	149.23	155.82	1	0.0719	115.27	122.41	129.28	135.9012	142.31	148.52	154.56
11.50 – 11.99	1	0.0699	119.51	125.87	132.27	138.7157	145.20	151.73	158.29	1	0.0699	118.01	125.07	131.86	138.4230	144.77	150.94	156.93
12.00 – 12.49	1	0.0683	122.08	128.41	134.78	141.1861	147.64	154.12	160.65	1	0.0680	120.68	127.65	134.36	140.8439	147.13	153.24	159.18
12.50 – 12.99	1	0.0667	124.60	130.89	137.22	143.5820	149.99	156.43	162.91	1	0.0660	123.30	130.15	136.77	143.1703	149.38	155.42	161.29
13.00 – 13.49	1	0.0651	127.09	133.32	139.60	145.9132	152.27	158.65	165.08	1	0.0641	125.85	132.59	139.10	145.4082	151.53	157.49	163.29
13.50 – 13.99	1	0.0635	129.53	135.71	141.93	148.1890	154.48	160.81	167.17	1	0.0621	128.35	134.96	141.36	147.5642	153.59	159.46	165.18
14.00 – 14.49	1	0.0619	131.96	138.07	144.23	150.4186	156.64	162.90	169.20	1	0.0602	130.80	137.28	143.55	149.6450	155.57	161.34	166.97
14.50 – 14.99	1	0.0603	134.36	140.41	146.49	152.6098	158.76	164.95	171.16	1	0.0582	133.20	139.54	145.69	151.6577	157.47	163.14	168.67
15.00 – 15.49	1	0.0587	136.75	142.72	148.73	154.7701	160.84	166.95	173.08	1	0.0563	135.57	141.76	147.77	153.6097	159.30	164.86	170.29
15.50 – 15.99	1	0.0571	139.13	145.02	150.95	156.9056	162.89	168.91	174.96	1	0.0544	137.90	143.94	149.80	155.5085	161.08	166.51	171.83
16.00 – 16.49	1	0.0555	141.51	147.31	153.15	159.0218	164.92	170.85	176.80	1	0.0524	140.21	146.08	151.79	157.3616	162.80	168.11	173.31
16.50 – 16.99	1	0.0539	143.88	149.60	155.35	161.1226	166.93	172.76	178.62	1	0.0505	142.50	148.20	153.76	159.1776	164.47	169.65	174.73
17.00 – 17.49	1	0.0523	146.26	151.89	157.53	163.2112	168.92	174.65	180.40	1	0.0485	144.77	150.30	155.70	160.9652	166.12	171.16	176.10
17.50 – 17.99	1	0.0507	148.65	154.17	159.72	165.2901	170.89	176.51	182.16	1	0.0466	147.04	152.40	157.62	162.7322	167.73	172.63	177.44
18.00 – 18.49	1	0.0491	151.04	156.46	161.90	167.3620	172.85	178.37	183.90	1	0.0446	149.31	154.48	159.54	164.4859	169.33	174.08	178.75
18.50 – 18.99	1	0.0475	153.44	158.75	164.08	169.4292	174.81	180.20	185.62	1	0.0427	151.59	156.57	161.45	166.2319	170.92	175.52	180.03
19.00 – 19.49	1	0.0459	155.85	161.04	166.26	171.4938	176.75	182.03	187.33	1	0.0408	153.87	158.67	163.37	167.9751	172.50	176.94	181.30

[1]Smoothed L, M, and S curves for height were generated by using equivalent df of 1, 5 and 4 for both males andfemales.L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for height can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the following formula: $Z = \frac{(height\ (cm)/M)^L - 1}{L \times S}$

Table 4.6: Age- and sex-specific reference percentiles for weight in children and adolescents aged 1 – 19 years[1]

	Weight (kg)																	
	Males									Females								
Age (years)	L	S	3rd	10th	25th	(M)	75th	90th	97th	L	S	3rd	10th	25th	(M)	75th	90th	97th
1.00 – 1.49	0.4400	0.2402	4.28	5.09	5.99	7.0813	8.28	9.45	10.69	0.5351	0.2197	4.28	5.04	5.86	6.8353	7.88	8.89	9.93
1.50 – 1.99	0.3608	0.2315	5.21	6.11	7.12	8.3589	9.73	11.08	12.52	0.5296	0.2152	5.11	5.98	6.93	8.0549	9.26	10.42	11.62
2.00 – 2.49	0.2843	0.2231	6.14	7.13	8.24	9.6046	11.13	12.64	14.28	0.5240	0.2108	5.93	6.91	7.97	9.2414	10.60	11.90	13.25
2.50 – 2.99	0.2113	0.2151	7.09	8.14	9.34	10.8182	12.48	14.14	15.95	0.5185	0.2066	6.74	7.82	9.00	10.3982	11.90	13.33	14.81
3.00 – 3.49	0.1429	0.2076	8.03	9.15	10.42	12.0018	13.79	15.58	17.55	0.5130	0.2026	7.54	8.73	10.01	11.5290	13.16	14.71	16.33
3.50 – 3.99	0.0798	0.2007	8.97	10.15	11.48	13.1574	15.05	16.97	19.08	0.5074	0.1989	8.35	9.62	11.00	12.6371	14.39	16.06	17.80
4.00 – 4.49	0.0232	0.1943	9.90	11.13	12.53	14.2842	16.28	18.31	20.55	0.5019	0.1955	9.14	10.50	11.97	13.7243	15.59	17.38	19.23
4.50 – 4.99	–0.0263	0.1885	10.81	12.09	13.55	15.3795	17.47	19.60	21.96	0.4964	0.1924	9.93	11.37	12.93	14.7905	16.77	18.66	20.63
5.00 – 5.49	–0.0678	0.1832	11.69	13.02	14.53	16.4362	18.61	20.83	23.29	0.4908	0.1896	10.70	12.22	13.87	15.8311	17.92	19.92	21.99
5.50 – 5.99	–0.1006	0.1786	12.54	13.92	15.48	17.4486	19.70	21.99	24.55	0.4853	0.1872	11.45	13.05	14.79	16.8426	19.04	21.13	23.31
6.00 – 6.49	–0.1246	0.1746	13.35	14.77	16.39	18.4218	20.74	23.11	25.76	0.4798	0.1851	12.18	13.86	15.68	17.8316	20.13	22.32	24.60
6.50 – 6.99	–0.1399	0.1713	14.13	15.60	17.27	19.3638	21.76	24.20	26.93	0.4742	0.1835	12.90	14.66	16.56	18.8076	21.21	23.50	25.89
7.00 – 7.49	–0.1467	0.1689	14.87	16.39	18.12	20.2839	22.75	25.27	28.08	0.4687	0.1822	13.61	15.45	17.43	19.7802	22.29	24.69	27.18
7.50 – 7.99	–0.1452	0.1672	15.58	17.16	18.95	21.1929	23.75	26.35	29.24	0.4632	0.1814	14.32	16.23	18.30	20.7595	23.38	25.89	28.50
8.00 – 8.49	–0.1360	0.1665	16.27	17.91	19.78	22.1075	24.76	27.45	30.45	0.4576	0.1809	15.03	17.03	19.19	21.7560	24.50	27.12	29.85
8.50 – 8.99	–0.1198	0.1666	16.94	18.66	20.61	23.0451	25.81	28.61	31.72	0.4521	0.1807	15.75	17.84	20.10	22.7836	25.65	28.40	31.26
9.00 – 9.49	–0.0977	0.1675	17.61	19.42	21.47	24.0205	26.91	29.84	33.08	0.4466	0.1809	16.50	18.69	21.06	23.8695	26.88	29.76	32.76
9.50 – 9.99	–0.0709	0.1689	18.29	20.20	22.36	25.0460	28.08	31.15	34.53	0.4411	0.1813	17.30	19.60	22.08	25.0423	28.21	31.24	34.41
10.00 – 10.49	–0.0404	0.1707	18.99	21.01	23.29	26.1260	29.32	32.55	36.09	0.4355	0.1820	18.17	20.58	23.20	26.3219	29.67	32.87	36.21
10.50 – 10.99	–0.0074	0.1729	19.70	21.85	24.26	27.2620	30.64	34.03	37.75	0.4300	0.1828	19.11	21.65	24.42	27.7206	31.26	34.65	38.20
11.00 – 11.49	0.0275	0.1753	20.43	22.71	25.27	28.4502	32.01	35.59	39.50	0.4245	0.1838	20.11	22.81	25.73	29.2288	32.98	36.58	40.35
11.50 – 11.99	0.0640	0.1779	21.17	23.60	26.32	29.6865	33.45	37.23	41.33	0.4189	0.1847	21.18	24.02	27.12	30.8267	34.81	38.63	42.64
12.00 – 12.49	0.1021	0.1805	21.92	24.51	27.40	30.9702	34.95	38.93	43.24	0.4134	0.1856	22.27	25.28	28.56	32.4757	36.69	40.75	45.00
12.50 – 12.99	0.1421	0.1831	22.69	25.44	28.52	32.3016	36.51	40.69	45.21	0.4079	0.1864	23.38	26.55	30.00	34.1359	38.59	42.88	47.37
13.00 – 13.49	0.1841	0.1855	23.48	26.41	29.68	33.6817	38.12	42.51	47.24	0.4023	0.1869	24.49	27.81	31.44	35.7802	40.46	44.97	49.71
13.50 – 13.99	0.2278	0.1874	24.32	27.43	30.89	35.1115	39.77	44.36	49.28	0.3968	0.1872	25.59	29.06	32.85	37.3872	42.29	47.01	51.98
14.00 – 14.49	0.2730	0.1885	25.20	28.50	32.15	36.5914	41.46	46.24	51.33	0.3913	0.1871	26.67	30.28	34.22	38.9459	44.05	48.98	54.15
14.50 – 14.99	0.3194	0.1888	26.15	29.64	33.47	38.1214	43.19	48.13	53.36	0.3857	0.1866	27.74	31.47	35.55	40.4500	45.74	50.85	56.22
15.00 – 15.49	0.3664	0.1882	27.18	30.84	34.86	39.7002	44.94	50.02	55.37	0.3802	0.1859	28.79	32.64	36.85	41.9013	47.36	52.63	58.18
15.50 – 15.99	0.4135	0.1866	28.28	32.12	36.31	41.3250	46.72	51.91	57.35	0.3747	0.1849	29.84	33.79	38.11	43.3049	48.92	54.34	60.05
16.00 – 16.49	0.4605	0.1843	29.47	33.48	37.82	42.9855	48.51	53.79	59.29	0.3691	0.1836	30.87	34.92	39.35	44.6693	50.42	55.98	61.83
16.50 – 16.99	0.5070	0.1812	30.73	34.89	39.37	44.6702	50.30	55.64	61.17	0.3636	0.1822	31.90	36.04	40.57	46.0040	51.88	57.56	63.54
17.00 – 17.49	0.5532	0.1777	32.05	36.35	40.96	46.3695	52.07	57.46	63.01	0.3581	0.1807	32.93	37.16	41.77	47.3163	53.31	59.10	65.20
17.50 – 17.99	0.5990	0.1738	33.42	37.85	42.57	48.0754	53.84	59.25	64.80	0.3525	0.1791	33.96	38.27	42.97	48.6134	54.72	60.62	66.83
18.00 – 18.49	0.6447	0.1696	34.83	39.39	44.20	49.7832	55.59	61.02	66.54	0.3470	0.1775	35.00	39.37	44.16	49.9018	56.11	62.11	68.44
18.50 – 18.99	0.6903	0.1654	36.28	40.94	45.85	51.4901	57.33	62.75	68.25	0.3415	0.1759	36.04	40.49	45.35	51.1871	57.50	63.60	70.03
19.00 – 19.49	0.7358	0.1611	37.76	42.52	47.50	53.1962	59.06	64.47	69.93	0.3359	0.1742	37.08	41.60	46.54	52.4714	58.88	65.08	71.60

[1]Smoothed L, M, and S curves for Weight were generated by using equivalent df of 3, 4 and 5 in males and 2, 3 and 5 in females respectively. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for weight can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the following formula: $Z = \frac{(weight\ (kg)/M)^{L} - 1}{L \times S}$

Table 4.7 Age- and sex-specific reference percentiles for Body Mass Index in children and adolescents aged 1 – 19 years[1]

	BMI (kgm^{-2})																	
	Males									Females								
Age (years)	L	S	3rd	10th	25th	(M)	75th	90th	97th	L	S	3rd	10th	25th	(M)	75th	90th	97th
1.00 – 1.49	0.2959	0.1675	12.20	13.79	15.50	17.3687	19.39	21.56	23.91	–0.5212	0.1871	11.43	12.73	14.26	16.0920	18.31	21.02	24.40
1.50 – 1.99	0.2828	0.1647	12.39	13.95	15.66	17.5032	19.50	21.66	23.98	–0.5068	0.1836	11.65	12.96	14.49	16.3192	18.52	21.19	24.50
2.00 – 2.49	0.2697	0.1620	12.48	14.02	15.70	17.5182	19.49	21.61	23.90	–0.4924	0.1801	11.79	13.09	14.62	16.4291	18.59	21.21	24.43
2.50 – 2.99	0.2566	0.1593	12.47	13.98	15.62	17.3941	19.32	21.39	23.63	–0.4779	0.1768	11.83	13.12	14.63	16.4060	18.52	21.07	24.17
3.00 – 3.49	0.2435	0.1567	12.36	13.82	15.41	17.1289	18.99	21.00	23.17	–0.4635	0.1735	11.78	13.05	14.52	16.2549	18.31	20.76	23.73
3.50 – 3.99	0.2304	0.1541	12.15	13.56	15.08	16.7316	18.52	20.45	22.53	–0.4491	0.1705	11.64	12.88	14.31	15.9885	17.97	20.32	23.15
4.00 – 4.49	0.2173	0.1516	11.87	13.20	14.66	16.2369	17.94	19.79	21.78	–0.4347	0.1676	11.43	12.63	14.01	15.6288	17.52	19.77	22.45
4.50 – 4.99	0.2042	0.1492	11.53	12.81	14.19	15.6891	17.31	19.07	20.96	–0.4202	0.1649	11.17	12.32	13.66	15.2060	17.02	19.15	21.69
5.00 – 5.49	0.1911	0.1470	11.19	12.40	13.72	15.1446	16.69	18.36	20.16	–0.4058	0.1625	10.89	12.00	13.29	14.7729	16.50	18.53	20.93
5.50 – 5.99	0.1781	0.1448	10.89	12.04	13.30	14.6588	16.13	17.72	19.44	–0.3914	0.1604	10.63	11.71	12.95	14.3826	16.04	17.98	20.26
6.00 – 6.49	0.1650	0.1429	10.65	11.76	12.96	14.2711	15.69	17.22	18.87	–0.3770	0.1587	10.42	11.48	12.68	14.0666	15.67	17.54	19.72
6.50 – 6.99	0.1519	0.1412	10.49	11.57	12.74	14.0053	15.38	16.86	18.47	–0.3625	0.1574	10.28	11.31	12.49	13.8456	15.41	17.22	19.34
7.00 – 7.49	0.1388	0.1397	10.41	11.46	12.60	13.8406	15.18	16.63	18.21	–0.3481	0.1566	10.19	11.21	12.38	13.7174	15.26	17.04	19.11
7.50 – 7.99	0.1257	0.1385	10.37	11.41	12.53	13.7515	15.07	16.50	18.05	–0.3337	0.1563	10.15	11.18	12.34	13.6703	15.20	16.97	19.02
8.00 – 8.49	0.1126	0.1375	10.39	11.41	12.53	13.7379	15.05	16.47	18.01	–0.3192	0.1564	10.15	11.18	12.34	13.6768	15.21	16.97	19.01
8.50 – 8.99	0.0995	0.1368	10.46	11.48	12.59	13.8014	15.11	16.54	18.08	–0.3048	0.1569	10.16	11.20	12.37	13.7122	15.25	17.02	19.07
9.00 – 9.49	0.0864	0.1363	10.57	11.59	12.71	13.9226	15.24	16.67	18.23	–0.2904	0.1578	10.19	11.23	12.42	13.7789	15.33	17.12	19.19
9.50 – 9.99	0.0733	0.1360	10.70	11.73	12.86	14.0814	15.41	16.86	18.43	–0.2760	0.1591	10.24	11.30	12.51	13.8910	15.47	17.28	19.38
10.00 – 10.49	0.0602	0.1359	10.85	11.90	13.03	14.2746	15.62	17.09	18.69	–0.2615	0.1606	10.35	11.43	12.67	14.0830	15.70	17.55	19.70
10.50 – 10.99	0.0471	0.1360	11.03	12.08	13.24	14.4983	15.87	17.37	19.00	–0.2471	0.1623	10.53	11.65	12.93	14.3848	16.05	17.97	20.18
11.00 – 11.49	0.0340	0.1363	11.20	12.28	13.45	14.7308	16.13	17.66	19.32	–0.2327	0.1642	10.78	11.94	13.27	14.7878	16.52	18.51	20.81
11.50 – 11.99	0.0210	0.1366	11.37	12.46	13.65	14.9505	16.37	17.93	19.63	–0.2183	0.1661	11.08	12.30	13.68	15.2652	17.08	19.16	21.55
12.00 – 12.49	0.0079	0.1370	11.52	12.62	13.83	15.1560	16.61	18.19	19.93	–0.2038	0.1680	11.38	12.66	14.10	15.7558	17.65	19.81	22.31
12.50 – 12.99	–0.0052	0.1375	11.66	12.78	14.01	15.3494	16.82	18.44	20.21	–0.1894	0.1696	11.66	12.98	14.48	16.1987	18.16	20.41	23.00
13.00 – 13.49	–0.0183	0.1380	11.79	12.92	14.17	15.5292	17.03	18.67	20.48	–0.1750	0.1710	11.89	13.25	14.80	16.5701	18.59	20.91	23.58
13.50 – 13.99	–0.0314	0.1385	11.91	13.06	14.31	15.6949	17.22	18.89	20.73	–0.1605	0.1722	12.06	13.46	15.05	16.8604	18.93	21.30	24.03
14.00 – 14.49	–0.0445	0.1390	12.03	13.18	14.46	15.8559	17.40	19.10	20.97	–0.1461	0.1730	12.19	13.61	15.24	17.0828	19.19	21.60	24.37
14.50 – 14.99	–0.0576	0.1395	12.15	13.32	14.61	16.0269	17.59	19.32	21.23	–0.1317	0.1735	12.29	13.74	15.39	17.2586	19.39	21.83	24.62
15.00 – 15.49	–0.0707	0.1399	12.31	13.49	14.79	16.2356	17.83	19.59	21.54	–0.1173	0.1737	12.39	13.86	15.53	17.4209	19.58	22.03	24.84
15.50 – 15.99	–0.0838	0.1402	12.51	13.71	15.04	16.5034	18.13	19.92	21.92	–0.1028	0.1736	12.51	14.00	15.69	17.5998	19.77	22.25	25.07
16.00 – 16.49	–0.0969	0.1404	12.74	13.97	15.32	16.8135	18.47	20.31	22.35	–0.0884	0.1733	12.65	14.16	15.87	17.8040	20.00	22.49	25.32
16.50 – 16.99	–0.1100	0.1406	12.99	14.24	15.62	17.1419	18.84	20.72	22.81	–0.0740	0.1729	12.82	14.35	16.08	18.0342	20.25	22.76	25.60
17.00 – 17.49	–0.1230	0.1408	13.25	14.51	15.92	17.4742	19.20	21.13	23.27	–0.0596	0.1724	13.00	14.55	16.30	18.2809	20.52	23.04	25.90
17.50 – 17.99	–0.1361	0.1409	13.50	14.79	16.21	17.7997	19.56	21.53	23.72	–0.0451	0.1717	13.18	14.76	16.53	18.5336	20.79	23.33	26.20
18.00 – 18.49	–0.1492	0.1410	13.74	15.05	16.50	18.1153	19.91	21.92	24.16	–0.0307	0.1711	13.37	14.97	16.77	18.7875	21.06	23.62	26.50
18.50 – 18.99	–0.1623	0.1410	13.98	15.31	16.78	18.4206	20.25	22.30	24.59	–0.0163	0.1705	13.55	15.18	17.00	19.0401	21.33	23.91	26.80
19.00 – 19.49	–0.1754	0.1411	14.21	15.56	17.05	18.7202	20.58	22.67	25.00	–0.0018	0.1698	13.74	15.38	17.23	19.2917	21.60	24.19	27.10

[1]Smoothed L, M, and S curves for BMI were generated by using equivalent df of 2, 4 and 8 in males and 2, 3 and 7 in females respectively. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for BMI can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the following formula: $Z = \frac{(BMI\ (kg/m^2)/M)^L - 1}{L \times S}$

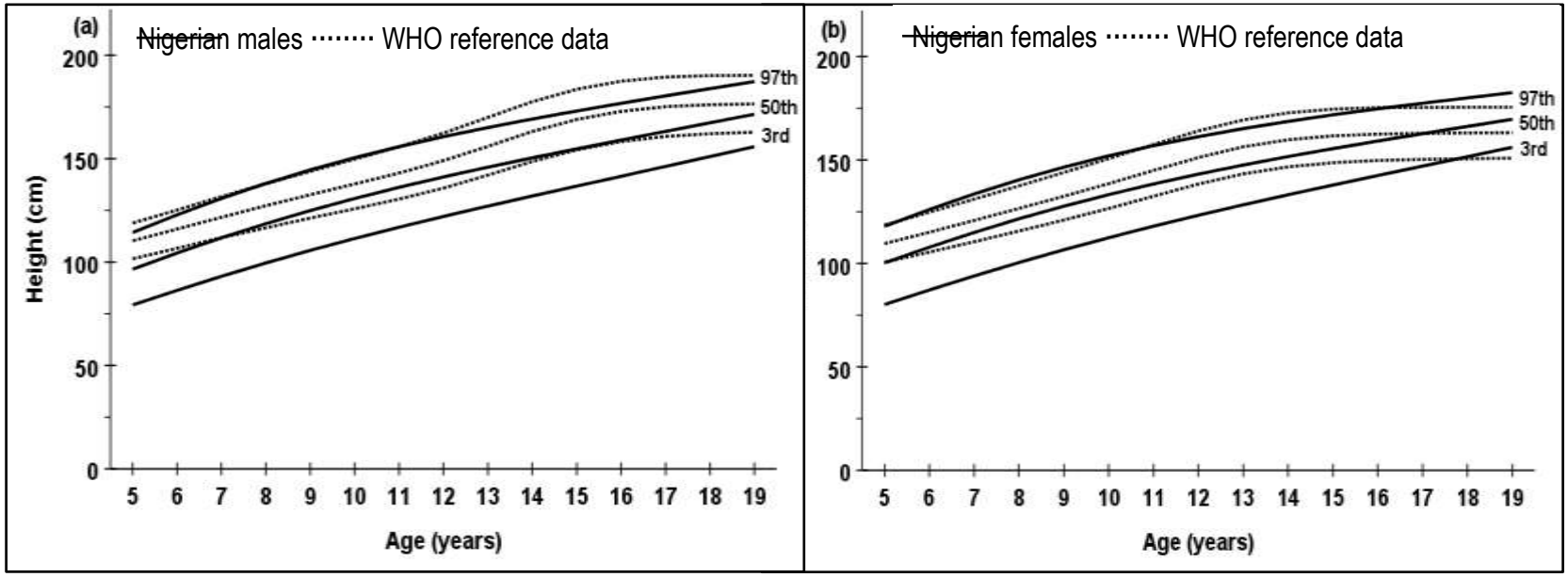

Figure 4.1: Comparison of growth pattern between Nigerian children and WHO (2007) data

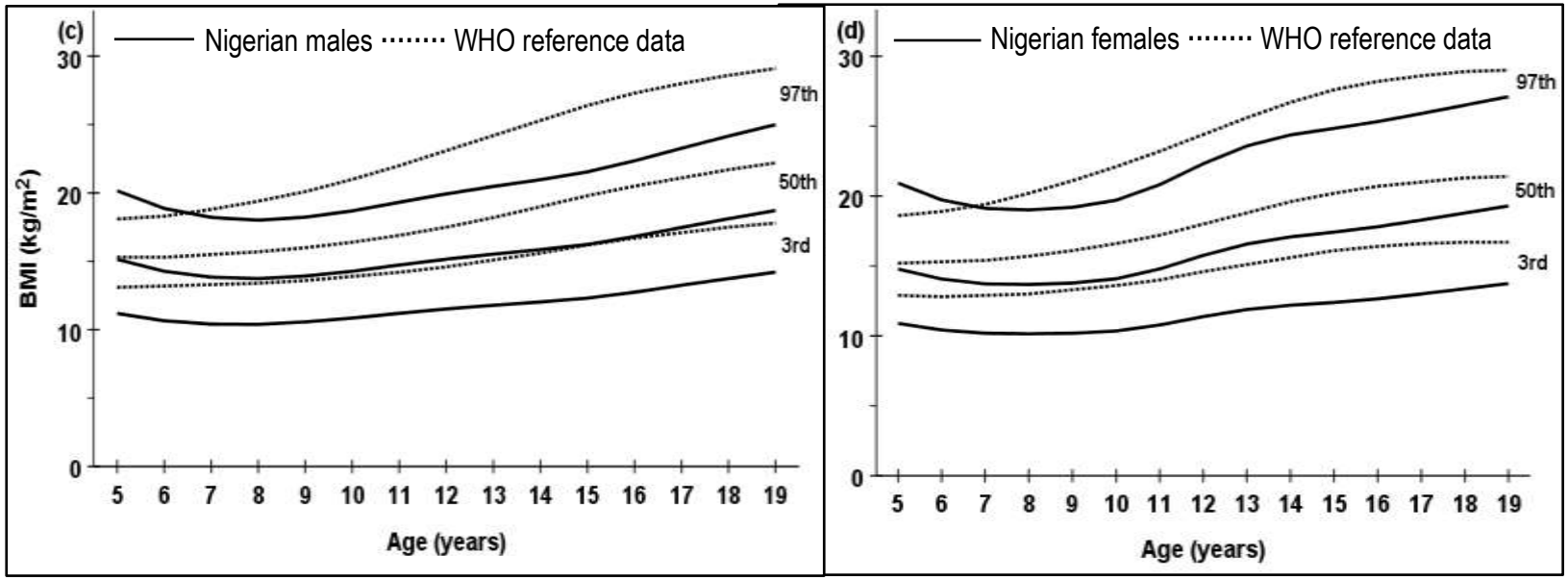

Figure 4.2: Comparison of growth pattern between Nigerian children and WHO (2007) data

4.3 Multiple Logistic Regressions Results for Stunting

The specific multiple logistic regression models used was:

$\log [(P/(1 - P)] = \beta_0 + \beta_1 \times FNE + \beta_2 \times FPE + \beta_3 \times FSE + \beta_4 \times FTE + \beta_5 \times MNE + \beta_6 \times MPE + \beta_7 \times MSE + \beta_8 \times A + \beta_9 \times E + \beta_{10} \times HF$

where stunting (moderate or severe) is the response variable and other variableswere predictors.

The regression coefficients of the independent variablesare presented in Table 4.8. The coefficients and odds ratio showed that father's level of education is inversely associated with moderate stunting. From the table, children whose father had tertiary education are 0.091 times less likely to be moderately stunted (P<0.001), whereas those whose father had secondary and primary education are respectively 1.876 and 2.069 times more likely to be moderately stunted (P <0.05). The results indicate increase in the odds of moderate stunting with decrease in paternal educational attainment. This is in keeping with the inverse association between father's level of education and stunting as seen in the coefficients of regression. Children whose mother had secondary education were 0.568 times less likely to be moderately stunted (P = 0.015), whereas those whose mother had no formal education were 3.258 times more likely to be moderately stunted (P <0.001). Ethnicity had no significant impact on moderate stunting compared to educational background as indicated by the Wald statistics.

Still on Table 4.8, the results revealed that children whose father had tertiary, secondary and primary education were 0.037, 0.076 and 0.263 times less likely to be severely stunted (P <0.05). Intuitively, the association between father's educational attainment and stunting is inverse as is the case with moderate stunting as indicated by the coefficients of

regression. Similarly, those whose mother had secondary education were 0.329 times less likely to be severely stunted. In contrast, those whose mother had primary and no formal education were 5.118 and 7.463 times more likely to be severely stunted. It therefore it follows that maternal educational attainment had stronger influence on both moderate and severe stunting. As expected, ethnicity had no significant impact on stunting ($P > 0.05$).

4.4 Multiple Logistic Regressions Results for Thinness

Thinness appears less sensitive to paternal and maternal educational attainment. Results of paternal educational attainment was in the direction of less likely for thinness even for fathers who had no formal education. For instance, the Odds ratio for children whose father have no formal education was 0.198 ($P <0.001$), even more less likely compared to children whose father had tertiary education (odds ratio = 0.470, $P > 0.05$). The results for maternal level of education were similar to paternal level of education. Expectedly, ethnicity wields the least influence on nutritional status. However, father's level of education showed significant linear association with severe thinness. For instance, those whose father had secondary, primary and no formal education were respectively 2.285, 2.226 and 4.023 times more likely to be severely thinness. Regressionequations for the prediction of stunting (moderate and severe) and thinness (moderate and severe) are presented in Table 4.9. Regressionequations for the prediction of moderate and severe stunting and thinnesswere presented in Table 4.10.

4.5 Stepwise Logistic Regression Results

Stepwise logistic regression (forward LR) was used to find the most influential factors influencing nutritional status (stunting and thinness). In this method, only variables with

significant influence were retained, while those with insignificant contribution were excluded from the final model. Results of the first step of the logistic regression analysis showed that the variable; mother not having formal education exerts the highest influence on moderate stunting as indicated by the Wald test statistics and the corresponding change in -2LR is also significant (P <0.001) (Table 4.11). The result also showed that children whose mother had no formal education are 3.544 times more likely to be moderately stunted (P <0.001). In the second step, in addition to variable in the first step, father not having formal educational background was included. The order of influence of factors identified from steps 1 – 4 is mother none > father none > father primary > mother secondary. In each case, the corresponding change in -2LR was significant at P <0.001.Results of the stepwise logistic regression for severe stunting is presented in Table 4.12. The results are similar to that for moderate stunting as expected. In the first step, mother not having formal education exerts the greatest influence on severe stunting as evident in the Wald statistics and odds ratio (P <0.001). The corresponding change in -2LR was also significant at P <0.001. In step two, father not having formal education was added to the variable in step one. The order of influence of the predictive variable is mother none > father none > father primary. In the fourth and final step, children whose mother had tertiary education are 0.155 times less likely to be severely stunted (P = 0.012).

Table 4.13 shows the summary results of stepwise logistic regression analysis with thinness and severe thinness as response variables. The stepwise logistic regression analysis showed that parents' educational attainment has no significant impact on thinness. In step one, children whose father had no formal education are 0.523 less likely to be thin. In step two, in addition to the variable in step one, children whose father had tertiary education are

1.416 times likely to be thin whereas, in step three, in addition to the variables in step one, children from Alago ethnic decent are 0.869 times less likely to be thin (P = 0.014). Regarding severe thinness, those whose father has no formal education are 1.691 times more likely to be severely thin as indicated in the first step (P <0.001). In the second step, in addition to the predictor variable in the first step, those whose father had only primary education are 1.494 times more likely to be severely thin (P <0.001).

Table 4.8: Multiple logistic regression estimates for the effects of socio-demographic factors on stunting

	Variable	Coefficients	SE	Wald	df	*P*-value	Odds ratio
1							
	Father's education						
	None	–0.727	0.470	2.396	1	0.122	2.776
	Primary	–1.021	0.470	4.723	1	**0.030**	2.069
	Secondary	–1.771	0.480	13.627	1	**<0.001**	1.876
	Tertiary	–2.014	0.494	16.621	1	**<0.001**	0.091
	Mother's education						
	None	1.354	0.198	46.716	1	**<0.001**	3.258
	Primary	–0.035	0.275	0.016	1	0.899	1.036
	Secondary	0.565	0.232	5.935	1	**0.015**	0.568
	Ethnicity						
	Alago	–0.107	0.192	0.309	1	0.579	0.899
	Eggon	0.127	0.205	0.388	1	0.534	1.136
	Hausa/Fulani	0.109	0.188	0.336	1	0.562	1.115
	Constant	–2.726	1.455	29.397	1	**<0.001**	0.065
2							
	Father's education						
	None	–0.916	0.648	1.996	1	0.158	0.400
	Primary	–1.336	0.654	4.170	1	**0.041**	0.263
	Secondary	–2.579	0.708	13.246	1	**<0.001**	0.076
	Tertiary	–3.302	0.851	15.044	1	**<0.001**	0.037
	Mother's education						
	None	3.066	0.724	17.954	1	**<0.001**	7.463
	Primary	1.633	0.794	4.226	1	**0.040**	5.118
	Secondary	1.992	0.766	6.757	1	**0.009**	0.329
	Ethnicity						
	Alago	–0.124	0.344	0.130	1	0.718	0.883
	Eggon	0.039	0.370	0.011	1	0.915	1.040
	Hausa/Fulani	0.141	0.324	0.190	1	0.663	1.152
	Constant	–5.058	0.968	6.837	1	**<0.001**	0.006

[1]Indicates moderate stunting
[2]Indicates severe stunting

Table 4.9: Multiple logistic regression estimates for the effects of socio-demographic factors on thinness

	Variable	Coefficients	SE	Wald	df	P-value	Odds ratio
1							
	Father's education						
	None	–1.620	0.323	25.186	1	**<0.001**	0.198
	Primary	–1.121	0.320	12.275	1	**<0.001**	0.326
	Secondary	–1.072	0.319	11.295	1	**<0.001**	0.342
	Tertiary	–0.756	0.319	5.615	1	**0.018**	0.470
	Mother's education						
	None	–0.092	0.069	1.772	1	0.183	0.912
	Primary	0.006	0.077	0.005	1	0.943	1.006
	Secondary	–0.152	0.074	4.219	1	**0.040**	0.859
	Ethnicity						
	Alago	–0.101	0.072	1.949	1	0.163	0.904
	Eggon	0.032	0.080	0.161	1	0.688	1.032
	Hausa/Fulani	0.055	0.075	0.532	1	0.466	1.056
	Constant	0.417	0.960	1.675	1	0.196	1.518
2							
	Father's education						
	None	1.392	0.368	14.348	1	**<0.001**	4.023
	Primary	0.800	0.360	4.944	1	**0.026**	2.226
	Secondary	0.826	0.359	5.303	1	**0.021**	2.285
	Tertiary	0.417	0.358	1.359	1	0.244	1.517
	Mother's education						
	None	0.094	0.093	1.022	1	0.312	1.099
	Primary	–0.117	0.101	1.361	1	0.243	0.889
	Secondary	0.070	0.099	0.506	1	0.477	1.073
	Tertiary	–0.155	0.073	4.461	1	**0.035**	0.856
	Ethnicity						
	Alago	–0.023	0.097	0.059	1	0.808	0.977
	Eggon	0.061	0.106	0.335	1	0.562	1.063
	Hausa/Fulani	–0.005	0.102	0.002	1	0.963	0.995
	Others	–0.006	0.083	0.006	1	0.937	0.994
	Constant	–4.497	1.081	17.313	1	**<0.001**	0.011

[1]Indicates moderate thinness
[2]Indicates severe thinness

Table 4.10: Prediction equations for stunting and thinness in children and adolescents aged 5–19 years

HAZ	Prediction equation
Moderate stunting	log [(P/(1 − P)] = – 2.726 – 0.727 × FNE – 1.021 × FPE – 1.771 × FSE – 2.014 × FTE + MNE × 1.354 – 0.035 × MPE + 0.565 × MSE – 0.107 × ALA + 0.127 × EGN + 0.109 × HF
Severe stunting	log [(P/(1 − P)] = – 5.058 – 0.916 × FNE – 1.336 × FPE – 2.579 × FSE – 3.302 × FTE + 3.066 × MNE + 1.633 × MPE + 1.992 × MSE – 0.124 × ALA + 0.039 × EGN + 0.141 × HF
BAZ	
Moderate thinness	log [(P/(1 − P)] = 0.417 – 1.620 × FNE – 1.121 × FPE – 1.072 × FSE – 0.756 × FTE – 0.092 × MNE + 0.006 × MPE – 0.152 × MSE – 0.101 × ALA + 0.032 × EGN + 0.055 × HF
Severe thinness	log [(P/(1 − P)] = – 1.014 – 1.392 × FNE – 0.800 × FPE – 0.826 × FSE – 0.417 × FTE – 0.094 × MNE + 0.117 × MPE – 0.070 × MSE – 0.023 × ALA + 0.061 × EGN – 0.005 × HF

HAZs and BAZs were calculated with the use of WHO 2007 SPSS macro (for individuals aged 5 – 19 y). Prediction coefficients were calculated through multiple logistic regression. FPE, father's primary education; FSE, father's secondary education; FTE, father's tertiary education; MPE, mother's primary education; MSE, mother's secondary education; MTE, mother's tertiary education; A, Alago; E, Eggon; HF, Hausa/Fulani

Table 4.11: Summary of the stepwise (forward LR) logistic regression analysis (first and final steps) for socio-demographic factors, where moderate stunting is the response variable

Step	Variable	Coefficients	S.E.	Wald	df	*P*-value	Odds ratio (95% CI)	Change in – 2LR‡
Step 1	Mother none	1.265	0.135	88.471	1	<**0.001**	3.544 (2.722, 4.612)	87.934
	Constant	–3.860	0.100	1488.159	1	<**0.001**	0.021	
Step 2	Father none	0.779	0.143	29.489	1	<**0.001**	2.179 (1.645, 2.887)	26.970
	Mother none	1.220	0.135	81.576	1	<**0.001**	3.389 (2.600, 4.416)	81.186
	Constant	–4.035	0.109	1378.690	1	<**0.001**	0.018	
Step 3	Father none	1.096	0.164	44.506	1	<**0.001**	2.991 (2.168, 4.126)	42.722
	Father primary	0.792	0.164	23.267	1	<**0.001**	2.207 (1.600, 3.045)	22.679
	Mother none	1.184	0.135	76.382	1	<**0.001**	3.268 (2.506, 4.261)	76.148
	Constant	–4.330	0.133	1062.286	1	<**0.001**	0.013	
Step 4	Father none	1.084	0.164	43.527	1	<**0.001**	2.956 (2.142, 4.079)	41.825
	Father primary	0.781	0.164	22.622	1	<**0.001**	2.184 (1.583, 3.013)	22.066
	Mother none	1.400	0.162	74.734	1	<**0.001**	4.056 (2.953, 5.572)	83.012
	Mother secondary	0.579	0.203	8.178	1	**0.004**	1.784 (1.200, 2.654)	7.909†
	Constant	–4.539	0.159	819.117	1	<**0.001**	0.011	

‡Change in -2LR significant at *P*<0.001 except indicated otherwise
†Change in -2LR significant at *P* <0.005

Table 4.12: Summary of the stepwise (forward LR) logistic regression analysis (first and final steps) for socio-demographic factors, where severe stunting is the response variable

Step	Variable	Coefficients	S.E.	Wald	df	*P*-value	Odds ratio (95% CI)	Change in -2LR‡
Step 1	Mother none	1.812	0.257	49.892	1	**<0.001**	6.122 (3.703, 10.122)	55.883
	Constant	–5.410	0.214	641.037	1	**<0.001**	0.004	
Step 2	Father none	1.152	0.240	23.001	1	**<0.001**	3.163 (1.976, 5.064)	21.054
	Mother none	1.737	0.258	45.493	1	**<0.001**	5.682 (3.430, 9.413)	50.871
	Constant	–5.715	0.233	602.976	1	**<0.001**	0.003	
Step 3	Father none	1.777	0.317	31.524	1	**<0.001**	5.915 (3.180, 11.001)	34.464
	Father primary	1.313	0.327	16.134	1	**<0.001**	3.718 (1.959, 7.058)	16.916
	Mother none	1.682	0.258	42.526	1	**<0.001**	5.374 (3.242, 8.908)	47.557
	Constant	–6.301	0.306	422.876	1	**<0.001**	0.002	
Step 4	Father none	1.693	0.316	28.628	1	**<0.001**	5.437 (2.924, 10.109)	31.363
	Father primary	1.272	0.327	15.134	1	**<0.001**	3.568 (1.880, 6.773)	15.879
	Mother none	1.283	0.266	23.207	1	**<0.001**	3.609 (2.141, 6.084)	26.273
	Mother tertiary	–1.864	0.744	6.282	1	**0.012**	0.155 (0.036, 0.666)	10.116
	Constant	–5.850	0.321	332.435	1	**<0.001**	0.003	

‡Change in -2LR significant at $P<0.001$ except indicated otherwise

Table 4.13: Summary of the stepwise (forward LR) logistic regression analysis (first and final steps) for socio-demographic factors, where moderate and severe thinness are the response variables

Step	Variable	Coefficients	S.E.	Wald	df	*P*-value	Odds ratio (95% CI)	Change in -2LR‡
*Step 1	Father none	–0.649	0.074	76.159	1	**<0.001**	0.523 (0.452, 0.605)	82.395
	Constant	–0.618	0.028	478.841	1	**<0.001**	0.539	
*Step 2	Father none	–0.527	0.077	46.469	1	**<0.001**	0.590 (0.507, 0.687)	49.018
	Father tertiary	0.348	0.059	34.739	1	**<0.001**	1.416 (1.261, 1.590)	34.542
	Constant	–0.740	0.035	436.170	1	**<0.001**	0.477	
*Step 3	Father none	–0.539	0.078	48.382	1	**<0.001**	0.583 (0.501, 0.679)	51.081
	Father tertiary	0.341	0.059	33.258	1	**<0.001**	1.406 (1.252, 1.579)	33.070
	Alago	–0.141	0.057	6.098	1	**0.014**	0.869 (0.777, 0.971)	6.140†
	Constant	–0.692	0.040	296.443	1	**<0.001**	0.501	
‡Step 1	Father tertiary	0.525	0.073	51.567	1	**<0.001**	1.691 (1.465, 1.952)	49.798
	Constant	–1.961	0.044	2028.847	1	**<0.001**	0.141	
‡Step 2	Father none	–0.580	0.114	25.652	1	**<0.001**	0.560 (0.448, 0.701)	28.329
	Father tertiary	0.402	0.076	27.943	1	**<0.001**	1.494 (1.288, 1.734)	27.450
	Constant	–1.837	0.048	1458.286	1	**<0.001**	0.159	

‡Change in -2LR significant at $P<0.001$ except indicated otherwise
†Change in -2LR significant at $P<0.050$
*Moderate thinness
‡Severe thinness

4.6 MID-UPPER ARM CIRCUMFERENCE,UPPER ARM MUSCLE AND FAT AREAS

Tables 4.14 – 16 and the corresponding Figures 4.3 – 8 show age- and sex-specific smoothed 3rd, 10th, 25th, 50th, 70th, 90th and 97th percentiles for MUAC, UAMA and UAFA for both boys and girls. The tables also present the median (M), the Box-Cox power to remove skewness (L) and the coefficient of variation (S).

4.6.1 MUAC-for-age

For both boys and girls, MUAC showed steady increase with age. The distribution of MUAC by age for boys was positively skewed from age 1.5 – 15 years, as such, a negative power (L) is required to remove the skewness from the data (Table 4.14), whereas a positive power was used to remove skewness in other age categories. Still on Table 4.6, the distribution of MUAC of girls aged 10 years and below was positively skewed and a negative power was required to normalize the data, while the distribution for those 10.5 years and above was positively skewed and a negative power was used to restore normality of the data distribution. The L, M and S curves for boys were fitted with 3 edf for skewness, 4 edf for the coefficient of variation and the edf for median curve was 6. For girls, the edf for skewness, coefficient of variation and median were respectively 3, 5 and 6. We noticed statistically significant differences in MUAC according to ages for both sexes. For boys, F = 4.425, $P < 0.001$ whereas, for girls, F = 5.063, $P < 0.001$.

4.6.2 UAMA-for-age

The distribution of UAMA by age was positively skewed for both boys and girls and a negative power was needed to remove the skewness from the data (Table 4.15). For both

sexes, the LMS curves were modelled with 3 edf for L, 5 edf for median, M and 4 edf for coefficient of variation, S. Because we couldn't collect TSFT for children younger than 3 years, the UAMA percentile curves were plotted from age 3 years and above. UAMA also showed steady increase with age. Like with MUAC, statistically significant difference in UAMA according to age for both sexes; for boys, F = 3.563, $P < 0.001$ while F = 2.949, $P < 0.001$ for girls.

4.6.3 UAFA-for-age

For UAFA, the curves were modelled on the original age scale like UAMA with edf 3 for the skewness, edf 5 for median and edf 4 for coefficient of variation for both sexes (Table 4.16). Compared to boys, girls consistently have higher UAFA at all ages as expected. However, the age increment in UAFA was slow irrespective of sex. Significant age-specific difference in UAFA for both sexes was observed; F = 1.452, $P < 0.001$ for boys and F = 2.115, $P < 0.001$ for girls.

Results for comparison of age- and sex-specific MUAC, UAMA and UAFA were presented in Table 4.17. From the table, there was gradual increase in MUAC and its derivatives with age. The results showed that prior to age 10 years, MUAC was independent of sex and age of the child. Nevertheless, boys were seen having higher MUAC from age 0.5 to 9 years. At age 10 years and above, the MUAC of girls were significantly higher than that of boys. In respect of UAMA, boys exhibit higher UAMA than girls. However, the difference in UAMA was not significant prior to age 14.5 years. From age 14.5 years, significant sex-dependence in UAMA was obtained. UAFA on the other hand, indicates significant sex-dependence from age 4.5 years with proclivity towards girls.

Table 4.14: Age- and sex-specific reference percentiles for MUAC in children and adolescents aged 0 – 18.5 years[1]

	MUAC (cm)																	
	Males									Females								
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	(M)	75th	90th	97th
0 – 0.5	0.0993	0.1177	10.94	11.86	12.84	13.8876	15.02	16.23	17.53	-0.7205	0.1115	11.09	11.85	12.69	13.6439	14.73	15.97	17.40
1.00 – 1.49	0.0480	0.1142	11.24	12.14	13.11	14.1445	15.26	16.46	17.75	-0.7108	0.1076	11.36	12.11	12.94	13.8794	14.94	16.15	17.53
1.50 – 1.99	-0.0031	0.1107	11.54	12.42	13.37	14.3947	15.50	16.69	17.96	-0.7005	0.1037	11.63	12.37	13.19	14.1146	15.15	16.32	17.66
2.00 – 2.49	-0.0537	0.1073	11.82	12.69	13.62	14.6315	15.72	16.89	18.16	-0.6889	0.0999	11.90	12.63	13.44	14.3486	15.36	16.50	17.79
2.50 – 2.99	-0.1031	0.1040	12.09	12.94	13.86	14.8508	15.92	17.08	18.33	-0.6756	0.0963	12.17	12.89	13.69	14.5808	15.57	16.68	17.92
3.00 – 3.49	-0.1510	0.1009	12.34	13.18	14.08	15.0523	16.10	17.24	18.48	-0.6600	0.0929	12.43	13.15	13.94	14.8106	15.78	16.85	18.06
3.50 – 3.99	-0.1968	0.0979	12.57	13.39	14.28	15.2371	16.27	17.39	18.60	-0.6419	0.0899	12.68	13.40	14.18	15.0351	15.98	17.03	18.20
4.00 – 4.49	-0.2401	0.0951	12.79	13.60	14.47	15.4084	16.42	17.52	18.72	-0.6206	0.0872	12.92	13.63	14.40	15.2499	16.18	17.21	18.34
4.50 – 4.99	-0.2805	0.0925	13.00	13.79	14.65	15.5714	16.57	17.65	18.83	-0.5959	0.0851	13.14	13.85	14.62	15.4543	16.37	17.38	18.49
5.00 – 5.49	-0.3178	0.0901	13.20	13.98	14.82	15.7298	16.71	17.78	18.94	-0.5674	0.0836	13.34	14.05	14.82	15.6518	16.56	17.56	18.66
5.50 – 5.99	-0.3516	0.0880	13.39	14.16	14.99	15.8890	16.86	17.91	19.06	-0.5347	0.0830	13.52	14.23	15.01	15.8469	16.76	17.76	18.85
6.00 – 6.49	-0.3816	0.0863	13.58	14.35	15.17	16.0554	17.02	18.06	19.19	-0.4977	0.0830	13.68	14.40	15.19	16.0434	16.97	17.98	19.08
6.50 – 6.99	-0.4081	0.0849	13.78	14.53	15.35	16.2337	17.19	18.23	19.36	-0.4564	0.0837	13.83	14.57	15.38	16.2519	17.20	18.23	19.35
7.00 – 7.49	-0.4314	0.0839	13.97	14.72	15.54	16.4243	17.38	18.42	19.55	-0.4102	0.0850	13.98	14.75	15.58	16.4784	17.45	18.51	19.65
7.50 – 7.99	-0.4517	0.0833	14.16	14.92	15.74	16.6267	17.59	18.63	19.77	-0.3589	0.0866	14.14	14.94	15.80	16.7267	17.73	18.82	20.00
8.00 – 8.49	-0.4692	0.0832	14.35	15.12	15.95	16.8426	17.82	18.87	20.03	-0.3029	0.0885	14.31	15.14	16.03	16.9992	18.04	19.17	20.39
8.50 – 8.99	-0.4842	0.0834	14.54	15.32	16.16	17.0752	18.07	19.14	20.32	-0.2429	0.0907	14.48	15.35	16.29	17.2946	18.38	19.55	20.82
9.00 – 9.49	-0.4965	0.0840	14.74	15.53	16.39	17.3246	18.34	19.44	20.65	-0.1798	0.0931	14.67	15.58	16.56	17.6121	18.75	19.97	21.28
9.50 – 9.99	-0.5053	0.0851	14.94	15.75	16.63	17.5871	18.63	19.77	21.01	-0.1147	0.0956	14.86	15.82	16.85	17.9592	19.15	20.42	21.79
10.00 – 10.49	-0.5093	0.0864	15.13	15.97	16.87	17.8608	18.94	20.11	21.40	-0.0488	0.0982	15.08	16.10	17.18	18.3396	19.58	20.91	22.34
10.50 – 10.99	-0.5078	0.0881	15.33	16.19	17.13	18.1483	19.26	20.49	21.83	0.0166	0.1005	15.34	16.40	17.54	18.7563	20.06	21.44	22.93
11.00 – 11.49	-0.4998	0.0900	15.53	16.42	17.39	18.4514	19.61	20.88	22.28	0.0814	0.1026	15.62	16.74	17.93	19.2077	20.56	22.01	23.54
11.50 – 11.99	-0.4843	0.0921	15.73	16.66	17.67	18.7707	19.98	21.30	22.77	0.1466	0.1044	15.92	17.10	18.35	19.6832	21.09	22.59	24.18
12.00 – 12.49	-0.4600	0.0944	15.94	16.91	17.96	19.1083	20.37	21.75	23.28	0.2134	0.1058	16.24	17.48	18.78	20.1679	21.63	23.18	24.81
12.50 – 12.99	-0.4260	0.0967	16.16	17.17	18.27	19.4663	20.78	22.23	23.82	0.2827	0.1068	16.56	17.85	19.21	20.6477	22.16	23.74	25.41
13.00 – 13.49	-0.3807	0.0990	16.39	17.44	18.59	19.8433	21.22	22.72	24.38	0.3555	0.1071	16.90	18.23	19.64	21.1106	22.65	24.26	25.95
13.50 – 13.99	-0.3231	0.1012	16.64	17.73	18.93	20.2384	21.67	23.23	24.95	0.4322	0.1065	17.24	18.61	20.05	21.5531	23.12	24.74	26.43
14.00 – 14.49	-0.2534	0.1032	16.89	18.04	19.29	20.6524	22.14	23.76	25.53	0.5124	0.1054	17.59	19.00	20.46	21.9783	23.55	25.17	26.85
14.50 – 14.99	-0.1722	0.1050	17.16	18.36	19.67	21.0884	22.63	24.30	26.12	0.5956	0.1037	17.94	19.38	20.86	22.3869	23.96	25.57	27.22
15.00 – 15.49	-0.0809	0.1065	17.45	18.71	20.08	21.5513	23.14	24.86	26.72	0.6811	0.1018	18.29	19.75	21.25	22.7793	24.34	25.94	27.57
15.50 – 15.99	0.0185	0.1079	17.75	19.08	20.51	22.0394	23.68	25.45	27.34	0.7679	0.1000	18.64	20.12	21.63	23.1590	24.72	26.29	27.90
16.00 – 16.49	0.1244	0.1091	18.07	19.47	20.96	22.5475	24.24	26.04	27.96	0.8558	0.0984	18.97	20.47	21.99	23.5289	25.08	26.65	28.22
16.50 – 16.99	0.2344	0.1101	18.40	19.87	21.42	23.0703	24.81	26.65	28.59	0.9445	0.0971	19.28	20.81	22.35	23.8908	25.44	26.99	28.55
17.00 – 17.49	0.3467	0.1109	18.74	20.28	21.90	23.6016	25.39	27.26	29.23	1.0342	0.0960	19.57	21.14	22.69	24.2461	25.80	27.34	28.89
17.50 – 17.99	0.4596	0.1117	19.07	20.68	22.37	24.1355	25.97	27.88	29.86	1.1246	0.0950	19.86	21.46	23.03	24.5995	26.15	27.69	29.22
18.00 – 18.49	0.5726	0.1124	19.39	21.09	22.85	24.6685	26.55	28.48	30.48	1.2152	0.0941	20.15	21.78	23.38	24.9545	26.51	28.05	29.56
18.50 – 18.99	0.6858	0.1131	19.71	21.49	23.32	25.2009	27.12	29.09	31.10	1.3059	0.0932	20.44	22.10	23.72	25.3105	26.87	28.40	29.91

[1]Smoothed L, M, and S curves for MUAC were generated by using equivalent df of 3, 6 and 4 in males and 3, 6 and 5 in females respectively. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation.

Table 4.15: Age- and sex-specific reference percentiles for UAMA in children and adolescents aged 2 – 18.5 years[1]

	UAMA(cm^2)																
	Males									Females							
Age, y	L	S	3rd	10th	25th	50th (M)	70th	90th	97th	L	S	3rd	10th	25th	50th (M)	70th	90th	97th
3.00 – 3.49	0.2205	0.2049	9.42	10.92	12.60	14.4707	16.56	18.87	21.42	-1.1619	0.1411	9.79	10.54	11.42	12.4915	13.80	15.45	17.58
3.50 – 3.99	0.1847	0.2012	9.70	11.19	12.86	14.7328	16.82	19.14	21.72	-1.0843	0.1454	10.12	10.93	11.88	13.0319	14.44	16.20	18.48
4.00 – 4.49	0.1489	0.1976	9.99	11.47	13.14	15.0072	17.10	19.43	22.03	-1.0068	0.1497	10.45	11.31	12.34	13.5705	15.08	16.96	19.38
4.50 – 4.99	0.1129	0.1940	10.29	11.77	13.44	15.3062	17.40	19.75	22.38	-0.9293	0.1540	10.76	11.69	12.79	14.1065	15.71	17.72	20.28
5.00 – 5.49	0.0771	0.1905	10.62	12.10	13.76	15.6352	17.74	20.11	22.76	-0.8522	0.1583	11.06	12.06	13.23	14.6423	16.35	18.48	21.18
5.50 – 5.99	0.0419	0.1873	10.97	12.45	14.12	16.0018	18.12	20.51	23.21	-0.7761	0.1627	11.36	12.42	13.68	15.1801	17.00	19.25	22.09
6.00 – 6.49	0.0076	0.1844	11.35	12.83	14.52	16.4152	18.56	20.99	23.72	-0.7012	0.1670	11.64	12.78	14.12	15.7185	17.65	20.02	23.00
6.50 – 6.99	-0.0255	0.1819	11.75	13.25	14.95	16.8741	19.05	21.52	24.32	-0.6282	0.1711	11.94	13.15	14.58	16.2765	18.32	20.82	23.93
7.00 – 7.49	-0.0574	0.1799	12.16	13.69	15.41	17.3681	19.59	22.11	24.99	-0.5565	0.1751	12.25	13.54	15.06	16.8619	19.02	21.65	24.89
7.50 – 7.99	-0.0881	0.1786	12.59	14.13	15.89	17.8888	20.16	22.76	25.71	-0.4858	0.1788	12.57	13.95	15.57	17.4792	19.76	22.52	25.89
8.00 – 8.49	-0.1178	0.1779	13.01	14.59	16.39	18.4381	20.78	23.45	26.52	-0.4166	0.1826	12.91	14.38	16.10	18.1298	20.54	23.43	26.94
8.50 – 8.99	-0.1473	0.1779	13.45	15.07	16.91	19.0220	21.44	24.22	27.41	-0.3498	0.1864	13.25	14.82	16.66	18.8135	21.36	24.40	28.05
9.00 – 9.49	-0.1761	0.1787	13.89	15.55	17.46	19.6435	22.16	25.06	28.41	-0.2860	0.1905	13.60	15.28	17.24	19.5321	22.23	25.43	29.24
9.50 – 9.99	-0.2029	0.1804	14.33	16.05	18.02	20.2980	22.93	25.97	29.52	-0.2264	0.1949	13.98	15.77	17.86	20.3060	23.17	26.54	30.54
10.00 – 10.49	-0.2259	0.1829	14.76	16.55	18.61	20.9832	23.75	26.97	30.74	-0.1723	0.1996	14.37	16.30	18.54	21.1463	24.19	27.77	31.98
10.50 – 10.99	-0.2438	0.1863	15.19	17.05	19.21	21.7066	24.62	28.05	32.08	-0.1254	0.2042	14.81	16.88	19.27	22.0591	25.31	29.10	33.55
11.00 – 11.49	-0.2559	0.1906	15.62	17.57	19.83	22.4763	25.57	29.23	33.56	-0.0862	0.2086	15.29	17.50	20.07	23.0412	26.50	30.53	35.24
11.50 – 11.99	-0.2618	0.1956	16.06	18.11	20.50	23.2994	26.60	30.52	35.20	-0.0524	0.2128	15.80	18.16	20.90	24.0690	27.75	32.03	37.01
12.00 – 12.49	-0.2609	0.2012	16.50	18.66	21.20	24.1883	27.73	31.94	37.00	-0.0218	0.2166	16.31	18.83	21.74	25.1115	29.02	33.55	38.81
12.50 – 12.99	-0.2523	0.2071	16.96	19.26	21.96	25.1562	28.95	33.49	38.96	0.0076	0.2199	16.83	19.49	22.57	26.1416	30.27	35.04	40.55
13.00 – 13.49	-0.2345	0.2129	17.47	19.91	22.79	26.2093	30.28	35.16	41.05	0.0380	0.2222	17.34	20.15	23.39	27.1394	31.46	36.44	42.17
13.50 – 13.99	-0.2061	0.2182	18.01	20.62	23.70	27.3497	31.70	36.92	43.21	0.0711	0.2234	17.84	20.79	24.19	28.0955	32.58	37.73	43.62
14.00 – 14.49	-0.1670	0.2229	18.59	21.38	24.68	28.5787	33.22	38.76	45.42	0.1074	0.2235	18.35	21.43	24.96	29.0108	33.63	38.90	44.89
14.50 – 14.99	-0.1175	0.2268	19.22	22.21	25.74	29.8989	34.83	40.68	47.65	0.1468	0.2227	18.85	22.06	25.72	29.8852	34.61	39.97	46.01
15.00 – 15.49	-0.0586	0.2299	19.89	23.11	26.88	31.3142	36.53	42.67	49.91	0.1887	0.2214	19.35	22.68	26.45	30.7229	35.54	40.95	47.00
15.50 – 15.99	0.0083	0.2323	20.60	24.07	28.11	32.8165	38.31	44.71	52.17	0.2326	0.2198	19.83	23.28	27.17	31.5346	36.42	41.87	47.93
16.00 – 16.49	0.0815	0.2339	21.34	25.07	29.39	34.3890	40.15	46.79	54.43	0.2777	0.2183	20.30	23.87	27.87	32.3325	37.29	42.78	48.82
16.50 – 16.99	0.1588	0.2349	22.10	26.12	30.73	36.0145	42.04	48.89	56.66	0.3237	0.2169	20.76	24.45	28.56	33.1221	38.15	43.67	49.70
17.00 – 17.49	0.2379	0.2353	22.87	27.19	32.11	37.6750	43.95	50.99	58.86	0.3707	0.2155	21.20	25.02	29.25	33.9041	39.00	44.55	50.57
17.50 – 17.99	0.3175	0.2354	23.63	28.27	33.50	39.3528	45.87	53.08	61.03	0.4179	0.2142	21.63	25.59	29.94	34.6835	39.84	45.42	51.43
18.00 – 18.49	0.3971	0.2353	24.37	29.35	34.90	41.0360	47.78	55.15	63.17	0.4653	0.2128	22.07	26.16	30.62	35.4638	40.69	46.29	52.29
18.50 – 18.99	0.4768	0.2351	25.08	30.42	36.30	42.7205	49.69	57.22	65.30	0.5128	0.2114	22.50	26.73	31.31	36.2442	41.53	47.16	53.15

[1]Smoothed L, M, and S curves for UAMA were generated by using equivalent df of 3, 5 and 4 respectivelyfor both males and females. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for UAMA can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the following formula: $Z = \frac{(UAMA\ (cm^2)/M)^L - 1}{L \times S}$

Table 4.16: Age- and sex-specific reference percentiles for UAFA in children and adolescents aged 2 – 18.5 years[1]

	UAFA(cm^2)																	
	Males									Females								
Age, y	L	S	3rd	10th	25th	50th (M)	70th	90th	97th	L	S	3rd	10th	25th	50th (M)	70th	90th	97th
3.00 – 3.49	-0.2002	0.2179	2.66	3.04	3.50	4.0346	4.68	5.44	6.37	0.2762	0.2220	3.04	3.59	4.20	4.8825	5.64	6.49	7.42
3.50 – 3.99	-0.1607	0.2183	2.63	3.01	3.47	4.0061	4.64	5.40	6.30	0.2639	0.2275	2.96	3.51	4.12	4.8102	5.58	6.44	7.39
4.00 – 4.49	-0.1214	0.2188	2.60	2.99	3.44	3.9793	4.61	5.36	6.24	0.2516	0.2331	2.89	3.43	4.05	4.7406	5.52	6.39	7.37
4.50 – 4.99	-0.0823	0.2194	2.57	2.96	3.42	3.9567	4.58	5.32	6.19	0.2394	0.2386	2.82	3.36	3.98	4.6759	5.47	6.35	7.35
5.00 – 5.49	-0.0433	0.2204	2.55	2.94	3.40	3.9406	4.57	5.30	6.15	0.2271	0.2442	2.75	3.29	3.91	4.6171	5.42	6.32	7.34
5.50 – 5.99	-0.0045	0.2220	2.52	2.93	3.39	3.9329	4.56	5.29	6.13	0.2150	0.2499	2.69	3.23	3.85	4.5651	5.38	6.30	7.34
6.00 – 6.49	0.0336	0.2243	2.50	2.91	3.39	3.9354	4.57	5.30	6.14	0.2031	0.2558	2.64	3.18	3.80	4.5255	5.35	6.29	7.36
6.50 – 6.99	0.0706	0.2276	2.49	2.90	3.39	3.9475	4.59	5.33	6.18	0.1918	0.2620	2.60	3.14	3.77	4.5082	5.35	6.32	7.43
7.00 – 7.49	0.1055	0.2317	2.47	2.90	3.40	3.9695	4.63	5.38	6.24	0.1813	0.2689	2.57	3.12	3.77	4.5226	5.40	6.40	7.56
7.50 – 7.99	0.1375	0.2366	2.45	2.90	3.41	4.0024	4.68	5.45	6.33	0.1720	0.2766	2.56	3.13	3.80	4.5776	5.49	6.55	7.77
8.00 – 8.49	0.1660	0.2424	2.44	2.90	3.44	4.0463	4.75	5.54	6.45	0.1643	0.2855	2.57	3.16	3.86	4.6792	5.64	6.77	8.08
8.50 – 8.99	0.1902	0.2489	2.43	2.91	3.47	4.1028	4.83	5.66	6.60	0.1582	0.2952	2.59	3.21	3.95	4.8205	5.85	7.06	8.48
9.00 – 9.49	0.2095	0.2556	2.43	2.93	3.51	4.1713	4.93	5.80	6.78	0.1539	0.3056	2.63	3.28	4.06	4.9969	6.11	7.42	8.96
9.50 – 9.99	0.2240	0.2623	2.43	2.95	3.56	4.2496	5.04	5.95	6.98	0.1508	0.3165	2.68	3.37	4.20	5.2095	6.41	7.84	9.54
10.00 – 10.49	0.2336	0.2689	2.44	2.98	3.61	4.3367	5.17	6.12	7.20	0.1487	0.3275	2.74	3.47	4.37	5.4584	6.77	8.33	10.20
10.50 – 10.99	0.2378	0.2754	2.46	3.02	3.67	4.4330	5.31	6.30	7.44	0.1468	0.3387	2.82	3.60	4.57	5.7488	7.18	8.90	10.97
11.00 – 11.49	0.2367	0.2819	2.48	3.06	3.75	4.5391	5.46	6.51	7.71	0.1447	0.3498	2.91	3.75	4.80	6.0827	7.65	9.55	11.84
11.50 – 11.99	0.2299	0.2879	2.51	3.11	3.83	4.6550	5.62	6.73	7.99	0.1419	0.3608	3.02	3.92	5.05	6.4564	8.18	10.28	12.83
12.00 – 12.49	0.2178	0.2934	2.55	3.18	3.91	4.7791	5.79	6.96	8.30	0.1381	0.3716	3.13	4.11	5.33	6.8645	8.76	11.09	13.93
12.50 – 12.99	0.2024	0.2983	2.60	3.24	4.01	4.9080	5.96	7.19	8.62	0.1338	0.3817	3.26	4.31	5.63	7.2995	9.38	11.94	15.10
13.00 – 13.49	0.1860	0.3026	2.65	3.31	4.10	5.0366	6.14	7.43	8.94	0.1302	0.3908	3.40	4.52	5.95	7.7518	10.02	12.83	16.32
13.50 – 13.99	0.1703	0.3063	2.70	3.38	4.19	5.1630	6.31	7.66	9.25	0.1280	0.3990	3.54	4.74	6.27	8.2195	10.68	13.75	17.57
14.00 – 14.49	0.1559	0.3093	2.76	3.45	4.29	5.2883	6.48	7.89	9.55	0.1271	0.4066	3.69	4.96	6.61	8.7040	11.36	14.70	18.87
14.50 – 14.99	0.1434	0.3117	2.82	3.53	4.38	5.4133	6.64	8.11	9.83	0.1275	0.4139	3.84	5.19	6.95	9.2033	12.07	15.69	20.22
15.00 – 15.49	0.1322	0.3133	2.88	3.60	4.48	5.5392	6.81	8.32	10.11	0.1291	0.4212	3.98	5.42	7.30	9.7122	12.80	16.70	21.61
15.50 – 15.99	0.1214	0.3141	2.95	3.69	4.58	5.6645	6.97	8.52	10.38	0.1322	0.4285	4.12	5.64	7.64	10.2257	13.54	17.74	23.03
16.00 – 16.49	0.1106	0.3141	3.02	3.77	4.68	5.7878	7.12	8.72	10.62	0.1369	0.4357	4.25	5.86	7.98	10.7388	14.28	18.78	24.46
16.50 – 16.99	0.1001	0.3136	3.09	3.85	4.78	5.9076	7.27	8.90	10.85	0.1427	0.4424	4.37	6.07	8.32	11.2496	15.02	19.82	25.89
17.00 – 17.49	0.0902	0.3127	3.16	3.94	4.88	6.0222	7.40	9.07	11.07	0.1495	0.4488	4.48	6.28	8.66	11.7587	15.76	20.86	27.30
17.50 – 17.99	0.0810	0.3117	3.23	4.02	4.97	6.1321	7.54	9.23	11.26	0.1569	0.4549	4.60	6.49	8.99	12.2678	16.50	21.90	28.71
18.00 – 18.49	0.0723	0.3105	3.30	4.10	5.06	6.2383	7.66	9.38	11.45	0.1646	0.4607	4.70	6.69	9.32	12.7779	17.24	22.94	30.13
18.50 – 18.99	0.0637	0.3092	3.38	4.18	5.15	6.3431	7.78	9.53	11.63	0.1724	0.4664	4.81	6.88	9.65	13.2888	17.99	23.99	31.56

[1]Smoothed L, M, and S curves for UAFA were generated by using equivalent df of 3, 5 and 4 respectivelyfor both males and females. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for UAMA can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the following formula: $Z = \frac{(UAFA\ (cm^2)/M)^L - 1}{L \times S}$

Table 4.17: Age- and sex-specific comparison of MUAC, UAMA and UAFA

	MUAC		UAMA		UAFA				
	Males	Females	Males	Females	Males	Females			
Age	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P*§	*P*†	*P*‡
0.5	13.90 ± 1.73	13.61 ± 1.60	-	-	-	-	0.530	-	-
1.0	14.04 ± 1.52	13.65 ± 0.90	-	-	-	-	0.430	-	-
1.5	14.57 ± 0.82	14.36 ± 1.82	-	-	-	-	0.348	-	-
2.0	15.65 ± 0.94	14.64 ± 1.99	-	-	-	-	0.287	-	-
2.5	15.13 ± 1.19	14.76 ± 1.39	-	-	-	-	0.069	-	-
3.0	15.42 ± 1.88	14.80 ± 0.97	14.43 ± 2.63	13.01 ± 1.37	4.10 ± 1.29	5.74 ± 1.12	0.088	0.376	0.178
3.5	15.90 ± 1.68	15.85 ± 1.62	15.81 ± 3.44	13.05 ± 1.00	4.15 ± 0.99	5.89 ± 1.14	0.704	0.159	0.085
4.0	15.93 ± 1.27	15.90 ± 1.49	16.14 ± 3.01	13.92 ± 4.20	4.16 ± 1.23	4.38 ± 2.12	0.531	0.169	0.681
4.5	16.95 ± 1.61	16.52 ± 1.36	16.21 ± 2.75	14.39 ± 2.33	4.17 ± 0.30	4.41 ± 0.98	0.555	0.130	**0.019**
5.0	16.96 ± 1.41	16.63 ± 0.96	16.33 ± 3.34	15.24 ± 1.80	4.21 ± 0.96	4.44 ± 1.21	0.118	0.632	**<0.001**
5.5	16.97 ± 1.46	16.72 ± 1.20	16.42 ± 2.75	15.39 ± 2.94	4.23 ± 0.91	4.50 ± 1.20	0.161	0.215	**<0.001**
6.0	16.99 ± 1.37	16.86 ± 1.38	16.53 ± 3.16	15.83 ± 2.99	4.25 ± 0.86	4.56 ± 1.20	0.813	0.089	**<0.001**
6.5	17.52 ± 1.39	16.98 ± 1.25	17.25 ± 3.28	16.60 ± 2.63	4.27 ± 0.83	4.61 ± 1.21	0.865	0.194	**0.003**
7.0	17.56 ± 1.37	17.28 ± 1.59	17.95 ± 3.26	17.40 ± 3.84	4.30 ± 1.08	4.67 ± 1.26	0.923	0.257	**<0.001**
7.5	17.74 ± 1.31	17.37 ± 1.50	18.25 ± 3.18	17.99 ± 3.58	4.33 ± 0.87	4.78 ± 0.89	0.735	0.592	**<0.001**
8.0	17.86 ± 1.37	17.42 ± 1.44	18.72 ± 3.31	18.29 ± 3.08	4.36 ± 0.78	4.94 ± 1.42	0.362	0.302	**<0.001**
8.5	17.90 ± 1.44	17.57 ± 1.75	18.97 ± 3.56	18.34 ± 4.06	4.37 ± 1.10	5.43 ± 1.53	0.613	0.422	**<0.001**
9.0	17.94 ± 1.38	17.68 ± 1.45	19.99 ± 3.31	19.36 ± 3.20	4.39 ± 1.25	5.53 ± 1.62	0.758	0.074	**<0.001**
9.5	17.96 ± 1.53	18.10 ± 1.56	21.07 ± 4.09	20.66 ± 3.84	4.40 ± 1.13	5.61 ± 1.71	0.137	0.387	**<0.001**
10.0	17.98 ± 1.52	18.86 ± 2.03	21.32 ± 3.87	21.31 ± 4.82	4.44 ± 1.19	5.63 ± 1.89	**0.014**	0.534	**<0.001**
10.5	18.06 ± 1.74	18.92 ± 1.90	22.21 ± 4.58	21.69 ± 4.33	4.57 ± 1.06	5.89 ± 2.11	**0.001**	0.314	**<0.001**
11.0	18.59 ± 1.61	19.19 ± 1.92	23.10 ± 4.15	23.26 ± 4.76	4.60 ± 1.36	6.35 ± 2.05	**0.003**	0.756	**<0.001**
11.5	18.88 ± 1.61	19.82 ± 1.77	23.80 ± 4.34	23.83 ± 4.78	4.76 ± 1.49	6.67 ± 1.84	**<0.001**	0.063	**<0.001**
12.0	19.09 ± 1.72	20.27 ± 2.11	24.40 ± 4.67	24.44 ± 5.36	4.82 ± 1.32	7.11 ± 2.96	**<0.001**	0.627	**<0.001**
12.5	19.64 ± 1.98	21.06 ± 2.35	25.72 ± 5.53	25.74 ± 6.60	5.28 ± 1.60	8.30 ± 3.23	**<0.001**	0.511	**<0.001**
13.0	20.11 ± 2.32	21.46 ± 2.65	27.20 ± 7.12	27.32 ± 7.36	5.31 ± 1.71	8.44 ± 3.84	**<0.001**	0.067	**<0.001**
13.5	20.43 ± 2.14	21.40 ± 2.22	28.29 ± 6.67	28.39 ± 6.50	5.38 ± 1.53	8.54 ± 3.32	**<0.001**	0.896	**<0.001**
14.0	21.05 ± 2.48	22.03 ± 2.57	29.08 ± 7.77	29.11 ± 7.24	5.46 ± 1.95	9.08 ± 3.62	**<0.001**	0.997	**<0.001**
14.5	20.76 ± 2.09	22.62 ± 2.32	31.64 ± 6.63	29.72 ± 7.41	5.51 ± 1.57	9.89 ± 3.73	**<0.001**	**0.027**	**<0.001**
15.0	21.48 ± 2.25	22.79 ± 2.13	32.24 ± 7.23	30.38 ± 6.37	5.69 ± 2.00	10.31 ± 4.01	**<0.001**	**<0.005**	**<0.001**
15.5	22.34 ± 2.78	23.17 ± 2.01	34.37 ± 9.07	31.46 ± 6.36	5.76 ± 1.96	11.57 ± 4.89	**0.007**	**0.003**	**<0.001**
16.0	22.50 ± 2.56	23.48 ± 2.33	34.90 ± 8.72	32.06 ± 6.13	5.88 ± 1.84	12.12 ± 5.73	**0.003**	**<0.005**	**<0.001**
16.5	23.24 ± 2.47	24.28 ± 2.09	36.88 ± 8.17	32.98 ± 7.39	6.58 ± 2.03	12.21 ± 5.30	**0.001**	**<0.001**	**<0.001**
17.0	23.54 ± 2.96	24.89 ± 2.43	40.21 ± 9.80	33.55 ± 8.12	6.61 ± 1.73	12.25 ± 6.12	**0.003**	**<0.001**	**<0.001**
17.5	23.89 ± 2.28	25.04 ± 1.88	42.25 ± 7.19	33.90 ± 7.08	6.70 ± 2.13	12.77 ± 5.70	**0.004**	**<0.001**	**<0.001**
18.0	24.04 ± 2.39	25.02 ± 2.57	43.76 ± 8.59	36.13 ± 7.33	6.82 ± 1.75	13.50 ± 5.25	**<0.001**	**<0.001**	**<0.001**
18.5	24.45 ± 2.29	25.63 ± 2.82	44.38 ± 8.42	36.82 ± 8.32	6.96 ± 1.42	16.71 ± 3.83	**<0.001**	**0.009**	**<0.001**

§ *P*-value for comparison of MUAC between males and females

† *P*-value for comparison of UAMA between males and females

‡ *P*-value for comparison of UAFA between males and females

No UAMA and UAFA was recorded for children less than 2 years old because triceps skinfold was not collected for these age groups. Significant difference was expressed in boldface

4.7 Comparison of Centile Curves

4.7.1 Mid-Upper Arm Circumference

Figure 4.6 shows 3rd, 50th and 97th centiles of MUAC by sex, age and region; Nigeria and US (international reference) from 1 to 19 years. The US curves are shown as dotted lines whereas Nigerian curves are shown in solid lines, and it is obvious that the US curves used for comparisons do not track neatly to Nigerian curves for both boys and girls. However, for both sexes, the US curves are shown to be appreciably higher than Nigeria's across all ages and all centiles considered.

The 3rd centile curves for both sexes were found to be below the 3rd centile of the US reference data while the median and 97th percentiles of MUAC for boys was found to consistently diverge from age 2 to 19 years. At ages ~15 and 16 years, the 97th centile curve for Nigerian boys intersect with the median of the US reference data. Comparison of the median curves of Nigerian girls to their US counterparts indicates that the median curve of Nigerian girls was also found to be below that of the US. Still on girls, the 97th centile curve diverged from early life to 19 years, similar to that of Nigerian boys. Although, the 97th centile of Nigerian girls did not intersect with the US median curve, as seen in boys.

4.7.2 Mid-Upper Arm Muscle Area

Figure 4.7 gives the 3rd, median and 97th centiles by age, sex and region. In comparison to US reference data, the UAMA curves of Nigerian boys and girls are similar in terms of age trends and rankings. The median and 97th UAMA curves of Nigerian boys and the US reference data intersect at age 3 years and appreciably begin to diverge at age 4 years. Further divergence between the two curves for the three centiles was noticed at age 12.

Note that the 3rd centile of the reference curve further diverges until it was slightly below the median UAMA of Nigerian boys at ages ~15 to19 years. Comparison of the female centile curves to the reference data indicates that the two centile curves were much closer together, although the western centiles were relatively higher across most ages. The 3rd centiles intersect at 3 to 10 years while the median intersect at ages ~17 and 19 years. The 97th centile of the West is higher compared to that of Nigeria from age 2 to 15 years, they intersect at age 18 and 19 years.

4.7.3 Mid-Upper Arm Fat Area

Figure 4.8 gives the 3rd, median and 97th centiles of UAFA by age, sex and region. Note that the 3rd and median centiles are similar and much closer to each other in terms of age trends and rankings for both sexes. In early life, the median curve of boys and 3rd centile of the reference data overlapped then slightly diverged and remained relatively close to each other. The 97th centile of boys and the median of the reference track relatively close to each other across all ages but for ages 9 to 13 years. In contrast, the 97th centile curve of the West rose steeply across all ages in both boys and girls. The pattern of 3rd and median curves for girls is slightly similar to those of boys. However, the 97th centile for girls diverged appreciably higher from age 7 to 18 years. The Western reference of UAFA are relatively higher in girls than boys at 97th. The reasons for the marginal difference for the 97th percentiles for the reference and Nigerian children was unexplained, but it is less likely to be related to smoothing.

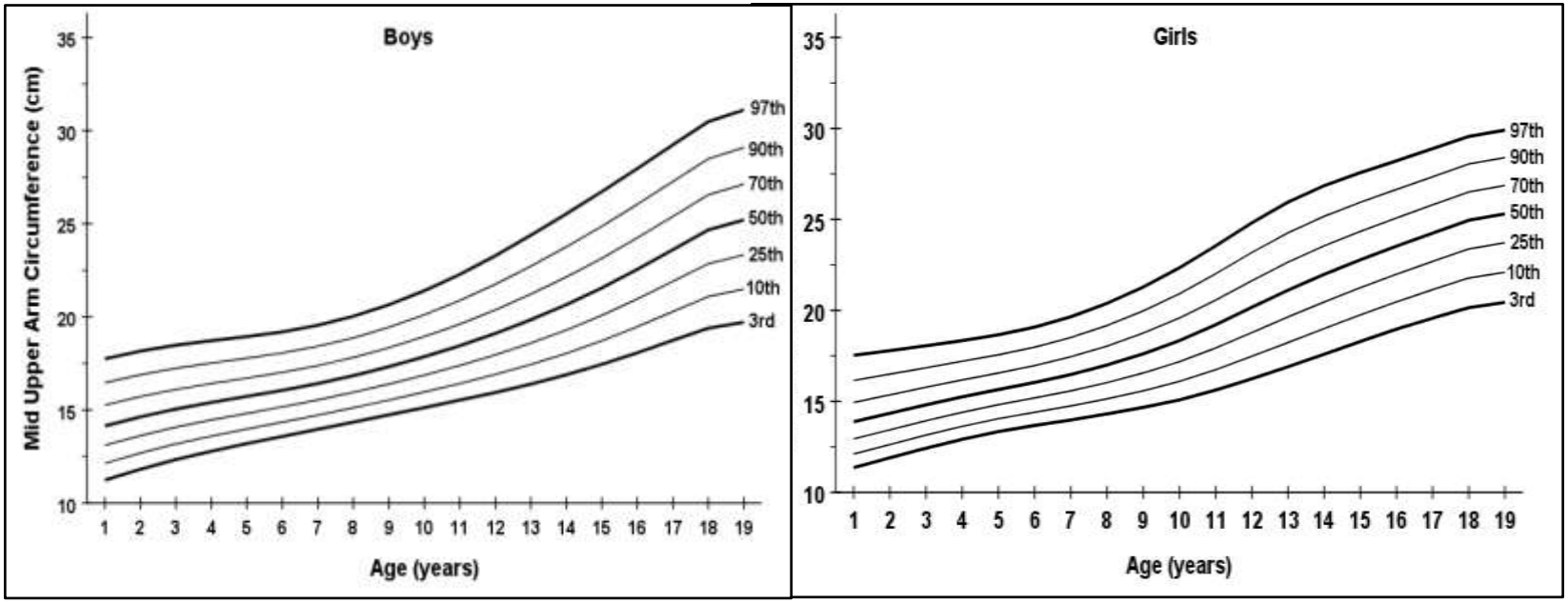

Figure 4.3: Reference curves for mid-upper arm circumference-for-age in Nigerian boys and girls; 3rd, 10th, 25th, 50th, 70th, 90th and 97th centiles are shown.

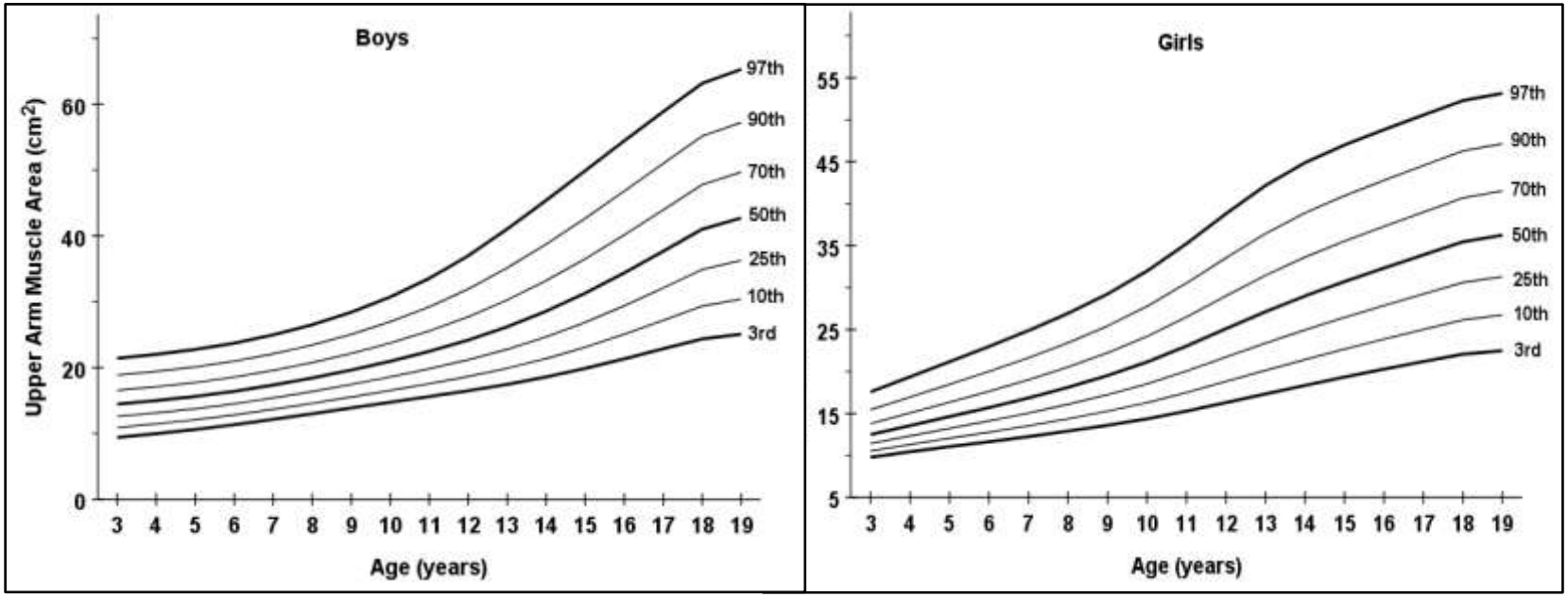

Figure 4.4: Reference curves for mid-upper arm muscle area-for-age in Nigerian boys and girls; 3rd, 10th, 25th, 50th, 70th, 90th and 97th centiles are shown.

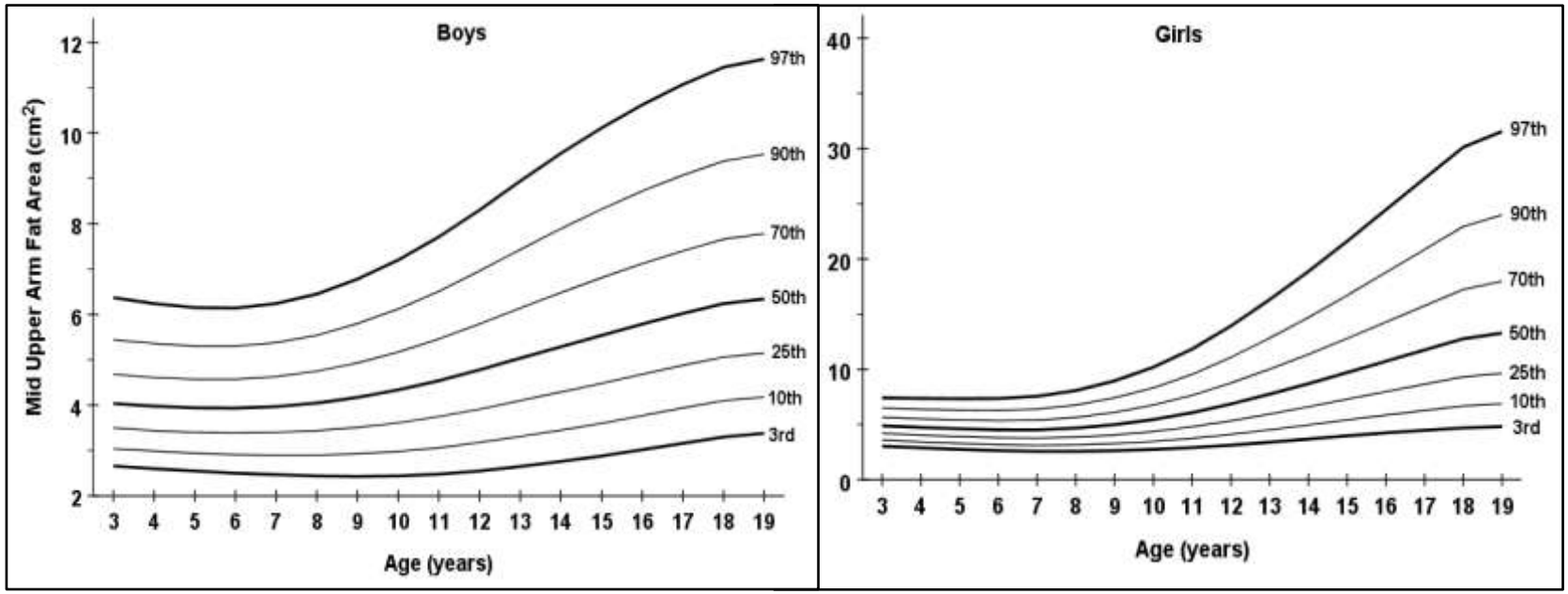

Figure 4.5: Reference curves for mid-upper arm fat area-for-age in Nigerian boys and girls; 3rd, 10th, 25th, 50th, 70th, 90th and 97th centiles are shown.

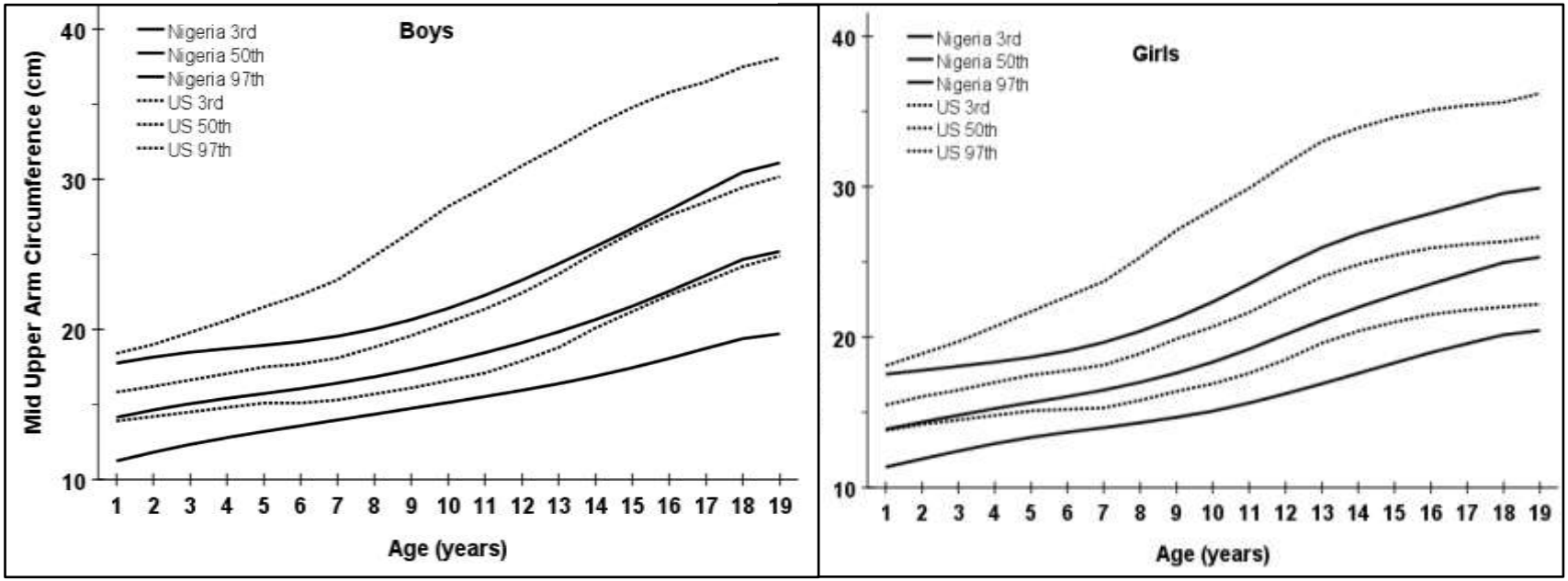

Figure 4.6: The 3rd, median and 97th centiles of MUAC in boys and girls by age of Nigerian boys and girls (solid lines) with US reference data (dotted lines).

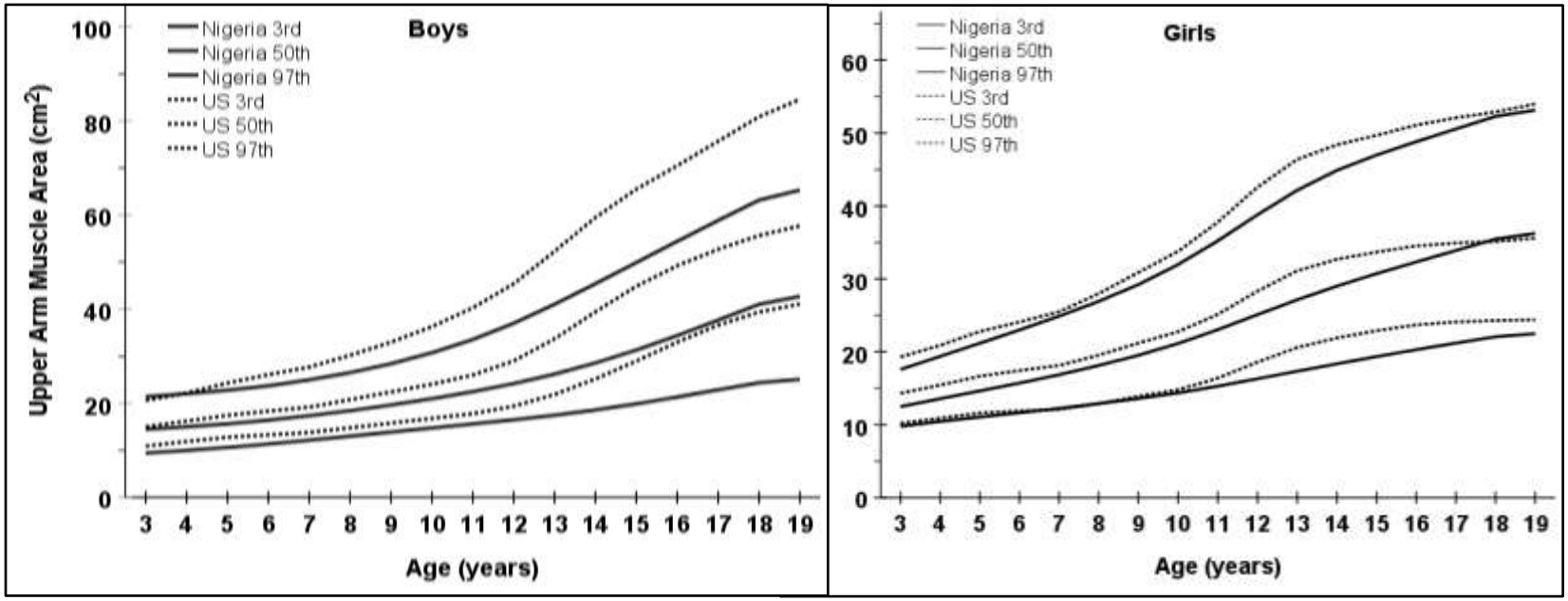

Figure 4.7: The 3rd, median and 97th centiles of UAMA in boys and girls by age of Nigerian boys and girls (solid lines) with US reference data (dotted lines).

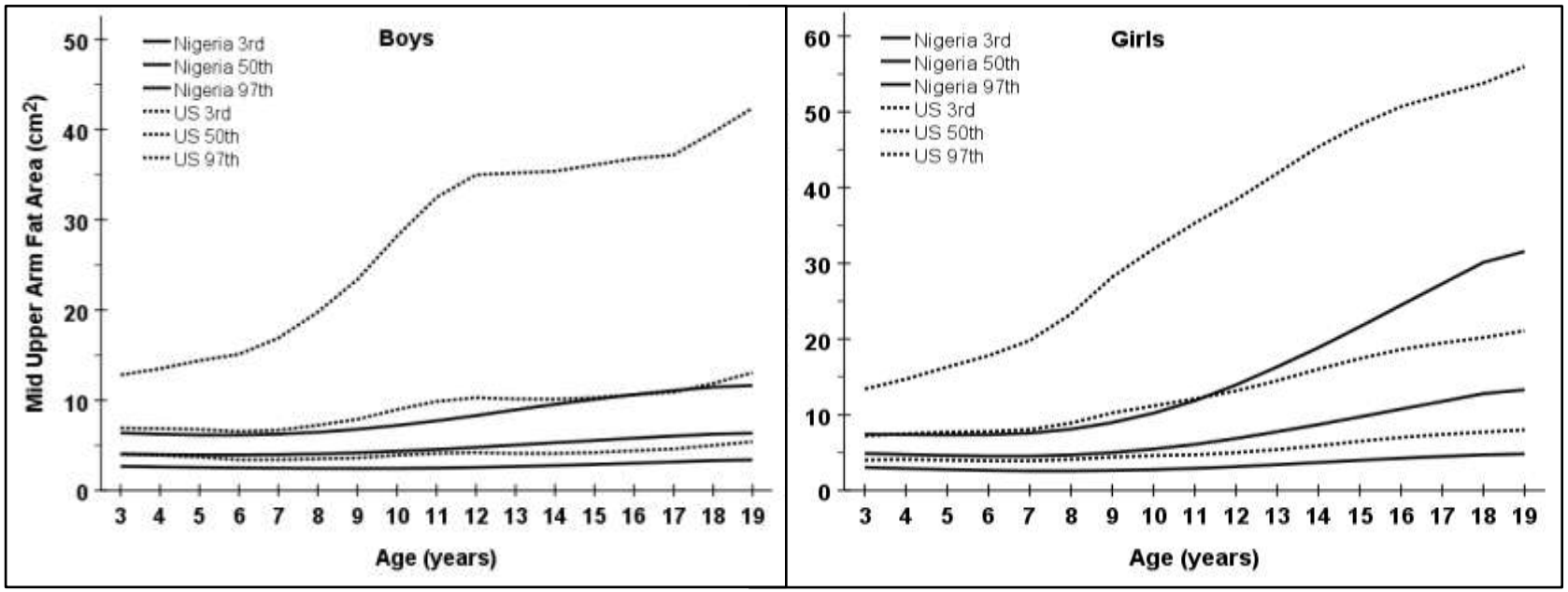

Figure 4.8: The 3rd, median and 97th centiles of UAFA in boys and girls by age of Nigerian boys and girls (solid lines) with US reference data (dotted lines).

4.8 Associations Between BMI and MUAC

The correlations between BMI and MUAC are shown in Table 4.18. The correlations between MUAC and BMI were generally positive and moderately high for both males and females. Males showed stronger significant correlations than females at ages 5 – 10 and 16 – 19 years, whereas females showed higher significant correlations than males at age 11 – 15 years. The strongest correlation for males was at age 14 – 19 years (r = 0.59, P<0.001) whereas, the lowest correlation was at age 11 years (r = 0.24, P<0.001), while others were between 0.30 – 0.50 (P<0.001). females on the other hand have the strongest correlation (r = 0.62, P<0.00) at age 15 years. BMI and MUAC were not significantly correlated (r = 0.16, P = 0.077) at age 5 years. Other correlations are between 0.28 – 0.60 (P<0.001). Equivalent figures computed across all ages 5 – 19 years showed strong correlation between BMI and MUAC (Figures 4.9 and 4.10).

Table 4.18: Intercorrelation between BMI and MUAC

	Correlation coefficient (r)	
Age (yrs.)	Males	Females
5	0.44	0.16
6	0.40	0.31
7	0.30	0.29
8	0.38	0.36
9	**0.50**	0.34
10	0.43	0.28
11	0.24	0.34
12	0.30	0.49
13	0.44	**0.50**
14	**0.59**	**0.60**
15	**0.59**	**0.62**
16 – 19	**0.59**	**0.57**

Pearson correlations were used. BMI was directly correlated with MUAC across all ages and for both sex except for females aged 5 yrs ($r = 0.163$, $P>0.05$). The significance is shown as 0.00 because it was rounded to 2 decimal places. Bold figures represent the best performing parameter.

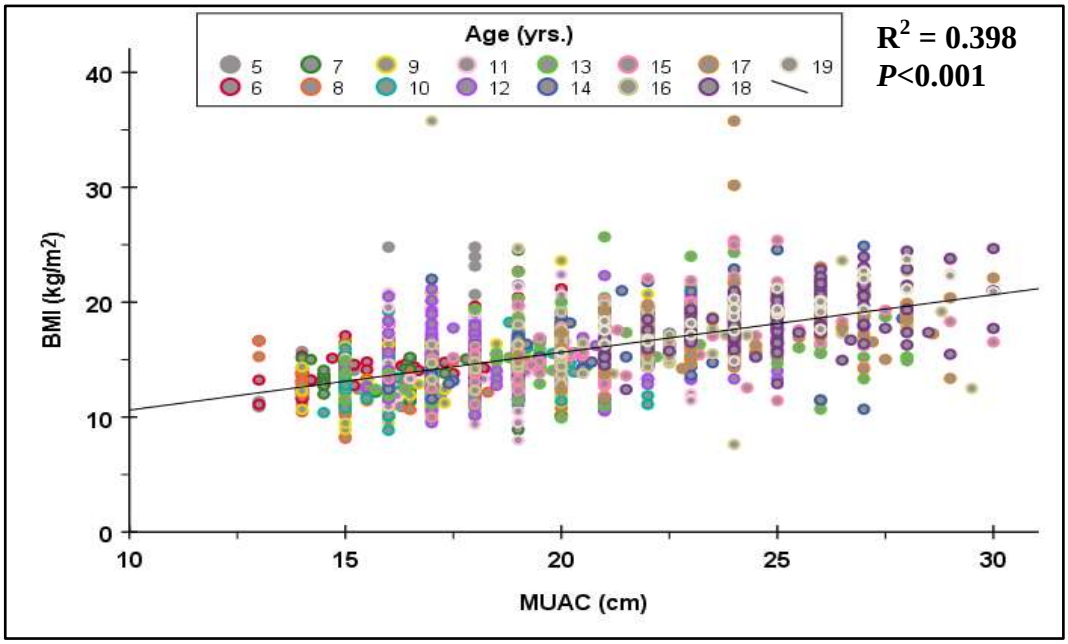

Figure 4.9: Scatterplots corresponding to the relationship between BMI and MUAC with fitted regression lines, model R^2 and *P*-values for boys

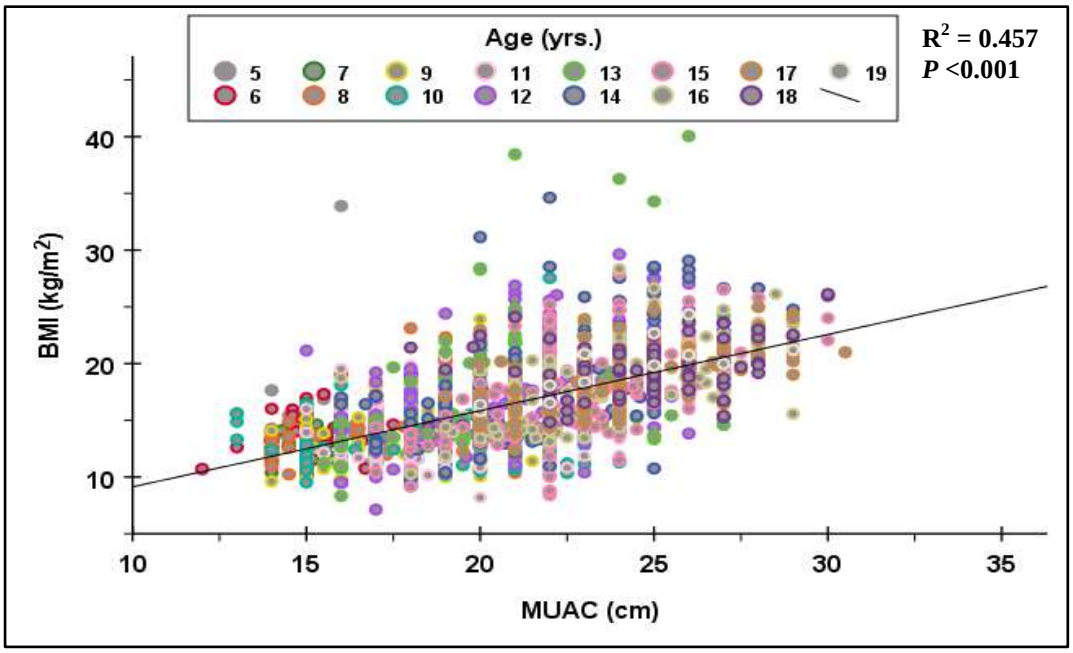

Figure 4.10: Scatterplots corresponding to the relationship between BMI and MUAC with fitted regression lines, model R^2 and *P*-values for girls

4.9 Accuracy of MUAC as Indicator for Thinness and Severe Thinness

The trade–off between sensitivity and specificity (that is, any increase in sensitivity will lead to consequential decrease in specificity) is presented in the form of receiver operating characteristic (ROC) curve. Tables 4.19 and 4.20summarized the sensitivity (SN), specificity (SP), predictive values and likelihood ratios of arm circumference as an indicator of thinness (BAZ < –2) and severe thinness (BAZ <– 3) of participants using BMI as the gold standard screening test.

The MUAC cut-off values for thinness in both sexes increase with age. The cut-off values of MUAC to detect thinness among males aged 5 – 9, 10 – 15 and 16 – 19 years are respectively ≤16.7 cm (SN = 62%, SP = 63%), ≤19.8 cm (SN = 69%, SP = 59%) and 24.5 cm (SN = 81%, SP = 56%). Single-age cut-off points ranges between ≤15.3 cm (SN = 64%, SP = 68%) at age 5 years and ≤21.5 cm (SN = 80%, SP = 78%) at age 15 years. Regarding area under the ROC curve, age 15 years was found to be the best age with the highest area under the ROC curve 0.83 (95% CI 0.78, 0.89) for males. Other ages with similar high AUC among males were ages 13, 14, 10 and 16 – 19 years with AUC of 0.81 (95% CI 0.76, 0.85), 0.80 (95% CI 0.75, 0.85), 0.75 (95% CI 0.70, 0.81) and 0.75 (95% CI 0.71, 0.79) respectively (Table 4.19).The optimal cut–point values of MUAC with sensitivity ≥ 80% in predicting thinness were ≤ 21.5 cm and ≤ 24.5 cm at ages 15 and 16 – 19 years respectively. The highest sensitivity (81%) was recorded at age 16 – 19 years while, the highest specificity (91%) was at age 9 years. The lowest sensitivity 44% in males was at age 9 years, age six had the lowest specificity. The optimal PPV for detecting thin individuals using MUAC when the gold standard also detects such individuals as thin is 79% whereas the lowest PPV is 33%, at ages 15 and 6, respectively. Both ages 7 and 16 –

19 years had equally optimal NPV (84%) for detecting not being thin when result of the gold standard also declares such individuals not thin. Figure 4.11a depicts the corresponding ROC curves.

Furthermore on Table 4.19, the optimal MUAC cut-off values for girls at ages 5 – 9 years, 10 – 15 years and 16 – 19 years are respectively ≤17.8 cm (SN = 78%, SP = 41%), ≤20.8 cm (SN = 72%, SP = 64%) and ≤23.0 cm (SN = 90%, SP = 70%). Whereas, single-age cut-off points ranges between ≤15.5 cm (SN = 53%, SP = 74%) and ≤22.8 cm (SN = 74%, SP = 74%) respectively. Age range 16 – 19 years is the best age for detecting thinness among females with an optimal AUC of 0.84 (95% CI 0.80, 0.87).MUAC was also found to be a good predictor of thinness at ages 13, 14, 15 and 12 years with AUC of 0.82 (95% CI 0.77, 0.87), 0.80 (95% CI 0.75, 0.85), 0.80 (95% CI 0.74, 0.85) and 0.74 (95% CI 0.68, 0.80) respectively.For females, the cut–off points of MUAC with sensitivity ≥ 80% in predicting thinness were ≤ 17.5 cm and 23 cm at ages 7 and 16 – 19 years respectively. The highest sensitivity (90%) was at age 16 – 19 years, whereas the highest specificity (78%) was at age 13 years. The specificity at ages were equal for males at ages (5, 6 and 14) and also at ages (15 and 16 – 19) years. The lowest specificity (31%) was at age 7 years. Age 13 years has the highest PPV (57%) whereas ages 16 – 19 years had the highest NPV (97%). Sex-wise comparison revealed that girls have higher MUAC cut-off points than their male counterparts except at age 6 years and 16 – 19 years. Figure 4.11b shows the corresponding ROC curves.

MUAC performed optimally as an indicator of severe thinness among males aged 15 years with the highest AUC of 0.81 (95% CI 0.75, 0.86) (Table 4.20). Single-age MUAC for boys ranged between ≤15.0 cm (SN = 61%, SP = 64%) at 5 years to ≤21.0 cm (SN = 92%,

SP = 63%) at 15 years. The cut-off values of MUAC at ages 5 – 9 years, 10 – 15 years and 16 – 19 years and their corresponding SN and SP are respectively ≤16.5 cm (SN = 67%, SP = 60%), ≤19.5 cm (SN = 74%, SP = 54%) and ≤23.0 cm (SN = 72%, SP = 69%). The performance of MUAC as screening tool for severe thinness were relatively high too at ages 14, 13 and 16 – 19 years with AUC of 0.80 (95% CI 0.75, 0.85), 0.78 (95% CI 0.73, 0.82) and 0.74 (95% CI 0.70, 0.78), respectively. The optimal cut-points of MUAC with sensitivity ≥ 80% in predicting severe thinness were 19.0 cm at age 12 years and 21.0 cm at age 15 years. The highest sensitivity is 92% at age 15 years whereas the highest specificity is 85% at age 9 years. The lowest sensitivity and specificity are 51% and 52% at ages 9 and 7, respectively. The highest PPV for detecting severe thinness using MUAC measure among males is 41% while the lowest is 21%. The highest NPV for predicting severe thinness using MUAC as diagnostic criterion is 95% while the lowest is 89%. Figure 4.12c is the corresponding ROC curves.

In females, the cut-off value ranged from ≤15.5 cm (SN = 64%, SP = 70%) at age 5 years to ≤21.7 cm at age 15 years (SN = 78%, SP = 84%) (Table 4.20) respectively. The performance of MUAC as diagnostic indicator of severe thinness increased significantly (*P* <0.001) from moderate (at age 9 years) to optimal (at age 16 – 19 years) with the AUC as 0.59 (95% CI 0.53, 0.64) and 0.89 (95% CI 0.86, 0.92) respectively. The ROC curves for ages 5 – 8 years are not significantly different (*P*> 0.05) from 0.5, indicating MUAC inability to distinguish between subjects with severe thinness from the normal group. The optimal cut-point values of MUAC with sensitivity ≥ 80% for predicting severe thinness were 20.0 cm, 21.0 cm and 22.0 cm at ages 13, 14 and 16 – 19 years. The cut-off value at age 10 years had the highest specificity (89%), age 14 has the highest sensitivity (95%)

while age 10 years has the lowest significant sensitivity (32%) for detecting severe thinness in females. The highest and lowest specificity values were 89% and 67%, respectively. The optimal PPV for detecting severe thinness using MUAC is 45% at age 10 whereas the lowest is 25%. Also, the highest and lowest NPV for detecting severe thinness were 99% and 83%, respectively. Comparing sex-wise, the optimal MUAC cut-off value for screening severe thinness were higher among girls at ages 5, 6, 11, 13, 14 and 15 years than those of boys. Figure 4.12d is the corresponding ROC curves.

Table 4.19: Performance of various cut-off points of Mid-Upper Arm Circumference as predictor of thinness (BAZ <-2 as gold diagnostic standard) for children and adolescents aged 5 – 19 years

Age (yrs.)	CP§	SN (%)	SP (%)	YI	LR	ROC AUC	PPV (%)	NPV (%)	FP (%)	FN (%)
Males (n = 3,426)										
5	≤15.3	64 (46, 79)	68 (56, 77)	0.31	1.94	**0.70 (0.59, 0.80)**	46 (36, 56)	82 (74, 88)	54	18
6	≤16.0	75 (62, 86)	43 (35, 51)	0.18	1.31	**0.62 (0.53, 0.70)**	33 (29, 38)	82 (74, 88)	67	18
7	≤16.0	73 (60, 83)	56 (48, 64)	0.28	1.63	**0.67 (0.59, 0.75)**	40 (34, 45)	84 (77, 89)	60	16
8	≤16.5	54 (44, 64)	79 (72, 85)	0.34	2.62	**0.70 (0.63, 0.76)**	63 (55, 71)	73 (68, 77)	37	27
9	≤16.7	44 (34, 54)	91 (86, 94)	0.34	4.61	**0.71 (0.65, 0.77)**	70 (59, 79)	76 (73, 79)	30	24
10	≤17.0	61 (52, 69)	82 (76, 87)	0.43	3.39	**0.75 (0.70, 0.81)**	68 (61, 75)	77 (72, 80)	32	23
11	≤18.5	66 (55, 75)	62 (55, 69)	0.27	1.72	**0.65 (0.59, 0.72)**	46 (40, 51)	79 (73, 83)	54	21
12	≤19.0	75 (65, 83)	56 (50, 63)	0.31	1.71	**0.67 (0.60, 0.73)**	44 (40, 49)	83 (77, 87)	56	17
13	≤19.8	71 (63, 79)	81 (74, 86)	0.52	3.70	**0.81 (0.76, 0.85)**	72 (66, 78)	80 (75, 84)	28	20
14	≤20.7	73 (64, 81)	80 (72, 87)	0.51	3.28	**0.80 (0.75, 0.85)**	70 (63, 76)	80 (75, 85)	30	20
15	≤21.5	80 (71, 87)	78 (70, 85)	0.60	4.00	**0.83 (0.78, 0.89)**	79 (72, 85)	81 (74, 86)	21	19
5 - 9	≤16.7	62 (56, 67)	63 (60, 67)	0.25	1.68	**0.65 (0.62, 0.68)**	45 (42, 48)	78 (75, 80)	55	22
10 - 15	≤19.8	69 (65, 72)	59 (56, 62)	0.28	1.70	**0.69 (0.66, 0.71)**	51 (50, 53)	75 (73, 77)	49	25
16 – 19	≤24.5	81 (75, 87)	56 (50, 61)	0.37	1.84	**0.75 (0.71, 0.79)**	50 (47, 54)	84 (80, 88)	50	16
Females (n = 3,482)										
5	≤15.5	53 (34, 72)	74 (63, 82)	0.27	2.02	**0.68 (0.58, 0.76)**	41 (30, 53)	82 (75, 87)	59	18
6	≤15.5	50 (35, 65)	74 (66, 81)	0.24	1.90	**0.63 (0.53, 0.72)**	39 (30, 49)	82 (76, 86)	61	18
7	≤17.5	87 (76, 94)	31 (24, 40)	0.18	1.26	**0.62 (0.53, 0.70)**	37 (34, 41)	84 (72, 91)	63	16
8	≤17.6	71 (59, 81)	51 (43, 58)	0.22	1.43	**0.63 (0.56, 0.71)**	38 (33, 44)	80 (73, 86)	62	20
9	≤17.8	69 (60, 77)	64 (57, 71)	0.33	1.93	**0.69 (0.63, 0.75)**	56 (50, 61)	76 (70, 81)	44	24
10	≤18.0	72 (64, 79)	56 (48, 63)	0.30	1.63	**0.67 (0.61, 0.73)**	56 (51, 60)	72 (66, 78)	44	28
11	≤19.2	73 (63, 81)	59 (52, 66)	0.33	1.81	**0.68 (0.62, 0.75)**	50 (45, 55)	80 (74, 85)	50	20
12	≤20.0	76 (65, 85)	63 (56, 69)	0.39	2.04	**0.74 (0.68, 0.80)**	40 (35, 45)	89 (84, 92)	60	11
13	≤20.7	79 (69, 86)	78 (72, 83)	0.57	3.55	**0.82 (0.77, 0.87)**	57 (51, 63)	91 (87, 94)	43	9
14	≤21.7	78 (68, 86)	74 (68, 80)	0.53	3.06	**0.80 (0.75, 0.85)**	54 (48, 61)	90 (85, 93)	46	10
15	≤22.8	74 (64, 83)	70 (63, 75)	0.46	2.65	**0.80 (0.74, 0.85)**	52 (46, 57)	87 (83, 91)	48	13
5 - 9	≤17.8	78 (74, 83)	41 (37, 45)	0.19	1.33	**0.61 (0.58, 0.64)**	38 (36, 40)	80 (76, 83)	62	20
10 - 15	≤20.8	72 (68, 64)	64 (61, 67)	0.36	1.99	**0.74 (0.72, 0.76)**	48 (45, 50)	83 (82, 85)	52	17
16 – 19	≤23.0	90 (82, 96)	70 (66, 75)	0.61	3.05	**0.84 (0.80, 0.87)**	40 (36, 44)	97 (95, 99)	60	3

CP cut-off point, SN sensitivity, SP specificity, YI Youden index, LR likelihood ratio, ROC receiver operating characteristics, AUC area under curve, PPV positive predictive value, NPV negative predictive value, FP false positive, FN false negative

Boldface represents statistical significance for AUC

§ Each cut-off point was chosen so that 95% of all malnourished children would be identified as such by the MUAC value.

Table 4.20: Performance of various cut-off points of Mid-Upper Arm Circumferenceas indicator of severe thinness (BAZ <-3 as gold diagnostic standard) for children and adolescents aged 5 – 19 years

Age (yrs.)	CP§	SN (%)	SP (%)	YI	LR	ROC AUC	PPV (%)	NPV (%)	FP (%)	FN (%)
Males (n = 3,426)										
5	≤15.0	61 (36, 83)	64 (54, 73)	0.24	1.66	**0.65 (0.55, 0.73)**	22 (16, 31)	90 (84, 94)	78	10
6	≤15.0	65 (43, 84)	73 (66, 77)	0.38	2.37	**0.71 (0.64, 0.77)**	23 (17, 31)	94 (90, 97)	77	6
7	≤16.0	75 (57, 89)	52 (45, 59)	0.26	1.54	**0.64 (0.57, 0.70)**	21 (17, 26)	92 (87, 96)	79	8
8	≤16.0	61 (46, 75)	72 (66, 78)	0.34	2.17	**0.65 (0.59, 0.71)**	34 (28, 41)	89 (84, 92)	66	11
9	≤16.0	51 (36, 66)	85 (80, 89)	0.36	3.43	**0.73 (0.68, 0.78)**	39 (30, 49)	90 (88, 93)	61	10
10	≤17.0	68 (55, 80)	73 (67, 78)	0.41	2.51	**0.72 (0.67, 0.77)**	36 (30, 42)	91 (88, 94)	64	9
11	≤18.0	73 (58, 84)	59 (53, 65)	0.32	1.77	**0.67 (0.62, 0.73)**	26 (22, 31)	91 (87, 94)	74	9
12	≤19.0	85 (72, 93)	52 (46, 58)	0.37	1.78	**0.72 (0.64, 0.79)**	25 (22, 29)	95 (90, 97)	75	5
13	≤19.5	76 (63, 86)	67 (61, 73)	0.43	2.33	**0.78 (0.73, 0.82)**	34 (29, 39)	93 (89, 95)	66	7
14	≤20.0	79 (67, 89)	67 (60, 73)	0.46	2.39	**0.80 (0.75, 0.85)**	40 (34, 45)	92 (88, 95)	60	8
15	≤21.0	92 (81, 98)	63 (55, 70)	0.55	2.48	**0.81 (0.75, 0.86)**	41 (37, 47)	97 (91, 99)	59	3
5 – 9	≤16.5	67 (60, 75)	60 (56, 63)	0.27	1.67	**0.65 (0.62, 0.68)**	23 (21, 26)	91 (89, 93)	77	9
10 - 15	≤19.5	74 (68, 78)	54 (51, 56)	0.27	1.59	**0.69 (0.67, 0.71)**	27 (25, 29)	90 (88, 92)	73	10
16 – 19	≤23.0	72 (59, 83)	69 (64, 73)	0.41	2.30	**0.74 (0.70, 0.78)**	24 (20, 28)	95 (92, 97)	76	5
Females (n = 3,482)										
5	≤15.5	64 (31, 89)	70 (60, 79)	0.33	2.11	0.64 (0.55, 0.82)	18 (11, 27)	95 (89, 98)	82	5
6	≤15.5	48 (27, 69)	73 (66, 80)	0.21	1.78	0.59 (0.51, 0.66)	19 (12, 27)	90 (86, 93)	81	10
7	≤16.0	81 (58, 95)	46 (38, 53)	0.27	1.49	0.62 (0.54, 0.69)	16 (13, 19)	95 (89, 98)	84	5
8	≤16.0	48 (30, 67)	72 (65, 78)	0.20	1.73	0.55 (0.48, 0.61)	21 (15, 28)	90 (87, 93)	79	10
9	≤16.0	35 (22, 49)	83 (78, 88)	0.18	2.05	**0.59 (0.53, 0.64)**	30 (22, 40)	86 (83, 88)	70	14
10	≤16.4	32 (22, 45)	89 (85, 93)	0.22	2.97	**0.61 (0.55, 0.66)**	45 (34, 57)	83 (80, 85)	55	17
11	≤18.2	63 (46, 77)	74 (68, 79)	0.36	2.40	**0.66 (0.60, 0.71)**	29 (23, 36)	92 (89, 95)	71	8
12	≤18.7	48 (29, 68)	87 (83, 91)	0.35	3.69	**0.70 (0.65, 0.75)**	26 (17, 36)	95 (93, 96)	74	5
13	≤20.0	90 (76, 97)	70 (64, 75)	0.59	2.93	**0.84 (0.80, 0.87)**	26 (22, 30)	98 (96, 99)	74	2
14	≤21.0	95 (82, 99)	67 (61, 73)	0.62	2.90	**0.85 (0.80, 0.89)**	29 (25, 33)	99 (96, 100)	71	1
15	≤21.7	78 (62, 89)	84 (79, 88)	0.61	4.80	**0.85 (0.80, 0.88)**	40 (33, 48)	96 (94, 98)	60	4
5 – 9	≤16.7	57 (48, 65)	57 (54, 60)	0.14	1.31	**0.56 (0.53, 0.59)**	17 (15, 20)	89 (87, 91)	83	11
10 - 15	≤20.8	76 (70, 81)	57 (55, 60)	0.33	1.78	**0.73 (0.71, 0.75)**	21 (20, 23)	94 (93, 95)	79	6
16 – 19	≤22.0	91 (76, 98)	80 (75, 83)	0.70	4.44	**0.89 (0.86, 0.92)**	25 (21, 30)	99 (98, 100)	75	1

CP cut-off point, SN sensitivity, SP specificity, YI Youden index, LR likelihood ratio, ROC receiver operating characteristics, AUC area under curve, PPV positive predictive value, NPV negative predictive value, FP false positive, FN false negative. 95% CIs in parentheses.

Boldface represents statistical significance for AUC

§ Each cut-off point was chosen so that 95% of all malnourished children would be identified as such by the MUAC value.

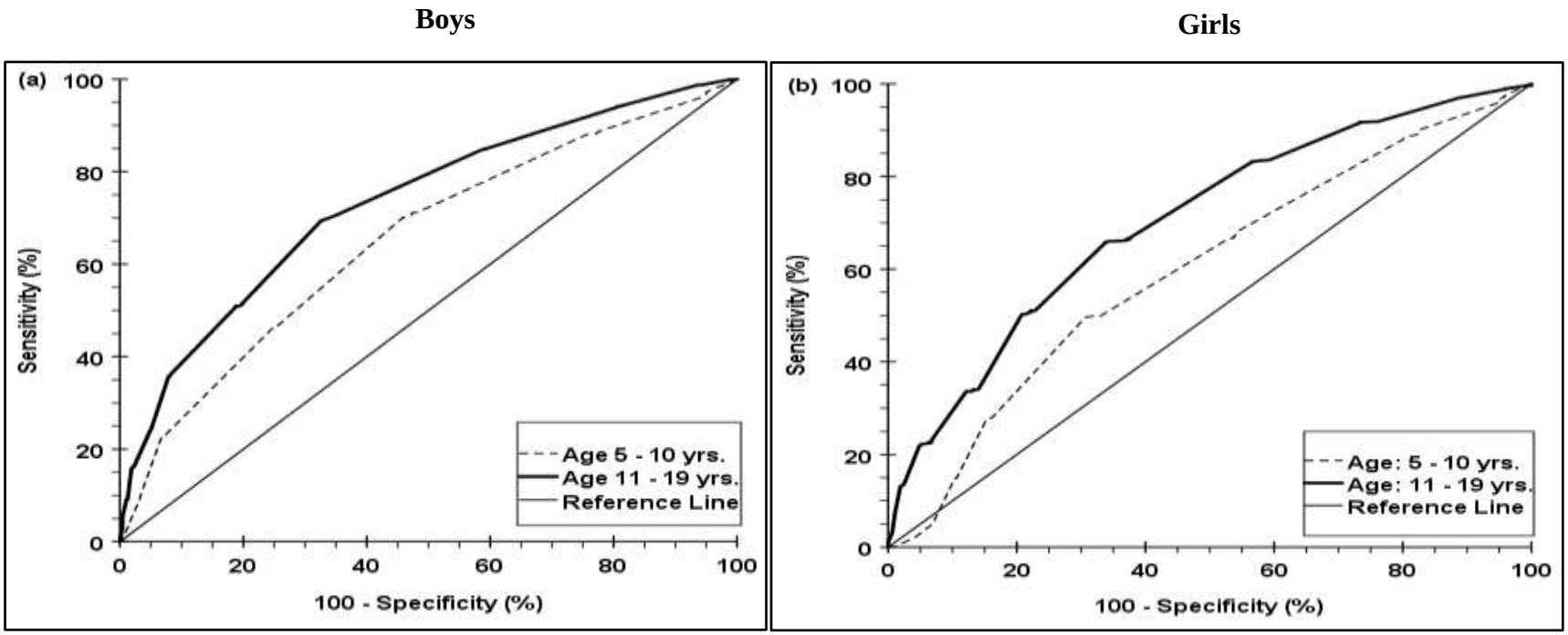

Figure 4.11: Ability of receiver operating characteristic (ROC) curves of MUAC to detect thinness (BMI-for-age <-2) for children aged 5– 19 years. MUAC was significantly better than chance as a diagnostic test for thinness in both boys and girls. (a) Sensitivity = 54.13 (49.6, 58.6), specificity = 70.13 (67.1, 73.0), AUC = 0.654, *P* <0.001, associated criterion = 16.5 cm for boys aged 5 – 10 yrs. Sensitivity = 65.34 (61.8, 68.8), specificity = 60.90 (58.1, 63.7), AUC = 0.679, *P* <0.001, associated criterion = 20.7 cm for boys aged 11 – 19 yrs. (b) Sensitivity = 69.39 (65.0, 73.5), specificity = 49.50 (46.2, 52.8), AUC = 0.599, *P*<0.001, associated criterion = 17.8 cm for girls aged 5 – 10 yrs. Sensitivity = 76.55 (72.7, 80.1), specificity = 66.86 (64.4, 69.2), AUC = 0.775, *P* <0.001, associated criterion = 21.8 cm for girls aged 11 – 19 yrs.

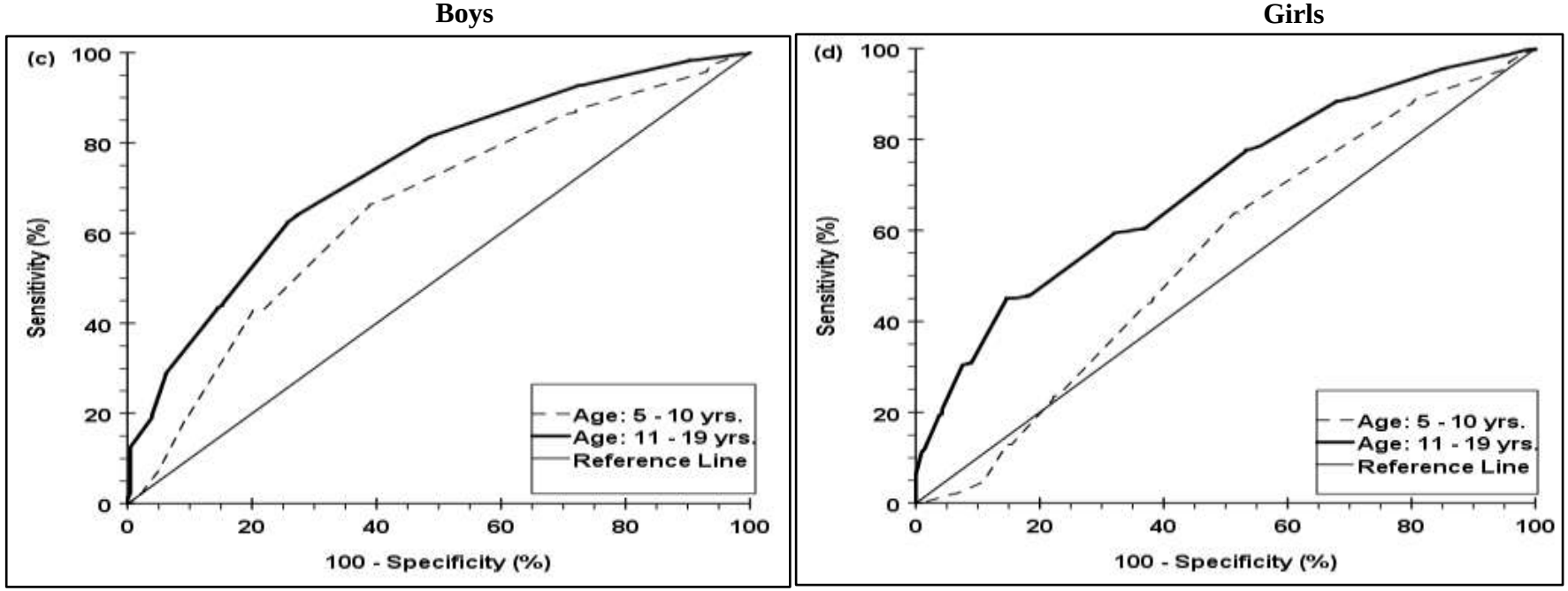

Figure 4.12: Ability of receiver operating characteristic (ROC) curves of MUAC to detect severe thinness (BMI-for-age <-3) for children aged 5 – 10 and 11 – 19 years. MUAC was significantly better than chance as a diagnostic test for severe thinness in both boys and girls. (c) Sensitivity = 61.14 (54.5, 67.5), specificity = 66.31 (63.6, 69.0), AUC = 0.656 (0.63, 0.68), *P* <0.001, associated criterion = 16.5 cm for boys, 5 – 10 yrs. Sensitivity = 60.55 (55.0, 65.9), specificity = 71.45 (69.1, 73.6), AUC = 0.716 (0.70, 0.74), *P* <0.001, associated criterion = 19.5 cm for boys aged 11 – 19 yrs. Sensitivity = 48.58 (41.7, 55.5), specificity = 63.94 (61.1, 66.7), AUC = 0.549 (0.52, 0.58), *P* = 0.025, associated criterion = 16.7 cm for girls 5 – 10 yrs. Sensitivity = 84.79 (79.3, 89.3), specificity = 60.80 (58.5, 63.0), AUC = 0.778 (0.76, 0.80), *P*<0.001, associated criterion = 21.7 cm for girls aged 11 – 19 yrs.

4.10 Prevalence of Thinness and Severe Thinness

Table 4.21 compares the prevalence of thinness and severe thinness using the two test techniques. Boys aged 6 years have the highest burden of thinness using the MUAC screening technique with a prevalence of 62%. This was followed by boys aged 12, 15 and 7 years with prevalence of 53.5%, 49.3% and 47.9%, respectively. The lowest prevalence was among boys aged 16 – 19 years, with prevalence of 17.5%. comparison of the prevalence between MUAC and BAZ screening tools revealed higher prevalence of thinness based on MUAC as screening tool than BAZ at all ages except 8, 9, 13 and 16 – 19 years in which MUAC underestimate thinness compared to the gold standard screening tool. The highest prevalence of severe thinness among boys using MUAC as screening tool showed highest and lowest prevalence of 53.5% and 20.2% at ages 12 and 9 years, respectively. The results also revealed that the prevalence of sever thinness using MUAC as screening tool is consistently higher compared to BAZ. Similarly, the prevalence of thinness in girls using MUAC as diagnostic tool was consistently higher compared to BAZ. The highest and lowest prevalence of thinness using the new measure are 74.5% and 32.2%, respectively. However, the prevalence of severe thinness was consistently higher using MUAC as screening tool across all ages, except for girls 10 years old.

4.11 Inter-Rater Agreement

Inter-rater agreement (Kappa) results between BMI and MUAC as measurement tools for thinness and severe thinness in boys are given in Table 4.22. Regarding thinness in boys, the inter-rater reliability ranges from poor to moderate (k = 0.13 to k = 0.60). Although the agreement between BMI and MUAZ reaches significance (P <0.01), the strength of agreement between the two as diagnostic tools is low especially from age 5 to 9, 11, 12 and

16 to 19 years in boys. The strength of agreement between the tools in screening thin girls is similar to that of boys. Regarding severe thinness, the strength of agreement between the two screening tools is lower irrespective of sex. The minimum value of k = 0.11 for both sex whereas, the maximum value of k = 0.43 and k = 0.44 for boys and girls respectively. Overall, the strength of agreement between BMI and MUAC was below good.

Table 4.21: Comparison of the burden of thinness and severe thinness based on MUAC and BMI-for-age standard deviation of Nigerian children and adolescents

	Males						Females					
		MUAC†	BAZ¶		MUAC‡	BAZ*		MUAC†	BAZ¶		MUAC‡	BAZ*
Age (yrs.)	MUAC CU§ ‡	< - 2	< - 2	MUAC CU‖	< - 3	< - 3	MUAC CU§	< - 2	< - 2	MUAC CU‖	< - 3	< - 3
5	≤15.3	42.1%	29.8%	≤15.0	40.5%	14.9%	≤15.5	33.3%	25.6%	≤15.5	33.3%	9.4%
6	≤16.0	62.0%	27.3%	≤15.0	31.7%	11.2%	≤15.5	32.2%	25.1%	≤15.5	32.2%	12.6%
7	≤16.0	47.9%	28.6%	≤16.0	47.9%	14.7%	≤17.5	74.5%	31.8%	≤16.0	57.3%	10.9%
8	≤16.5	34.5%	39.6%	≤16.0	33.7%	19.2%	≤17.6	55.5%	30.3%	≤16.0	30.7%	13.0%
9	≤16.7	21.7%	33.4%	≤16.0	20.2%	15.6%	≤17.8	48.7%	39.6%	≤16.0	19.9%	17.4%
10	≤17.0	34.8%	39.0%	≤17.0	34.8%	18.3%	≤18.0	56.4%	43.6%	≤16.4	15.5%	21.6%
11	≤18.5	47.2%	32.7%	≤18.0	46.2%	16.8%	≤19.2	51.8%	35.6%	≤18.2	31.3%	14.4%
12	≤19.0	53.5%	31.5%	≤19.0	53.5%	15.9%	≤20.0	46.9%	24.8%	≤18.7	16.0%	8.5%
13	≤19.8	40.6%	41.3%	≤19.5	40.3%	18.1%	≤20.7	37.4%	27.0%	≤20.0	35.8%	10.7%
14	≤20.7	43.5%	41.6%	≤20.0	42.0%	21.6%	≤21.7	40.2%	28.0%	≤21.0	38.9%	12.2%
15	≤21.5	49.3%	48.9%	≤21.0	48.4%	22.2%	≤22.8	41.1%	28.5%	≤21.7	23.6%	12.3%
16 – 19	≤24.5	17.5%	35.6%	≤23.0	36.4%	12.1%	≤23.0	40.3%	26.7%	≤22.0	23.5%	7.0%

‡Each cut-off point was chosen so that 95% of all malnourished children would be identified as such by the MUAC value.
§MUAC cut-off point (cm) for thinness
†Prevalence (%) of thinness based on MUAC
¶Prevalence (%) of thinness based on BMI-for-age z-score
‖MUAC cut-off point (cm) for severe thinness
‡Prevalence (%) of severe thinness based on MUAC
*Prevalence (%) of severe thinness based on BAZ

Table 4.22: Evaluation of inter-rater reliability between BAZ as gold standard and MUAC cut-off points for males

BAZ <-2 SD vs MUAC	Males			Females		
Age (years)	Kappa	*P-value*	LA¶‡	Kappa	*P-value*	LA¶‡
5	0.25	<0.001	Fair	0.25	0.007	Fair
6	0.13	0.018	Poor	0.22	0.003	Fair
7	0.19	0.002	Poor	0.13	0.007	Poor
8	0.34	<0.00	Fair	0.18	0.002	Poor
9	0.38	<0.001	Fair	0.32	<0.001	Fair
10	0.44	<0.001	Moderate	0.27	<0.001	Fair
11	0.25	<0.001	Fair	0.30	<0.001	Fair
12	0.26	<0.001	Fair	0.30	<0.001	Fair
13	0.52	<0.001	Moderate	0.51	<0.001	Moderate
14	0.51	<0.001	Moderate	0.47	<0.001	Moderate
15	0.60	<0.001	Moderate	0.41	<0.001	Moderate
16 – 19	0.27	<0.001	Fair	0.38	<0.001	Fair
BAZ <-3 SD vs MUAC						
5	0.14	0.053	Poor	0.16	0.025	Poor
6	0.12	0.074	Poor	0.11	0.087	Poor
7	0.09	0.026	Poor	0.09	0.020	Poor
8	0.11	0.041	Poor	0.13	0.022	Poor
9	0.15	0.006	Poor	0.17	0.003	Poor
10	0.18	<0.001	Poor	0.24	<0.001	Fair
11	0.23	<0.001	Fair	0.25	<0.001	Fair
12	0.15	<0.001	Poor	0.25	<0.001	Fair
13	0.35	<0.001	Fair	0.28	<0.001	Fair
14	0.33	<0.001	Fair	0.31	<0.001	Fair
15	0.43	<0.001	Moderate	0.44	<0.001	Moderate
16 – 19	0.20	<0.001	Fair	0.28	<0.001	

¶Level of agreement taken from McHugh (2012)

‡Level of agreement according to value of Kappa: Poor: < 0.20; Fair: 0.21 – 0.40; Moderate: 0.41 – 0.60; Good: 0.61 – 0.80; Very good: 0.81 – 1.00.

Altman DG (1991) Practical statistics for medical research. London: Chapman and Hall.

4.12 Skinfold Thicknesses

The smoothed age- and sex-specific percentiles and their corresponding L, M and S parameters for biceps, triceps, sub-scapular and supra-iliac skinfold thicknesses are presented in Tables 4.23 – 26 and some of the corresponding curves are presented for better appreciation in Figures 4.13 – 4.16 for boys and girls separately. The tables show the median (M), the Box-Cox power to remove skewness (L) and the coefficient of variation (S) based on sex and age separately for each skinfold. All the reference curves for the four skinfolds were modelled without skewness except triceps skinfold for girls which was found to be positively skewed and as a result requires a negative power (L) to remove the skewness from the data (Table 4.26). The percentile values are indication of subcutaneous adiposity distribution pattern across age and sex. Comparison of the smoothed median and higher skinfold percentiles across all age between boys and girls revealed that girls consistently have higher values than boys for the four skinfolds. All measured skinfold showed relatively steady increase with age especially in girls.

4.12.1 Biceps Skinfold

In boys, median biceps increased from 3.33 mm (3 years) and peak at age 19 years. An initial slow decrease in median biceps was noticed from 3 years to 10 years, then rebounds at 10.5 years and increased steadily to age 19 years. Compared to the median, higher percentiles have earlier rebound after initial decrease in skinfold thickness. For girls, median biceps increased from 4.35 mm at 3 years to 6.61 mm at 19 years while the 97th percentile increased from 7.25 mm at 3 years to 15.53 mm at 19 years. After an initial decrease of median percentile from 3 years (3.80 mm) to 8 years (3.77 mm), it begins to rebound from 8.5 years and peak at 19 years (6.61 mm). Both the 90thh and 97thh

percentiles showed similar pattern of decrease in from age 3 years but began to increase 1 year earlier (7.5 years) than median percentile.

4.12.2 Triceps Skinfold

For triceps skinfold thickness in boys, median percentile decreased from 5.81 mm (3 years) to 5.00 mm (9 years) then begins to increase at age 9.5 years steadily to 19 years. Similarly, the 97th percentile decreased from 9.47 mm (3 years) to 8.59 mm (8.5 years), then rebounds from 9 years and continues to increase steadily up to adolescence. In girls, median and 97th percentiles of triceps skinfold thickness decreased *ab initio* then rebounds and continues to increase steadily to adolescence.

4.12.3 Sub-scapular Skinfold

Median sub-scapular skinfold for boys showed minimal changes with age. It however plateaus at age 8.50 and 12 years. Ninety-seventh percentile increased from 6.43 mm (3 years) to 8.67 mm and peaks at 19 years. At first, it decreases continuously from 3 years to 6 years then increased appreciably from age 6.5 years to 19 years. Median sub-scapular skinfold in girls first showed slight decrease from 5.43 mm (3 years) to 5.41 mm (4.5 years), then begins to increase from age 5 years, plateaus at 5 and 8.5 years and peak at 19 years. Ninety-seventh percentile increased appreciably from 3 years and peak at 19 years. It, however, the plateaus occurred at young age (3 and 7 years).

4.12.4 Supra-iliac Skinfold

Median supra-iliac skinfold thickness for boys decreased from 4.93 mm (3 years) to 4.76 mm (7.5 years), then begins to increase appreciably from 4.77 mm (8 years) to 6.93 mm

(19 years). It plateaus at age 11 and 13.5 years. ninety-seventh percentile increased steadily from 3 years and peak at 19 years. Both median and 97th percentiles for girls showed appreciable increase from 3 years (4.89 vs 7.48 mm) and peak at 19 years (11.84 vs 34.41 mm) respectively.

Table 4.23: Biceps skinfold-for-age variables and percentiles by age and sex[1]

	Biceps skinfold (mm)																	
	Males									Females								
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	50th (M)	75th	90th	97th
3.00 – 3.49	-0.1224	0.2943	2.26	2.72	3.28	3.9847	4.86	5.96	7.34	0.2953	0.2523	2.55	3.09	3.70	4.3980	5.18	6.06	7.04
3.50 – 3.99	-0.1248	0.2931	2.23	2.68	3.23	3.9194	4.78	5.85	7.20	0.2647	0.2567	2.50	3.03	3.64	4.3400	5.13	6.02	7.02
4.00 – 4.49	-0.1273	0.2919	2.19	2.64	3.18	3.8536	4.69	5.74	7.07	0.2221	0.2628	2.44	2.96	3.56	4.2597	5.06	5.97	7.00
4.50 – 4.99	-0.1296	0.2907	2.16	2.59	3.13	3.7867	4.61	5.64	6.93	0.1797	0.2688	2.37	2.89	3.48	4.1805	4.99	5.92	6.98
5.00 – 5.49	-0.1320	0.2895	2.13	2.55	3.07	3.7189	4.52	5.53	6.79	0.1373	0.2747	2.32	2.82	3.41	4.1024	4.92	5.86	6.97
5.50 – 5.99	-0.1343	0.2883	2.10	2.51	3.02	3.6512	4.44	5.42	6.65	0.0955	0.2803	2.26	2.75	3.33	4.0242	4.84	5.81	6.95
6.00 – 6.49	-0.1367	0.2869	2.06	2.47	2.97	3.5851	4.35	5.31	6.52	0.0544	0.2857	2.21	2.69	3.26	3.9470	4.77	5.75	6.93
6.50 – 6.99	-0.1394	0.2851	2.04	2.43	2.92	3.5230	4.27	5.21	6.38	0.0144	0.2909	2.16	2.63	3.19	3.8759	4.70	5.71	6.92
7.00 – 7.49	-0.1432	0.2832	2.01	2.40	2.88	3.4692	4.20	5.12	6.26	-0.0241	0.2962	2.12	2.58	3.14	3.8181	4.65	5.68	6.93
7.50 – 7.99	-0.1493	0.2817	2.00	2.38	2.85	3.4280	4.15	5.05	6.17	-0.0607	0.3019	2.09	2.54	3.10	3.7819	4.63	5.68	7.00
8.00 – 8.49	-0.1581	0.2810	1.98	2.36	2.83	3.3991	4.11	5.00	6.12	-0.0948	0.3083	2.07	2.52	3.08	3.7732	4.64	5.74	7.12
8.50 – 8.99	-0.1700	0.2815	1.97	2.35	2.81	3.3794	4.09	4.98	6.11	-0.1259	0.3154	2.07	2.52	3.08	3.7923	4.69	5.84	7.32
9.00 – 9.49	-0.1846	0.2832	1.96	2.34	2.80	3.3663	4.08	4.98	6.12	-0.1529	0.3234	2.07	2.53	3.10	3.8352	4.78	5.99	7.58
9.50 – 9.99	-0.2018	0.2861	1.95	2.32	2.78	3.3575	4.08	4.99	6.17	-0.1749	0.3321	2.08	2.54	3.14	3.8973	4.88	6.18	7.90
10.00 – 10.49	-0.2210	0.2901	1.94	2.31	2.77	3.3528	4.09	5.02	6.24	-0.1908	0.3414	2.09	2.57	3.18	3.9750	5.02	6.40	8.26
10.50 – 10.99	-0.2417	0.2953	1.93	2.30	2.77	3.3530	4.10	5.07	6.34	-0.2005	0.3511	2.11	2.60	3.24	4.0672	5.17	6.65	8.67
11.00 – 11.49	-0.2638	0.3015	1.92	2.29	2.76	3.3578	4.13	5.14	6.48	-0.2042	0.3609	2.13	2.64	3.30	4.1753	5.34	6.93	9.12
11.50 – 11.99	-0.2871	0.3085	1.91	2.28	2.76	3.3672	4.16	5.22	6.64	-0.2024	0.3705	2.16	2.69	3.38	4.3019	5.54	7.24	9.60
12.00 – 12.49	-0.3115	0.3158	1.90	2.28	2.76	3.3810	4.20	5.31	6.83	-0.1953	0.3791	2.19	2.75	3.47	4.4460	5.76	7.57	10.10
12.50 – 12.99	-0.3364	0.3228	1.89	2.27	2.76	3.3984	4.25	5.41	7.04	-0.1832	0.3863	2.24	2.81	3.58	4.6049	6.00	7.91	10.59
13.00 – 13.49	-0.3613	0.3292	1.89	2.27	2.77	3.4183	4.30	5.51	7.25	-0.1665	0.3917	2.29	2.89	3.70	4.7728	6.23	8.24	11.05
13.50 – 13.99	-0.3861	0.3349	1.90	2.28	2.78	3.4390	4.34	5.61	7.46	-0.1453	0.3952	2.34	2.98	3.82	4.9434	6.47	8.55	11.45
14.00 – 14.49	-0.4110	0.3397	1.90	2.28	2.79	3.4604	4.39	5.71	7.68	-0.1202	0.3971	2.39	3.06	3.94	5.1137	6.69	8.84	11.78
14.50 – 14.99	-0.4363	0.3437	1.91	2.29	2.80	3.4824	4.43	5.81	7.88	-0.0923	0.3978	2.45	3.15	4.07	5.2847	6.91	9.10	12.08
15.00 – 15.49	-0.4622	0.3468	1.92	2.31	2.81	3.5051	4.48	5.90	8.09	-0.0622	0.3976	2.51	3.24	4.20	5.4570	7.13	9.36	12.34
15.50 – 15.99	-0.4889	0.3492	1.93	2.32	2.83	3.5274	4.52	5.98	8.29	-0.0308	0.3968	2.57	3.33	4.33	5.6303	7.34	9.60	12.57
16.00 – 16.49	-0.5163	0.3511	1.95	2.33	2.84	3.5484	4.55	6.06	8.49	0.0014	0.3955	2.63	3.42	4.46	5.8027	7.55	9.83	12.79
16.50 – 16.99	-0.5444	0.3527	1.96	2.35	2.86	3.5685	4.59	6.14	8.69	0.0339	0.3937	2.69	3.51	4.59	5.9695	7.75	10.04	12.99
17.00 – 17.49	-0.5730	0.3539	1.98	2.36	2.88	3.5874	4.62	6.22	8.89	0.0668	0.3914	2.74	3.60	4.71	6.1289	7.94	10.24	13.15
17.50 – 17.99	-0.6015	0.3547	2.00	2.38	2.89	3.6047	4.65	6.29	9.09	0.1000	0.3887	2.80	3.69	4.83	6.2820	8.11	10.41	13.28
18.00 – 18.49	-0.6300	0.3552	2.01	2.39	2.90	3.6210	4.68	6.36	9.29	0.1334	0.3857	2.85	3.78	4.95	6.4319	8.28	10.58	13.40
18.50 – 18.99	-0.6584	0.3555	2.03	2.41	2.92	3.6373	4.71	6.42	9.49	0.1668	0.3826	2.90	3.86	5.07	6.5811	8.45	10.74	13.52
19.00 – 19.49	-0.6823	0.3558	2.04	2.42	2.93	3.6510	4.73	6.48	9.67	0.1931	0.3801	2.94	3.93	5.17	6.6985	8.58	10.86	13.62

[1]Smoothed L, M, and S curves for biceps skinfold were generated by using equivalent df of 3, 4 and 5respectively for both males and females.

L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for biceps skinfold can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the formula: $Z = \frac{(biceps\ \ skinfold\ \ (mm)/M)^{L} - 1}{L \times S}$

Table 4.24: Triceps skinfold-for-age variables and percentiles by age and sex[1]

	Triceps skinfold (mm)																
	Males									Females							
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	50th (M)	75th	90th	97th
3.00 – 3.49	0.1224	0.2507	3.46	4.13	4.90	5.8033	6.85	8.05	9.44	0.4421	0.2486	3.90	4.78	5.76	6.8420	8.03	9.32	10.72
3.50 – 3.99	0.1153	0.2499	3.42	4.07	4.83	5.7152	6.74	7.93	9.29	0.4047	0.2491	3.86	4.72	5.67	6.7364	7.91	9.20	10.61
4.00 – 4.49	0.1081	0.2491	3.37	4.01	4.76	5.6270	6.63	7.80	9.14	0.3528	0.2498	3.80	4.62	5.55	6.5906	7.75	9.03	10.44
4.50 – 4.99	0.1010	0.2482	3.33	3.96	4.69	5.5392	6.53	7.67	8.99	0.3009	0.2504	3.75	4.54	5.43	6.4474	7.59	8.86	10.28
5.00 – 5.49	0.0938	0.2473	3.29	3.90	4.62	5.4532	6.42	7.55	8.84	0.2492	0.2510	3.69	4.45	5.32	6.3098	7.43	8.70	10.13
5.50 – 5.99	0.0865	0.2466	3.24	3.85	4.55	5.3707	6.32	7.43	8.70	0.1981	0.2517	3.64	4.37	5.21	6.1787	7.29	8.55	9.98
6.00 – 6.49	0.0789	0.2460	3.20	3.80	4.49	5.2936	6.23	7.32	8.58	0.1482	0.2528	3.58	4.28	5.11	6.0554	7.15	8.41	9.86
6.50 – 6.99	0.0708	0.2457	3.17	3.75	4.43	5.2230	6.15	7.22	8.47	0.1002	0.2547	3.52	4.21	5.01	5.9462	7.04	8.30	9.77
7.00 – 7.49	0.0616	0.2460	3.13	3.70	4.38	5.1605	6.08	7.14	8.38	0.0548	0.2576	3.48	4.14	4.93	5.8620	6.95	8.24	9.74
7.50 – 7.99	0.0504	0.2469	3.10	3.67	4.33	5.1092	6.02	7.08	8.32	0.0128	0.2620	3.44	4.10	4.88	5.8160	6.92	8.24	9.81
8.00 – 8.49	0.0365	0.2486	3.07	3.63	4.29	5.0711	5.98	7.05	8.30	-0.0249	0.2682	3.42	4.08	4.87	5.8184	6.96	8.33	9.98
8.50 – 8.99	0.0191	0.2512	3.05	3.61	4.27	5.0468	5.97	7.05	8.32	-0.0575	0.2760	3.41	4.08	4.89	5.8695	7.06	8.51	10.29
9.00 – 9.49	-0.0024	0.2545	3.03	3.59	4.25	5.0368	5.97	7.07	8.38	-0.0843	0.2853	3.42	4.10	4.94	5.9643	7.23	8.78	10.71
9.50 – 9.99	-0.0279	0.2586	3.02	3.58	4.24	5.0398	5.99	7.13	8.49	-0.1046	0.2960	3.43	4.14	5.02	6.0993	7.45	9.13	11.24
10.00 – 10.49	-0.0568	0.2635	3.01	3.57	4.24	5.0542	6.03	7.21	8.63	-0.1176	0.3078	3.46	4.20	5.12	6.2673	7.71	9.55	11.88
10.50 – 10.99	-0.0886	0.2692	3.00	3.57	4.25	5.0785	6.09	7.31	8.82	-0.1235	0.3205	3.49	4.26	5.23	6.4634	8.03	10.03	12.60
11.00 – 11.49	-0.1228	0.2755	3.00	3.57	4.26	5.1110	6.15	7.44	9.04	-0.1229	0.3340	3.52	4.33	5.37	6.6852	8.38	10.57	13.42
11.50 – 11.99	-0.1588	0.2820	3.00	3.58	4.28	5.1516	6.24	7.59	9.30	-0.1168	0.3478	3.55	4.41	5.52	6.9328	8.77	11.17	14.32
12.00 – 12.49	-0.1954	0.2884	3.01	3.59	4.30	5.1987	6.32	7.75	9.59	-0.1058	0.3615	3.59	4.50	5.68	7.2059	9.20	11.82	15.29
12.50 – 12.99	-0.2306	0.2943	3.02	3.60	4.33	5.2473	6.41	7.92	9.88	-0.0907	0.3748	3.63	4.60	5.86	7.4997	9.66	12.51	16.30
13.00 – 13.49	-0.2622	0.2999	3.03	3.62	4.35	5.2908	6.50	8.07	10.16	-0.0719	0.3870	3.68	4.70	6.05	7.8077	10.13	13.21	17.32
13.50 – 13.99	-0.2893	0.3049	3.04	3.63	4.37	5.3251	6.57	8.21	10.42	-0.0496	0.3980	3.72	4.81	6.24	8.1256	10.61	13.91	18.30
14.00 – 14.49	-0.3122	0.3092	3.04	3.63	4.38	5.3505	6.62	8.32	10.64	-0.0239	0.4077	3.77	4.93	6.45	8.4522	11.10	14.61	19.26
14.50 – 14.99	-0.3312	0.3129	3.04	3.63	4.39	5.3683	6.66	8.41	10.83	0.0049	0.4165	3.81	5.04	6.66	8.7876	11.60	15.30	20.18
15.00 – 15.49	-0.3473	0.3158	3.04	3.63	4.39	5.3813	6.70	8.48	10.98	0.0364	0.4246	3.85	5.15	6.87	9.1296	12.10	15.99	21.07
15.50 – 15.99	-0.3617	0.3180	3.04	3.63	4.39	5.3895	6.72	8.54	11.10	0.0702	0.4322	3.88	5.26	7.08	9.4727	12.60	16.66	21.92
16.00 – 16.49	-0.3755	0.3195	3.04	3.63	4.39	5.3929	6.73	8.58	11.20	0.1060	0.4393	3.90	5.36	7.29	9.8113	13.09	17.32	22.73
16.50 – 16.99	-0.3888	0.3207	3.04	3.63	4.39	5.3903	6.74	8.60	11.27	0.1430	0.4460	3.91	5.45	7.48	10.1418	13.57	17.95	23.48
17.00 – 17.49	-0.4011	0.3217	3.03	3.62	4.38	5.3792	6.73	8.61	11.32	0.1809	0.4524	3.90	5.52	7.67	10.4643	14.04	18.55	24.19
17.50 – 17.99	-0.4126	0.3225	3.02	3.61	4.36	5.3590	6.71	8.60	11.35	0.2192	0.4586	3.87	5.59	7.86	10.7829	14.50	19.14	24.87
18.00 – 18.49	-0.4234	0.3234	3.01	3.59	4.34	5.3324	6.69	8.58	11.35	0.2576	0.4646	3.84	5.65	8.04	11.1004	14.95	19.72	25.53
18.50 – 18.99	-0.4339	0.3242	2.99	3.57	4.31	5.3036	6.66	8.56	11.36	0.2960	0.4704	3.79	5.71	8.22	11.4182	15.41	20.30	26.19
19.00 – 19.49	-0.4427	0.3250	2.98	3.55	4.29	5.2793	6.63	8.54	11.36	0.3262	0.4750	3.74	5.74	8.35	11.6690	15.77	20.75	26.70

[1]Smoothed L, M, and S curves for triceps skinfold were generated by using equivalent df of 3, 5 and 4respectively for both males and females. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for triceps skinfold can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the formula:

$$Z = \frac{(triceps\ \ skinfold\ \ (mm)/M)^{L} - 1}{L \times S}$$

Table 4.25: Sub-scapular skinfold-for-age variables and percentiles by age and sex[1]

	Sub-scapular skinfold (mm)																
	Females									Males							
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	50th (M)	75th	90th	97th
3.00 – 3.49	0.0155	0.2622	2.79	3.33	3.97	4.7304	5.63	6.70	7.97	-0.0187	0.2705	3.18	3.80	4.55	5.4440	6.52	7.82	9.38
3.50 – 3.99	0.0092	0.2607	2.81	3.35	3.99	4.7429	5.64	6.71	7.98	-0.0280	0.2707	3.18	3.80	4.54	5.4358	6.51	7.81	9.38
4.00 – 4.49	0.0029	0.2592	2.83	3.37	4.00	4.7553	5.65	6.72	7.98	-0.0409	0.2710	3.17	3.79	4.53	5.4249	6.50	7.81	9.38
4.50 – 4.99	-0.0033	0.2576	2.85	3.38	4.01	4.7666	5.66	6.72	7.98	-0.0539	0.2713	3.17	3.79	4.52	5.4167	6.50	7.81	9.39
5.00 – 5.49	-0.0094	0.2561	2.86	3.40	4.03	4.7756	5.67	6.72	7.98	-0.0671	0.2718	3.17	3.78	4.52	5.4148	6.50	7.82	9.42
5.50 – 5.99	-0.0152	0.2546	2.88	3.41	4.04	4.7814	5.67	6.72	7.97	-0.0804	0.2729	3.18	3.79	4.52	5.4200	6.51	7.84	9.47
6.00 – 6.49	-0.0209	0.2532	2.89	3.42	4.04	4.7834	5.66	6.71	7.96	-0.0939	0.2748	3.18	3.79	4.53	5.4328	6.54	7.89	9.55
6.50 – 6.99	-0.0267	0.2518	2.90	3.42	4.04	4.7818	5.66	6.70	7.94	-0.1074	0.2777	3.18	3.79	4.54	5.4551	6.58	7.96	9.67
7.00 – 7.49	-0.0337	0.2507	2.91	3.43	4.05	4.7802	5.65	6.69	7.93	-0.1203	0.2817	3.19	3.81	4.56	5.4950	6.64	8.07	9.85
7.50 – 7.99	-0.0428	0.2501	2.92	3.44	4.05	4.7853	5.66	6.70	7.93	-0.1323	0.2865	3.20	3.83	4.61	5.5621	6.75	8.23	10.09
8.00 – 8.49	-0.0547	0.2502	2.93	3.45	4.07	4.7994	5.67	6.72	7.97	-0.1431	0.2921	3.23	3.88	4.67	5.6622	6.90	8.45	10.42
8.50 – 8.99	-0.0696	0.2514	2.94	3.46	4.08	4.8222	5.71	6.77	8.05	-0.1524	0.2987	3.27	3.93	4.76	5.7918	7.09	8.73	10.84
9.00 – 9.49	-0.0874	0.2540	2.95	3.48	4.10	4.8529	5.76	6.84	8.16	-0.1597	0.3062	3.31	4.00	4.86	5.9450	7.32	9.07	11.33
9.50 – 9.99	-0.1077	0.2578	2.96	3.49	4.13	4.8910	5.82	6.94	8.31	-0.1647	0.3145	3.37	4.08	4.98	6.1236	7.58	9.46	11.89
10.00 – 10.49	-0.1291	0.2628	2.97	3.50	4.15	4.9366	5.89	7.07	8.51	-0.1673	0.3231	3.43	4.17	5.12	6.3267	7.88	9.89	12.54
10.50 – 10.99	-0.1501	0.2686	2.98	3.52	4.18	4.9885	5.98	7.21	8.73	-0.1675	0.3318	3.49	4.27	5.27	6.5504	8.21	10.37	13.24
11.00 – 11.49	-0.1691	0.2751	2.98	3.53	4.21	5.0450	6.08	7.37	8.99	-0.1656	0.3405	3.56	4.38	5.44	6.7927	8.56	10.89	13.99
11.50 – 11.99	-0.1846	0.2816	2.99	3.55	4.25	5.1086	6.18	7.54	9.26	-0.1615	0.3487	3.64	4.50	5.61	7.0521	8.94	11.44	14.78
12.00 – 12.49	-0.1947	0.2876	3.00	3.58	4.29	5.1815	6.30	7.72	9.54	-0.1551	0.3561	3.73	4.63	5.80	7.3261	9.33	12.00	15.58
12.50 – 12.99	-0.1972	0.2930	3.02	3.61	4.34	5.2630	6.42	7.90	9.81	-0.1461	0.3624	3.82	4.77	6.00	7.6091	9.73	12.56	16.37
13.00 – 13.49	-0.1910	0.2978	3.04	3.65	4.40	5.3506	6.55	8.09	10.07	-0.1342	0.3675	3.92	4.91	6.20	7.8962	10.13	13.11	17.12
13.50 – 13.99	-0.1771	0.3017	3.07	3.69	4.47	5.4456	6.68	8.27	10.31	-0.1190	0.3716	4.02	5.06	6.41	8.1864	10.53	13.64	17.82
14.00 – 14.49	-0.1582	0.3046	3.10	3.75	4.55	5.5529	6.83	8.45	10.54	-0.1004	0.3747	4.12	5.21	6.63	8.4819	10.92	14.16	18.49
14.50 – 14.99	-0.1371	0.3062	3.15	3.82	4.64	5.6767	6.98	8.64	10.76	-0.0793	0.3773	4.22	5.36	6.85	8.7854	11.33	14.68	19.13
15.00 – 15.49	-0.1155	0.3067	3.22	3.90	4.75	5.8196	7.16	8.85	11.00	-0.0569	0.3796	4.33	5.53	7.08	9.1004	11.74	15.21	19.78
15.50 – 15.99	-0.0940	0.3062	3.30	4.01	4.89	5.9818	7.35	9.07	11.24	-0.0340	0.3819	4.43	5.69	7.32	9.4272	12.17	15.76	20.44
16.00 – 16.49	-0.0725	0.3050	3.39	4.13	5.04	6.1622	7.56	9.31	11.50	-0.0108	0.3845	4.54	5.86	7.56	9.7629	12.62	16.32	21.13
16.50 – 16.99	-0.0508	0.3032	3.50	4.26	5.20	6.3575	7.79	9.57	11.77	0.0125	0.3871	4.64	6.02	7.80	10.1036	13.07	16.90	21.83
17.00 – 17.49	-0.0277	0.3009	3.61	4.40	5.37	6.5606	8.02	9.82	12.04	0.0360	0.3896	4.74	6.18	8.05	10.4454	13.53	17.48	22.53
17.50 – 17.99	-0.0031	0.2983	3.73	4.55	5.55	6.7654	8.25	10.07	12.29	0.0594	0.3920	4.83	6.34	8.29	10.7870	13.98	18.05	23.21
18.00 – 18.49	0.0226	0.2955	3.84	4.69	5.72	6.9694	8.48	10.32	12.54	0.0828	0.3944	4.92	6.50	8.53	11.1285	14.43	18.62	23.89
18.50 – 18.99	0.0486	0.2926	3.96	4.84	5.90	7.1728	8.71	10.56	12.77	0.1064	0.3967	5.01	6.66	8.77	11.4707	14.89	19.19	24.57
19.00 – 19.49	0.0703	0.2901	4.06	4.96	6.04	7.3428	8.90	10.76	12.97	0.1250	0.3984	5.07	6.78	8.96	11.7406	15.25	19.64	25.10

[1]Smoothed L, M, and S curves for sub-scapular skinfold were generated by using equivalent df of 2, 5 and 3 in males and 3, 5 and 4 in females respectively. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for sub-scapular skinfold can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the formula: $Z = \frac{(subscapular \quad skinfold \quad (mm)/M)^{L} - 1}{L \times S}$

Table 4.26: Supra-iliac skinfold-for-age variables and percentiles by age and sex[1]

	Supra-iliac skinfold (mm)																
	Males									Females							
Age (years)	L	S	3rd	10th	25th	50th (M)	75th	90th	97th	L	S	3rd	10th	25th	50th (M)	75th	90th	97th
3.00 – 3.49	0.1244	0.2071	3.24	3.74	4.31	4.9568	5.68	6.50	7.42	-1.0525	0.1908	3.85	4.24	4.71	5.3118	6.09	7.14	8.65
3.50 – 3.99	0.1058	0.2099	3.21	3.71	4.28	4.9323	5.67	6.50	7.44	-1.0212	0.1969	3.80	4.19	4.68	5.2923	6.09	7.18	8.76
4.00 – 4.49	0.0870	0.2128	3.18	3.68	4.26	4.9079	5.65	6.50	7.45	-0.9778	0.2053	3.73	4.13	4.63	5.2660	6.10	7.24	8.90
4.50 – 4.99	0.0683	0.2156	3.15	3.65	4.23	4.8840	5.63	6.49	7.47	-0.9345	0.2137	3.66	4.07	4.59	5.2427	6.11	7.30	9.05
5.00 – 5.49	0.0496	0.2183	3.13	3.63	4.20	4.8608	5.62	6.49	7.49	-0.8911	0.2222	3.59	4.02	4.55	5.2262	6.13	7.37	9.20
5.50 – 5.99	0.0309	0.2210	3.10	3.60	4.17	4.8385	5.60	6.49	7.51	-0.8477	0.2308	3.54	3.97	4.52	5.2205	6.16	7.46	9.38
6.00 – 6.49	0.0122	0.2236	3.08	3.57	4.15	4.8178	5.59	6.49	7.53	-0.8043	0.2395	3.49	3.94	4.50	5.2310	6.21	7.57	9.58
6.50 – 6.99	-0.0065	0.2260	3.06	3.55	4.13	4.8001	5.58	6.49	7.55	-0.7609	0.2483	3.45	3.92	4.50	5.2628	6.28	7.71	9.82
7.00 – 7.49	-0.0252	0.2284	3.04	3.54	4.11	4.7879	5.58	6.50	7.58	-0.7175	0.2573	3.43	3.91	4.52	5.3191	6.39	7.89	10.11
7.50 – 7.99	-0.0439	0.2306	3.03	3.52	4.10	4.7842	5.58	6.52	7.62	-0.6741	0.2665	3.43	3.93	4.57	5.4013	6.53	8.11	10.45
8.00 – 8.49	-0.0626	0.2329	3.03	3.52	4.10	4.7908	5.60	6.56	7.69	-0.6308	0.2760	3.43	3.96	4.63	5.5103	6.70	8.38	10.86
8.50 – 8.99	-0.0813	0.2353	3.03	3.53	4.11	4.8081	5.63	6.61	7.77	-0.5874	0.2858	3.45	4.00	4.71	5.6456	6.91	8.69	11.33
9.00 – 9.49	-0.1000	0.2377	3.04	3.54	4.13	4.8364	5.67	6.67	7.87	-0.5440	0.2960	3.47	4.06	4.81	5.8055	7.15	9.05	11.86
9.50 – 9.99	-0.1187	0.2403	3.06	3.56	4.16	4.8758	5.73	6.76	8.00	-0.5006	0.3065	3.51	4.13	4.93	5.9912	7.43	9.46	12.46
10.00 – 10.49	-0.1374	0.2431	3.08	3.59	4.20	4.9248	5.80	6.86	8.15	-0.4572	0.3170	3.56	4.22	5.07	6.2038	7.75	9.92	13.12
10.50 – 10.99	-0.1561	0.2461	3.10	3.62	4.24	4.9815	5.88	6.98	8.31	-0.4138	0.3275	3.61	4.31	5.23	6.4443	8.10	10.43	13.84
11.00 – 11.49	-0.1748	0.2495	3.13	3.65	4.28	5.0438	5.97	7.11	8.50	-0.3704	0.3378	3.67	4.43	5.41	6.7129	8.49	10.99	14.61
11.50 – 11.99	-0.1935	0.2531	3.15	3.69	4.33	5.1106	6.07	7.24	8.71	-0.3271	0.3479	3.74	4.55	5.60	7.0080	8.92	11.59	15.43
12.00 – 12.49	-0.2122	0.2568	3.18	3.72	4.38	5.1817	6.17	7.39	8.93	-0.2837	0.3576	3.82	4.68	5.82	7.3265	9.38	12.23	16.29
12.50 – 12.99	-0.2310	0.2606	3.21	3.76	4.43	5.2572	6.28	7.55	9.16	-0.2403	0.3667	3.90	4.83	6.04	7.6646	9.86	12.89	17.18
13.00 – 13.49	-0.2497	0.2644	3.25	3.81	4.49	5.3373	6.39	7.72	9.41	-0.1969	0.3753	3.98	4.98	6.28	8.0186	10.36	13.58	18.07
13.50 – 13.99	-0.2684	0.2681	3.29	3.86	4.55	5.4235	6.51	7.90	9.68	-0.1535	0.3833	4.06	5.13	6.53	8.3853	10.88	14.28	18.96
14.00 – 14.49	-0.2871	0.2716	3.33	3.91	4.63	5.5182	6.65	8.09	9.96	-0.1101	0.3907	4.14	5.28	6.78	8.7616	11.41	14.98	19.84
14.50 – 14.99	-0.3058	0.2748	3.38	3.97	4.71	5.6233	6.79	8.29	10.26	-0.0668	0.3976	4.21	5.43	7.03	9.1456	11.95	15.69	20.71
15.00 – 15.49	-0.3245	0.2777	3.44	4.05	4.80	5.7400	6.95	8.52	10.59	-0.0234	0.4041	4.28	5.58	7.29	9.5358	12.49	16.40	21.56
15.50 – 15.99	-0.3432	0.2803	3.51	4.13	4.90	5.8681	7.12	8.75	10.94	0.0200	0.4101	4.34	5.73	7.55	9.9305	13.04	17.11	22.40
16.00 – 16.49	-0.3619	0.2825	3.59	4.22	5.01	6.0064	7.30	9.01	11.30	0.0634	0.4159	4.39	5.87	7.81	10.3280	13.60	17.81	23.23
16.50 – 16.99	-0.3806	0.2845	3.68	4.32	5.12	6.1525	7.49	9.27	11.68	0.1068	0.4215	4.43	6.01	8.06	10.7268	14.15	18.51	24.05
17.00 – 17.49	-0.3993	0.2863	3.76	4.42	5.24	6.3033	7.69	9.54	12.08	0.1502	0.4269	4.46	6.14	8.32	11.1257	14.70	19.21	24.84
17.50 – 17.99	-0.4180	0.2879	3.85	4.52	5.37	6.4558	7.89	9.81	12.47	0.1936	0.4322	4.47	6.26	8.57	11.5243	15.25	19.90	25.63
18.00 – 18.49	-0.4367	0.2894	3.94	4.63	5.49	6.6085	8.08	10.08	12.88	0.2369	0.4374	4.47	6.36	8.81	11.9226	15.81	20.59	26.40
18.50 – 18.99	-0.4554	0.2910	4.03	4.73	5.61	6.7610	8.28	10.36	13.29	0.2803	0.4426	4.45	6.46	9.05	12.3208	16.36	21.27	27.17
19.00 – 19.49	-0.4711	0.2923	4.11	4.82	5.72	6.8885	8.45	10.60	13.65	0.3145	0.4466	4.43	6.53	9.24	12.6346	16.79	21.81	27.76

[1]Smoothed L, M, and S curves for supra-iliac skinfold were generated by using equivalent df of 2, 4 and 3 respectively for both males and females. L (t) denotes the Box-Cox power transformation to remove skewness at age *t*, M (t) denotes median and S (t) denotes the generalized coefficient of variation. The z-score or standard deviation scores for supra-iliac skinfold can be calculated with the use of the LMS coefficients that are specific to the completed age and sex of a child or adolescent using the formula:

$$Z = \frac{(suprailiac\ \ skinfold\ \ (mm)/M)^{L} - 1}{L \times S}$$

4.13 Comparison of Centile Curves for Skinfold Thicknesses

The skinfold thicknesses for individuals considered underweight were in general, consistently lower across ages, especially in girls. Figures 4.13 (A and B) gave the comparison of biceps skinfold for underweight and normal weight individuals for boys and girls respectively. Comparison of 97th percentiles between the underweight and normal weight showed that the centiles for the underweight were far below that of their normal weight counterparts for both sexes. The median biceps skinfold for underweight boys was below the 25th percentile for the normal weight while median underweight for girls tracks slightly above the 25th centile for normal girls.

Figures 4.14 (C and D) compares triceps skinfold for underweight and normal weight boys and girls. Median triceps skinfold thickness for underweight boys and girls were consistently below the 25th percentile of normal weight individuals. The 97th percentile for boys approximates the 75th percentile at several ages. At age ≈ 14 years, the 97th percentile tracked upwards. The cause of such deviation was not explained, but may be due to artefact during smoothing process. In girls, the 97th percentile also approximated the 75th percentile at early age. At age ≈ 11 years, the 97th percentile for the underweight tracked steadily below the 75th percentile for the normal weight. Again, although the reason for such discrepancy was not explained, that it occurred in girls suggests the tracking may more likely be empiric than artefact during modelling.

The median sub-scapular skinfold thickness for underweight boys approximates median skinfold for normal weight (Figure 4.15 E). The 97th percentile for underweight individuals however tracks below 75th percentile of the normal weight across all ages. In girls, median sub-scapular skinfold for the underweight approximates the 10th percentile for the normal

weight (Figure 4.15F). Ninety-seventh percentile for the underweight approximates the 75th percentile from lower age to ≈ 9 years, it then consistently continues to diverge below the 75th percentile of the normal weight across the remaining ages.

The median supra-iliac skinfold of underweight boys (Figure 4.16 G) was initially slightly above the 10th percentile of the normal weight individuals at age 5 to ≈11 years then approximated the 10th percentile up to ≈ 16 years then continued tracking below the 10th percentile. The 97th percentile for the underweight diverged below 90thh percentile of those with normal weight then continues slightly above the 75th percentile. At ≈ 16 years, it crosses the 75th percentile and continues below it. In general, supra-iliac skinfold percentiles underweight and normal individuals didn't track properly. In girls, median supra-iliac skinfold thickness of individuals identified as underweight was consistently below the 10th percentile of girls with normal weight (Figure 4.16 H). The 97th percentile of the underweight initially approximates the 75th percentile of normal weight girls up to ≈ 9 years, then began to track appreciably below the 75th percentile of normal weight girls.

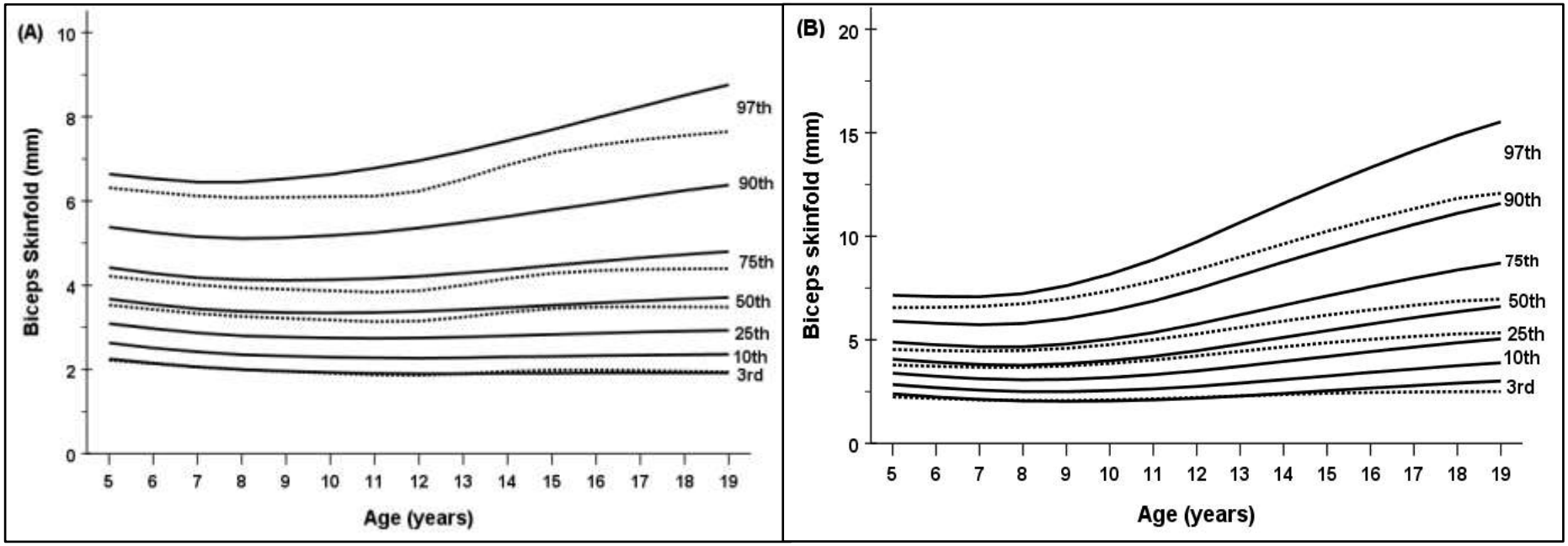

Figure 4.13: Comparison of smoothed-percentile curves of biceps skinfold-for-age curves for boys (A) and girls (B) across age. 3rd, 10th, 25th,25th, 50th, 75th, 90th and 97th centiles are shown.Solid lines represent percentile curves for Nigerian children and adolescents; dotted lines are corresponding curves for individuals classified as underweight [BMI (kg/m^2) *Z*-score between <2 and <3] using the 2007 WHO growth reference.

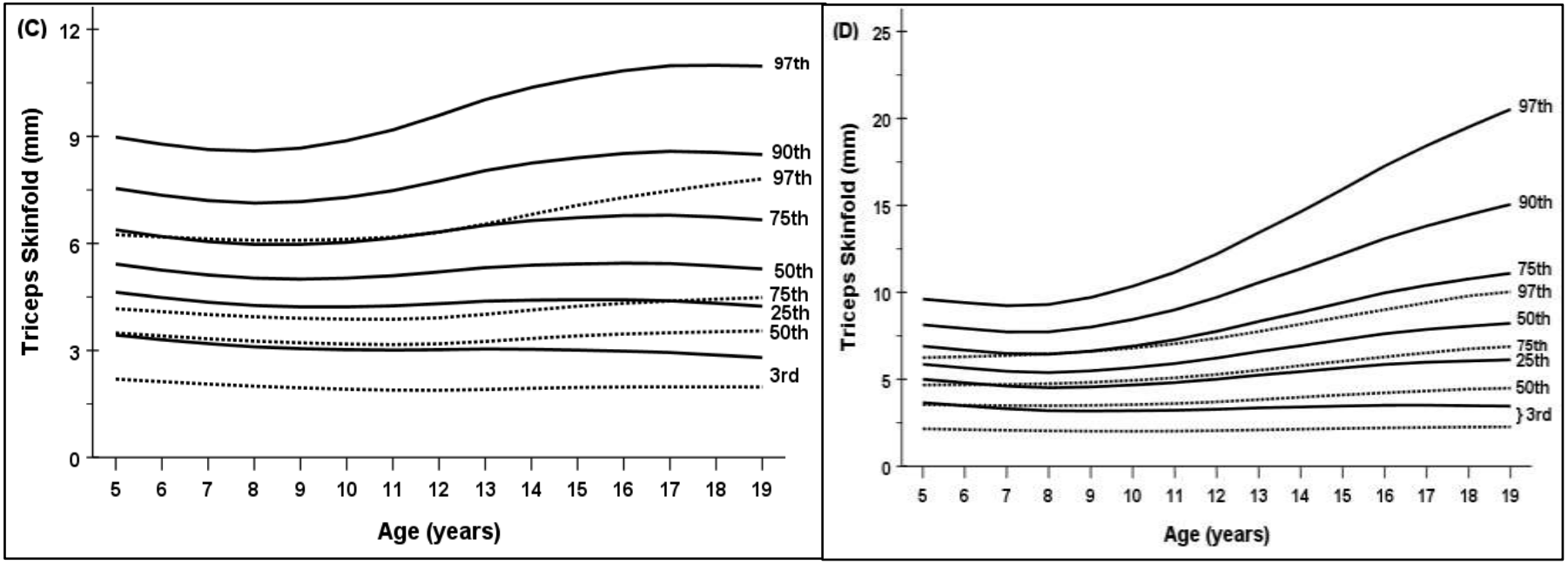

Figure 4.14: Comparison of smoothed reference curves for triceps skinfold-for-age curves for boys (C) and girls (D) across age. 3rd, 25th,25th, 50th, 75th, 90th and 97th centiles are shown. Solid lines represent percentile curves for Nigerian children and adolescents; dotted lines are corresponding curves for individuals classified as underweight [BMI (kg/m^2) *Z*-score between <2 and <3] using the 2007 WHO growth reference.

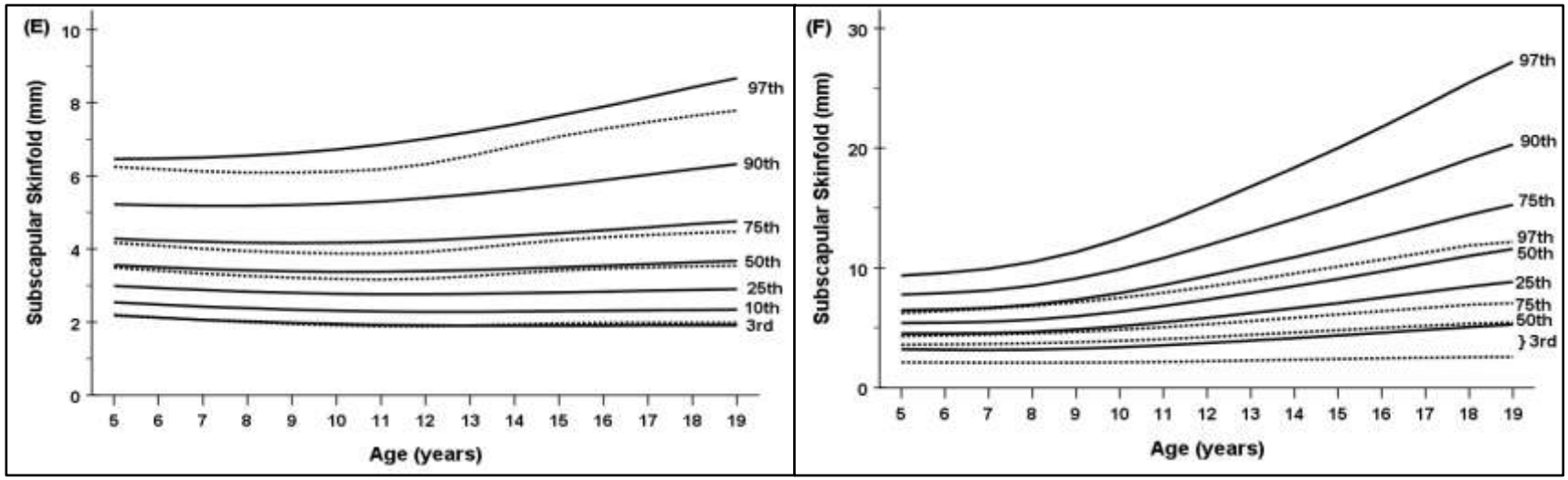

Figure 4.15: Comparison of smoothed-percentile curves of sub-scapular skinfold-for-age curves for boys (E) and girls (F) across age. 3rd, 25th,25th, 50th, 75th, 90th and 97th centiles are shown.Solid lines represent percentile curves for Nigerian children and adolescents; dotted lines are corresponding curves for individuals classified as underweight [BMI (kg/m^2) *Z*-score between <2 and <3] using the 2007 WHO growth reference.

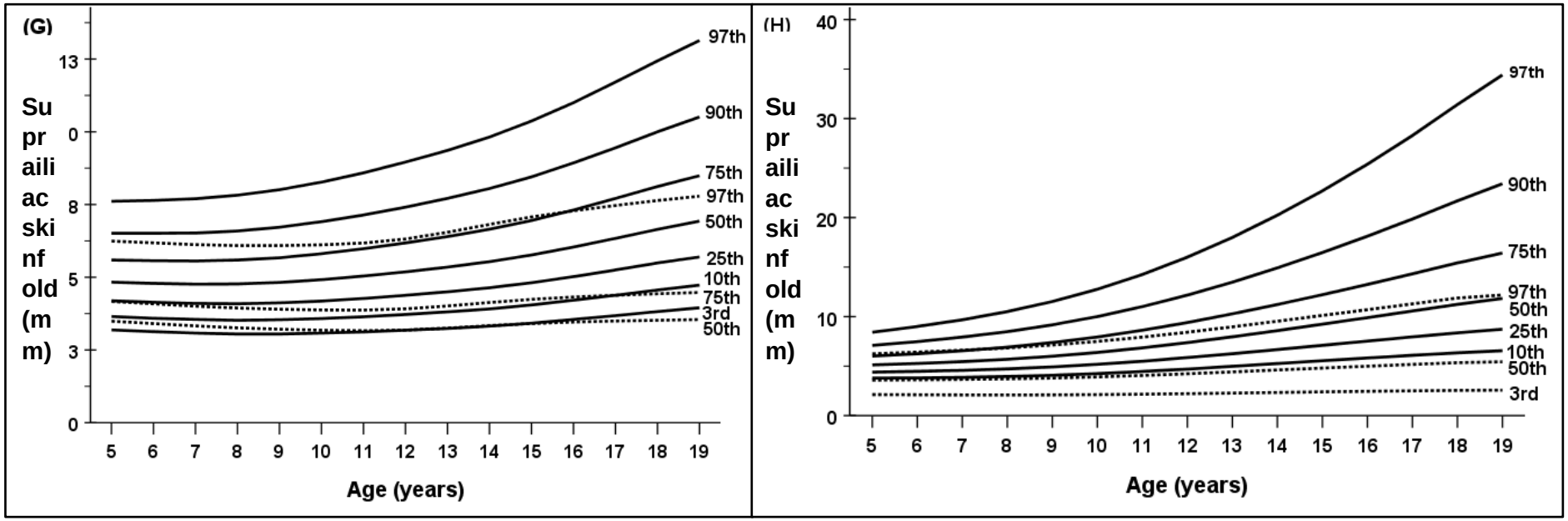

Figure 4.16: Comparison of smoothed-percentile curves of supra-iliac skinfold-for-age curves for boys (G) and girls (H) across age. 3rd, 25th,25th, 50th, 75th, 90th and 97th centiles are shown.Solid lines represent percentile curves for Nigerian children and adolescents; dotted lines are corresponding curves for individuals classified as underweight [BMI (kg/m^2) *Z*-score between <2 and <3] using the 2007 WHO growth reference.

CHAPTER FIVE

5.0 DISCUSSION

The present cross-sectional study assessed the prevalence of undernutrition among a population of healthy Nigerian children and adolescents (resident in Nasarawa State) aged 0 – 19 years and generated smoothed reference percentile curves specific for age and sex for height, weight and BMI. The study also compared percentile curves for height and BMI with those of the WHO (2007) reference data. Height and BMI are good indicators of nutritional status. They are respectively good indicators of chronic and acute malnutrition. The nutritional status of children and adolescents in the present study assessed from height-for-age and BMI-forage showed that undernutrition prevailed in these children and adolescents compared to the international reference.

It is observed that compared to the WHO (2007) reference, the mean z-scores for height and BMI in all age categories (except for age 5 in both sexes) were negative for Nigerian children and adolescents. A relatively high prevalence of stunting and thinness and low prevalence of overweight and obesity was noted from the results. The poor growth pattern of Nigerian children and adolescents is in congruent to those previously reported in sub-Saharan Africa (Bénéfice,1992a, 1993; Bénéfice*et al*., 1999;Prista *etal*., 2003;Semproli and Gualdi-Rossi, 2007; Nhantumbo *et al*., 2013; Augustin *et al.,* 2017; Hoffman *et al*., 2017). The prevalence of stunting (<−2 z-score) and severe stunting (<−3 z-score) in the study using the WHO (2007) reference were found to be 21.1% and 6.1% (in boys) and 18% and 5.9% (in girls), respectively. The prevalence of stunting and severe stunting in boys and girls were found to be similar. Also, the prevalence of severe and moderate thinness are 16.6% and 36.1% (for boys) and 12.4% and 29.5% (for girls) respectively. The prevalence

of severe and moderate thinness in boys and girls are significantly different with boys having higher prevalence. As stated earlier, height and BMI are indicators of chronic and acute malnutrition. Results of the present study indicates that undernutrition was a major public health issue in Nigeria. Unlike thinness, the prevalence of overweight between boys and girls were similar between boys and girls although its prevalence was higher among girls than boys.

The stunting of the surveyed children and adolescents was higher than that of children and adolescents in Kinshasha, 9.8% in boys and 3.4% in girls (Augustin *et al*., 2017). The present study suggests that the prevalence of stunting and thinness is higher than those previously reported in sub-Saharan Africa (Cameron, 1991; Cameron *etal*., 1992, 1994;Prista*etal*., 2003;Semproli and Gualdi-Rossi, 2007;Nhantumbo *et al*., 2013). The high prevalence of stunting (chronic nutritional deficiencies) and thinness (acute nutritional deficiencies) underscores how food insecurity, insufficient nutrient intake and other social factors confound normal growth among Nigerian children and adolescents. Aside these factors, genetic make-up, geography and ethnic differences may also be responsible for the high prevalence of stunting and thinness in the present study compared to the WHO (2007) reference.

In contrast to previous findings in other sub-Saharan Africa (Augustin *et al*., 2017; Muthuri *et al*., 2013;Semproli and Gualdi-Rossi, 2007; Prista *et al*., 2003), very low prevalence of overweight and obesity was observed from the sample population. This is an indication that undernutrition is still endemic in Nigeria and conforming to the study hypothesis. Intriguingly, rising tempo of double burden of malnutrition (overweight/obesity and

undernutrition) have been reported in other sub-Saharan African countries (dos Santos*etal*., 2014; Popkin and Gordon-Larsen,2004).

Furthermore, despite the mean z-scores of both sexes were in the same direction (negative), the results indicated a consistent pattern in terms of magnitude. That is, boys consistently have lower mean z-scores for height and BMI across ages, an indication of higher level of undernutrition in boys. Sexual dimorphism in the level of undernutrition have previously been reported (Bénéfice and Malina, 1996; Simondon *et al.,* 1998;Monyeki *et al.,* 2000;Semproli and Gualdi-Rossi,2007;Olivieri *et al*., 2008;Nhantumbo*et al.,* 2013). Difference in basal metabolic rate, dietary energy requirement, quality of food intake, response to environmental stressors might explain the difference in undernutrition. Furthermore, boys engage in more energy-requiring activities, for instance, some engage in artisanship after schooling hours, do more drudging labour in farm or other forms of irksome task as either breadwinners or to support their parents. The fact that some of these children can only eat if they earn a wage is a hammer blow to the nutritional status of these children and thousands more in other parts of Nigeria. The girl child is more cared for and indulged in less energy-requiring activities. Other possibilities include cultural practice that gave girls relatively higher advantages to serve meals to themselves then to other members of the family may mean they serving themselves higher ration than boys (Bénéfice 1992a; Bénéfice and Malina, 1996;Semproli andGualdi-Rossi, 2007). Another factor that may play role in sexual dimorphism in nutritional status is the timing of onset of puberty. Previous studies have shown that early maturation in girls is associated with corresponding greater pubertal height gain coupled with a longer pubertal growth to the stage of peak height velocity (Pantsiotou*et al.*, 2008).

Factors responsible for undernutrition in the present study have not been elucidated; howbeit poverty, lack of dietary protein and inadequate diet are plausible causes of the high level of malnutrition of Nigerian children and adolescents. Furthermore, life setting or socio-economic factors such as family size, urban/rural residence, family income, parents' educational attainment may also influence undernutrition. Although, the present study considered Nasarawa State alone, the staggering result of undernutrition might as well reflect the situation in other parts of Nigeria and other countries of low-income economy.

Regarding centile curves, centile curves for height, weight and BMI of children and adolescents (Tables 3 – 5) and their corresponding charts (Figures 1 and 2) were generated. Further, the study graphically compared growth pattern of the sample population to that of the WHO (2007). The results revealed relatively similar linear growth pattern compared to that of the WHO. It is observed that the growth centile curves of height-for-age and BMI-for-age in the present study remain below the centile curve of the WHO (2007) reference for both boys and girls. (Cameron, 1991; Bénéfice, 1993;Bénéfice and Malina, 1996;Henneberg and Louw, 1998;Bénéfice, 1999;Sellen, 1999;Pawloski, 2002;Prista *et al*., 2005;Olivieri *etal*.,2008). Although the growth curves of girls show a slightly better growth pattern compared to that of boys as the growth curves of girls was closer to the centile curves of the WHO (2007) reference than those of boys. Previous studies have also reported similar findings (Cameron *et al*., 1992; Zverev and Gondwe, 2001;Semproli and Gualdi-Rossi, 2007;Nhantumbo *et al.,* 2013).

Various reasons may be responsible for difference in centile curves (of height, weight and BMI) between the present study population and those of the WHO (2007) reference.

Racial-ethnic difference in the timing of puberty between Africans and their cohorts in developed countries have earlier been reported. Bénéfice (1993) reported smaller increments in anthropometric dimensions (height and weight) of blacks compared to whites in the Fels LongitudinalStudy.

For the first time, to my knowledge, centile curves for height, weight and BMI of school children and adolescents are modelled in Nasarawa State in particular and Nigeria at large, adopting a procedure that follows the prevailing recommendations regarding sampling and curve modelling laid out by the WHO (Borghi *etal*., 2006). There is no report about the prevalence of undernutrition about adolescents except for children aged 0 – 59 months. Unfortunately, Nigeria has no representative national growth references, which have been periodically updated for adolescents to apply to the current study along with an international growth reference. Therefore, the results from the current study provide a useful public health tool to health-care providers to assess and evaluate the health status of children and adolescent in Nigeria. The reference centile curves generated in the present study may also be useful for future comparisons to evaluate growth pattern among children and adolescent in Nigeria and not using international growth standards alone. It was for this reason, data in the present study were collected with standardized instruments while following global and well tested anthropometric procedures. The sample size was obtained from large representative sample of school children and adolescents of good health standing with sample size of at least 200 (except for few age groups) subjects per sex per age category coupled with a clearly defined reproducible methodologies.

Multiple logistic regression analysis was used to find the effect of socio-demographic measures on stunting. Stepwise logistic regression analysis was used to detect the major

factors influencing stunting. The coefficient of multiple logistic regression analysis showed that father's educational background was negatively associated (P <0.001) with stunting and that the Odds ratio demonstrated that the lower the father's educational attainment, the more likely the child will be stunted. The Odds ratio of multiple logistic regression analysis also showed that children whose mother had no western education are at higher risk (OR = 3.258, P <0.001) of being stunted, compared to when paternal educational attainment is primary (OR = 2.069, P = 0.030). Intriguingly, those whose father had tertiary education are less likely to be stunted. In contrast, father's educational attainment indicates that the

The study also constructs smoothed reference percentile curves for MUAC and its derivatives; UAMA and UAFA for Nigerian children and adolescents by age and sex. The three parameters for calculating z-scores are also presented for the three reference percentiles for each age and sex.

Two anthropometric indicators of SAM are MUAC and WHZ. The WHO and United Nations International Children's Emergency Funds (UNICEF) recommend the use of WHZ < - 3 (severely low WHZ) and MUAC < 115 mm (severely low MUAC) as cut-off values to guide admission of children with SAM to feeding programmes or further medical investigation. Whereas WHZ is a statistical expression that uses weight as a number of z-scores or standard deviations below and above reference median value for a particular stature, MUAC on the other hand is an absolute value (WHO, 1995). Compared to WHZ, MUAC is judged to be simple, inexpensive tool that requires single measurement for diagnosing malnutrition and has the potential to identify children at risk of mortality (Myatt*et al.,* 2006). Albeit, it is not clear which of these two indicators is a better predictor of children at elevated mortality risks (Grellety *et al.,* 2015; Isanaka *et al.,* 2015), the use of

absolute MUAC or in conjunction with WHZ as screening tool by field organisations to screen vulnerable children in need of intervention is becoming ubiquitous (Grellety and Golden, 2016). However, earlier studies have reported poor association between the use of MUAC and WHZ as malnutrition diagnostic tools for SAM (WHO/UNICEF, 2009). For instance, Berkley *etal*. (2005) reported 65.1% of children hospitalized after initially diagnosed of having WHZ <−3 were also identified as having MUAC < 115 mm, while 56% of the SAM cases based on MUAC were also found to have WHZ < -3 (Berkley *et al*., 2005).

Furthermore, studies by Fernandez and colleagues reported in a study of 34,937 children aged 6 – 59 months, 75% of children in the study with WHZ <−3 were also found to have MUAC < 115 mm (Fernandez *etal*., 2010).

From the foregoing, adopting a single approach for identifying and classifying children with SAM in children (especially those < 5 years), may not be suitable and may be marred with misclassification due to other extraneous variables such as age, sex and stunting, which frequently affect SAM children. Furthermore, such non-alignment between indicators pose significant intervention confusion and challenges because being fine-grained on one of these indicators may under-detect true level of acute malnutrition, thereby resulting in missed opportunities for intervention and treatment. Adopting an approach of diagnosing SAM either based on indicator can also lead to undue inflation of intervention programme due to uncertainty on whether or not children identified by one indicator and not by the other truly require robust nutritional rehabilitation.

A significant puzzle in public health nutrition is the potential the identification and application of the most-sensitive marker of undernutrition with a view to reducing risk of mortality. MUAC may serve as an alternate means of assessing nutritional status when routine anthropometric indicators of nutrition (weight, height and BMI) are difficult to come by. For this reason, MUAC measures in the present study may provide an alternative for monitoring, evaluation and management of nutritional status in Nigeria and other sub-Saharan countries that share common socio-demographic background with Nigeria. Since the LMS coefficients provided herein are age- and sex-specific for a child or adolescents, it makes it possible to compute z-scores for each of the three measures; MUAC, UAMA or UAFA:

$$Z = \frac{(y\ /M)^{L} - 1}{L \times S}$$ Addo and Himes, 2010

Therefore, there are no previously established centile patterns of MUAC, UAMA and UAFA in Nigeria, the reference ranges presented in the present study could not be compared to any local data. The reference ranges in the present study may serve as a reference guide to future studies. However, a comparison of the reference ranges presented in the current study with previous studies (Addo *etal*., 2017) revealed that the pattern of age change in MUAC, UAMA and UAFA from childhood to adolescents differs in both sexes. Intriguingly, it is observed that the 97th centiles of UAFA increased steeply as shown in Figure 4.8, comparing the Nigerian children and adolescents with contemporaneous US reference data. The MUAC has been used as a good alternative indicator of nutritional status especially during routine nutritional assessment and can be used as proxy for low weight-for-height (wasting) (de Onis *et al*., 1997). Although comparisons of these two indicators show that they are poorly associated (Gayle *et al*., 1988; Trowbridge and

Staeling, 1980), there appears to be consensus that low MUAC is a superior predictor of mortality than WHZ (Briend and Zimicki, 1986;Briend *et al.,* 1987;Jensen *et al.,* 2015).

The present study also evaluated age- and sex-specific difference in MUAC, UAMA and UAFA. Regarding MUAC, there is no significant difference in MUAC prior to 10 years. For much of early life, boys are relatively having higher MUAC compared to girls. As MUAC continues to increase with age, girls experienced significant MUAC rebound at age 10 years. One possible proposition is that MUAC is age- and sex independent in early life but indicates sex-dependent later in life (age 10 and above as seen in the current study) especially at puberty. For the most part, the difference in UAMA was age and sex dependent. The difference based on sex was appreciably in favour of boys than girls and the difference was not significant prior to age 14 years. It stands to reason therefore that UAMA was sex independent from early life to age 14 years while it indicates sex dependence from pubertal age and beyond.

Results for UAFA indicate significant difference from age 4.5 years and the sex difference was consistently in favour of girls. Findings on UAMA and UAFA were in congruent to that of Oyhenart*etal*. (2019). This is due to sexual dimorphism that exists in body composition with girls having relatively more fat mass and boys more muscle (Schorrl*et al*., 2018). Women have been reported to have ~ 10% higher body adiposity than men (Jackson *et al.,* 2002; Womersley and Durnin, 1977).

Comparison of MUAC-for-age of Nigerian boys and girl to that of the West showed that undernutrition prevailed in children and adolescents in the present study compared to those in the US. The low MUAC-for-age of the surveyed Nigerian children and adolescents

compared to those in the West indicates remarkable undernutrition. The prevalence of undernutrition among Nigerian children and adolescents has not been investigated recently. Although the factors underlying the low MUAC-for-age of present study have not been investigated, difference in genetic make-up, epigenetics, socio-economic and demographic status may partly be responsible. Other plausible and relevant factors that might have exacerbated the nutritional status of children and adolescents in this study compared to the US reference data include poor health care system, sanitation, low literacy level, diet and lifestyle.

The economic growth of Nigeria in 2018 and 2019, being the intervening period of the present study may have played a role in the low MUAC-for-age. The gross domestic product of Nigeria in 2018 and 2019 are 1.91% and 2.27% with per capita income of $2,032.73 and $2,229.859, respectively (World Bank, 2020). This is coupled with a frightening 23.1% unemployment rate, 20.21% underemployment rate, combined unemployment and underemployment rate of 43.3% (National Bureau of statistics), farmers' inability to farm due to escalated insecurity such as banditry, kidnapping, or farmers-herders' conflict and surge in prices of essential goods. The prevailing insecurities have fed hunger in Nigeria, although not as dire to biblical proportions but worrisome. The spade of insecurities is not abating and there are no meaningful steps being taking either at national or subnational level to mitigate the impact of food crisis. Consequently, the Nigeria's low economic growth has led to change in diet and lifestyle. Children now eat low diet food, spend more time after school performing menial jobs (either in the farms or engaged as artisan) to support family. Watching TV, playing computer games, living in good houses and reliance on transport system are now seen as luxury and for the well-off.

The new centile ranges for upper arm measures provide a description of the prevailing upper arm status of healthy Nigerian children and adolescents. To my knowledge, the present study is the first in Nigeria to construct centile curves of upper arm measures. Notwithstanding, the curves were fitted based on data from Nigerian children and adolescents, it is hoped that they may as well be of immense use not only in Nigeria, but in other sub-Saharan countries with similar socio-demographic background like Nigeria.

The present research also provides a reference data for four skinfold thicknesses and parameters for calculating their z-scores and as a simple and non-invasive means of estimating subcutaneous adiposity in Nigerian children and adolescents. Although BMI has been routinely used to assess underweight, the percentile and z-scores of skinfold thicknesses presented in this study makes for improved understanding of both truncal (in this case the sub-scapular and supra-iliac) and peripheral (the biceps and triceps) fat distribution. Skinfold thickness and BMI percentiles have long been recommended by the WHO for use globally as indicators of nutritional status (Must *et al.*, 1991). These percentiles were generated based on US data. The WHO 2007 skinfold percentiles, although developed from data from other countries in addition to the US, only consider children 3 – 60 months old. Potential problem and weakness with the WHO published triceps and sub-scapular skinfold percentiles include its applicability to Nigerian population is unknown.Its ability to predict future health risk is not clear and no specific recommendations were made for adolescent skinfolds. Demographics, socio-economic s and cultural practices are some factors responsible for variabilities of anthropometric variables across races.

Sexual dimorphism in biceps, triceps, sub-scapular and supra-iliac skinfold thicknesses was observed. Compared with other published references of skinfold thicknesses, lower skinfold thicknesses were noticed from the present study sample (Cronk and Roche, 1982; McDowell*et al.,* 2008;Addo and Himes 2010;Jaworski*et al*., 2012;Kuhle*et al*., 2016).

Both the percentiles and z-scores generated from the present study will enhance analyses of truncal and peripheral distribution of subcutaneous fat. Skinfold thicknesses, while receiving considerable attention in recent years, have not been widely adopted in selecting risk factors than BMI for children aged 4 – 9 years and the wide spread use of BMI expressions for estimating percentage body fat in children than skinfold thickness. While skinfold thickness is an indicator of whole-body adiposity and is sensitive to variations in nutritional status (Mascarenhas *et al*., 1998), a study found that BMI correlate with cardiovascular disease complications than centralized deposition of body fat determined by skinfold (Morrison*et al*., 1999). Therefore, the choice of including both BMI and skinfold thicknesses depends on the parameter that is being assessed.

To my knowledge, no previous study has been conducted in Nigeria to assess the four skinfold thicknesses and to establish their centile patterns at national, subnational or by researchers. The skinfold z-scores from this study may ease age- and sex-specific comparisons by other researchers.

Results from the present study showed that only few individuals were overweight and none were identified as obese. Although obesity is a growing global phenomenon (Lasserre *et al*., 2007; Kosti andPanagiotakos, 2006; Lobstein *et al*.,2004) as well as in many developing countries (Popkin,2004; Popkin and Gordon-Larsen, 2004), it seems that the

double burden of undernutrition and overnutrition problems is still not the case in urban and rural settings of Nasarawa State. Notwithstanding, as shown in Figures 4.9 – 4.12, the median and 97th percentiles of subjects classified as underweight by BMI criteria do not track properly and in some instances the chart for the underweight crosses that of normal weigh subjects. The patterns of median skinfold presented in this study are inadequate, nevertheless to determine the cut-off point of skinfold percentiles to accurately classify underweight in children and adolescent should not be adopted for this goal. Rather, to determine the maximum skinfold percentile cut-points to classify underweight would require another screening or diagnostic tool known as the receiver operating characteristics or its proxy.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The sample population (N) comprised 7,321 school-aged children and adolescents (n = 3,575 boys; n = 3,746 girls), selected using stratified random sampling technique from Lafia and Doma LGAs of Nasarawa State. The objectives were to: (1) develop absolute values of participants' anthropometric measures stratified by completed age and sex of school-aged children and adolescents, (2) assess participants' nutritional status by comparing measurements of height and BMI against the appropriate WHO (2007) cut-off points, (3) develop new percentile reference curves for height, weight, BMI, MUAC and its derivatives (UAMA and UAFA) and skinfold thicknesses (biceps, triceps, sub-scapular and supra-iliac), (4) generate values for LMS parameters that allows for the calculation of the corresponding z-scores of measures in (3) standardized for sex and age groups, (5) compare the smoothed-percentile curves of skinfold thicknesses to international values, (6) compare the smoothed-percentile curves of MUAC and its derivatives to an international published reference values, (7) assess the diagnostic accuracy of MUAC for screening thinness and severe thinness compared with BAZs <-2 and <-3 as the gold standard, (8) identify appropriate MUAC cut-off points for screening thinness and severe thinness, (9) assess the concordance of MUAC to BMI in assessing nutritional status, and finally (10) determine the effects of socio-demographic factors on nutritional status and to generate regression models and prediction equations.

Nutritional status was assessed using the WHO (2007) growth reference. Moderate and severe stunting were defined as HAZ <-2 and HAZ <-3 whereas, moderate and severe

thinness were defined as BAZ <−2 and BAZ <−3 respectively. For children and adolescents aged 5 – 19 years, the prevalence of moderate and severe stunting for the combined population are respectively 20.3% and 6.5%, whereas the prevalence of moderate and severe thinness is respectively 32.6% and 14.2%. Furthermore, stunting (moderate and severe) and thinness (moderate and severe) occur more frequently in boys than in girls. The prevalence of moderate and severe stunting in boys and girls are correspondingly (21.1% vs 6.1%) and (18.0% vs 5.9%), whereas the prevalence of moderate and severe thinness in boys and girls were (36.1% vs 16.6%) and (29.5% vs 12.4%)respectively. This study indicated that, relative to international reference values, the nutritional markers have lower means and relatively often fall below typical sample limits.

Centile patterns of children and adolescents in Nasarawa State fall below WHO (2007) references and are similar to those observed in other populations in sub-Saharan Africa. These up-to-date centile curves for height, weight and BMIprovide a basis for comparison in future studies and may beused to assess individual children within their environment.They are, however, descriptive growth references and notgrowth standards.The data may also be of value in other States of Nigeria and other Sub-Saharan countries that share the sameethnic and socio-economic background with Nasarawa State.

Heretofore, smoothed reference percentile curves have not been available for height, weight, BMI, MUAC (or its derivatives) and skinfold thicknesses either for a representative sample of children and adolescents from Nasarawa State or Nigeria at large. The centiles for these anthropometric measures were generated with the LMS method. This semiparametric method uses cubic splines to fit smoothed L (Box-Cox power to remove skewness), M (the median) and S (generalized coefficient of variation) curves across each

age and sex and for each anthropometric measure of interest by maximum penalized likelihood. The z-scores may be calculated with the use of the LMScoefficients that are specific to the nearest completed one-half year of age for a child or adolescent for each measured anthropometric measure (x) (that is, height, weight, BMI, MUAC, biceps, triceps, sub-scapular or supra-iliac skinfold thicknesses) with the followingexpression:

$$\text{z-score} = [(x \div M)^{L} - 1] \div L \times S$$

The new z-scores will greatly facilitate comparisons across ages, between sexes, States, geopolitical zones, national or to other sub-Saharan African countries with similar demographics like Nigeria. The study also investigated the effects of socio-demographic factors (parents' educational attainment) on stunting and thinness using multiple logistic regression and stepwise regression. The statistical tools demonstrated that children and adolescents whose parents had no or lower educational background were more likely to be stunted. Educational attainment showed weak association with thinness. Ethnic decent on the other hand, was not significantly ($P > 0.05$) associated with either stunting or thinness. Stepwise logistic models were used to determine the most influential socio-demographic factors to stunting and thinness. Prediction equations were developed for predicting the odds of being stunted or thin.

Age- and sex-specific cut-off points of MUAC with good predictive potential to screen thinness and severe thinness among children and adolescents aged 5 – 19 years were generated. Receiver-operating characteristic curve analysis was used to determine the area under the curve along with 95% confidence interval to establish the optimal cut-off points of MUAC to identify stunting and thinness. The concordance between MUAC and BAZ in detecting stunting and thinness were determined using Cohen's Kappa analysis. Significant

association was observed between these two, indicating plausible hope that they could be complementary. Contrary to the use of cut-off point across age range, the use of year-wise and sex-wise specific MUAC cut-off points for screening thinness and severe thinness is preferable. The use of cut-offs generated from MUAC measured locally was also more reliable to that generated from children and adolescents elsewhere.

6.2 Conclusion

In conclusion, the prevalence of moderate and severe stunting in the overall sample population were 20.3% and 6.5%, respectively. The prevalence of moderate and severe thinness in the overall sample population were 32.6% and 14.2%, respectively. The prevalence of moderate and severe stunting among boys were 21.1% and 6.1%,respectively whereas among girls, the values were 18.0% and 5.9%. Similarly, the prevalence of moderate and severe thinness in boys are respectively 36.1% and 16.6% correspondingly. For girls, the corresponding values were 29.5% and 12.4% respectively. This study indicated that, relative to international reference values, height and BMI reference ranges of children and adolescents from the present study fall below the WHO (2007) centile references.

The new up-to-date reference percentile ranges for height, weight, BMI, MUAC, muscle area, arm fat area and skinfold thicknesses (biceps, triceps, sub-scapular and sub-iliac) for children and adolescents will provide a useful reference guide to future studies in other parts of Nigeria and sub-Saharan African countries. Smoothed z-scores have hitherto been available for height, weight, BMI, MUAC (and its derivatives) and skinfold thicknesses for Nigerian children and adolescents. The new z-scores corresponding to the percentile rankings of the anthropometric measurements can be calculated from the individual

anthropometric measure of interest and the values for the parameters L, M and S from the appropriate measurement, sex and age group. Thez-scores express the anthropometric measure in terms of SD units above or below the mean anthropometric measurement for that specific sex and age group. The age- and sex-standardized skinfold percentiles andz-scores may be appropriate for a wide range of research applicationsthat consider measures of subcutaneous fat.Since the reference centiles and parameters for calculating the z-scores were developed from data collected from representative sample of children and adolescents in Nigeria, they provide an essential new complementary assessment tool and reference excerpt both locally and to other sub-Saharan countries with similar cultural, ethnic and socio-demographic settings to Nigeria.

The MUAC has been used for many years as a handy alternative index of nutritional status, if the collection of height and weight measurements of children and adolescents were difficult or impossible. The new reference percentile ranges for MUAC, muscle area and arm fat area for children and adolescents may provide a useful nutritional-status assessment tool in a wide variety of settings. Further studies using tools such as ROC curve may be used to delineate cut-offs of MUAC for children and adolescents at elevated risk of near-term mortality in field settings, especially under emergency situations such as internally displaced persons (due to insurgency), banditry, famines or refugee crises. Parents' level of education was found to have nexus with nutritional status, whereas ethnicity has poor correlation with nutritional status.

6.3 Recommendations

Call to Action: Next Steps

i. The smoothed reference percentile curves (height, weight, BMI, skinfold thicknesses, MUAC and its derived measures;that is, UAFA and UAMA) provided in the present study are appropriate for application in Nigerian settings.
ii. There is need for routine nutritional evaluation, monitoring and assessment (NEMA) in Nasarawa and other States in Nigeria.
iii. There is need to expand the study to the entire Nasarawa State with a view to identifying the growth pattern and nutritional status of children and adolescents in the State.
iv. Future studies should investigate the growth patterns and nutritional status of children and adolescents in other parts of Nigeria.
v. There is the need to develop a national "growth standard" using longitudinal data or "growth reference" based on cross-sectional data at the national level.
vi. The underlying causes of undernutrition should be addressed to avoid humanitarian crises due to food insecurities.
vii. The smoothed reference percentile curves provided in the present study reveals the prevailing physical growth status of children and adolescents in Nigeria. They should by no means be regarded as the local growth standards for Nigerian children and adolescents since the sample subjects were not recruited based on optimal or controlled growth conditions.

REFERENCES

Abarca-Gomez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., Aguilar-Salinas, C., A.*et al*. (2017). Worldwide trends in body-mass index, underweight,overweight, and obesity from 1975 to 2016: a pooled analysis of2416 population-based measurement studies in 128·9million children,adolescents, and adults. *TheLancet*,390:2627–42.

Acham, H., Kikafunda, J. K., Oluka, S., Malde, M. K. and Tylleskar, T. (2008). Height,weight, body mass index and learning achievement in Kumi district,East of Uganda. *Scientific Research Essays*,3:001–8.

Adair, L. S. (2008). Child and adolescent obesity: epidemiology anddevelopmental perspectives. *Physiological Behaviour*, 94:8–16.

Addo, O. Y. and Himes, J. H. (2010). Reference curves for triceps andsub-scapular skinfold thicknesses in US children and adolescents.*American Journal of Clinical Nutrition*, 91(3):635–642.

Addo, O. Y., Himes, J. H. and Zemel, B. S. (2017). Reference ranges for midupper armcircumference, upper arm muscle area, and upper arm fat area in USchildren and adolescents aged 1-20 y. *American Journal of Clinical Nutrition*105:111–20.

Addo, O. Y., Stein, A. D., Fall, C. H., Gigante, D. P, Guntupalli, A. M., Horta, B. L.,Kuzawa, C. W., Lee, N., Norris, S. A., Prabhakaran, P.*et al*. (2013). Maternal heightand child growth patterns. *Journal of Paediatrics*163:549–54.e1.

Agarwal, D. K. and Agarwal, K. N. (1994). Physical growth in Indian affluentchildren (birth-6 years). *Indian Paediatrics*31:377–413.

Ahmed, S. M., Adams, A., Chowdhury, A. M.*et al*. (1998). Chronicenergy deficiency in women from rural Bangladesh: somesocio-economic determinants. *Journal of Biosocial Sciences*, 30, 349–358.

Akseer, N., Al-Gashm, S., Mehta, S., Mokdad, A. and Bhutta, Z. A. (2017). Global andregional trends in the nutritional status of young people: a critical andneglected age group. *Annals of New York Academic Sciences*, 1393:3–20.

Alderman, H. (2000). "Anthropometry." In *Designing Household Survey Questionnaires for Developing Countries: Lessons from 15 Years of the Living Standards Measurement Study*, ed. M. Grosh and P. Glewwe. *Washington, DC*: World Bank.

Allard, J. P., Aghdassi, E. and McArthur, M. (2004). Nutrition riskfactors for survival in the elderly living in Canadian long-termcare facilities. *Journal of American Geriatric Society*, 52, 59–65.

American Academy of Paediatrics, Committee on Nutrition, Kleinman, R., E. Paediatric nutrition: policy of the American Academy of Paediatrics.7th ed. Elk Grove Village (IL): *American Academy of Paediatrics,* 2014.

Amoo-Tella, S. Y., Danborno, B., Akuyam, S. A. and Adebisi, S. S. (2017). Gender-and age-related differences in anthropometric and body composition parameters in nigerians, Zaria, Nigeria. *Journal of Experimental and Clinical Anatomy* 16: 137 – 146.

Andaki, A. C. R., Quadros, T. and Gordia, A. P. (2017). Skinfold references curves and their use in predicting metabolic syndrome risk in children. *Journal de paediatra* 93 (5):490 – 496.

Anzo, M., Takahashi, T., Sato, S.*et al*. (2002). The cross-sectional headcircumference growth curves for Japanese from birth to 18 years ofage: the 1990 and 1992–1994 national survey data. *Annals of Human Biology*,29:373–88.

Araújo, A., J., S. Santos, A., C., O. and Prado, W. L. (2017). Body composition of obese adolescents: association between adiposity indicators and cardiometabolic risk factors. *Journal of Human Nutrition and Dietetics,* 30:193–202.

Atawodi, S. E., Aliyu, B. Abbas, O. and Ilouno, L. E. (2015). Nutritional Status of Primary School Children inKawo District of Kaduna Metropolis, Nigeria.*Annual Research and Review in Biology,* 5(1): 64-70.

Augustin,B. R., Roelants, M., Thomis,M. and Nkiama,E. C. (2017). Nutritional status and height, weight and BMI centiles of school-aged childrenand adolescents of 6–18-years from Kinshasa (DRC). *Annals of Human Biology*, 44(6):554−561.

Aune, D., Sen, A. and Prasad, M. (2016). BMI and all cause mortality:systematic review and non-linear dose–responsemeta-analysis of 230 cohort studies with 3.74 million deathsamong 30.3 million participants. *British Medical Journal*, 353, i2156.

Azcorra, H., Varela-Silva, M. I., Rodriguez, L., Bogin, B.and Dickinson, F. (2013). Nutritional status of Maya children, their mothers, andtheir grandmothers residing in the city of Merida, Mexico:revisiting the leg-length hypothesis. *American Journal of Human Biology*, 25:659–665.

Baer, M. T.and Harris, A. B. (1997). Paediatric nutrition assessment: identifying childrenat risk. *Journal of American Dietetic Association,* 97(10):S107-S115.

Bahwere, P. *et al*. (2011). "Impact of Household Food Insecurity on the Nutritional Status and the Response to Therapeutic Feeding of People Living with Human Immunodeficiency Virus." *Patient Preference and Adherence*. 5:619–27.

Baker, J., Hurtado, A. M., Pearson, O. M., Hill, K. R., Jones, T.and Frey, M. A. (2009). Developmental plasticity in fat patterning of Ache childrenin response to variation in interbirth intervals: a preliminarytest of the roles of external environment and maternalreproductive strategies. *American Journal of Human Biology*, 21:77–83.

Barba, C., Cavalli-Sforza, T., Cutter, J., Darnton-Hill, I., Deurenberg, P., Deurenberg-Yap, M., *et al*. (2004). Appropriate body-mass index for Asian populations and itsimplications for policy and intervention strategies. *Lancet,* 363:157–63.

Barker, D., Eriksson, J., Forsen, T. and Osmond C. (2002). Foetal originsof adult disease: strength of effects and biological basis. *International Journal of Epidemiology,* 31:1235–1239.

Becker, P. J, Nieman,C. L, Corkins, M. R., Monczka, J., Smith, E., Smith, S. E., Spear, B. A. and White, J. V. (2014). Consensus statement of the Academy ofNutrition and Dietetics/American Society for Parenteral and EnteralNutrition: indicators recommended for the identification and documentationof Paediatric malnutrition (undernutrition). *Journal of Academic Nutrition and Dietetics,* 114:1988–2000.

Bedogni, G., Lughetti, L., Ferrari, M.*et al*. (2003). Sensitivity and specificity ofbody mass index and skinfold thicknesses in detecting excess adiposityin children aged 8-12 years. *Annals of Human Biology*,30:132–9.

Bellisari, A. and Roche, A. F. (2005). Anthropometry and ultrasound. In: Heymsfield, S.,Lohman, T., ZiMian, W. and Going, S. eds. Human body composition. 2nd ed.Champaign, Illinois:*Human Kinetics*,109–27.

Benedict, R. K., Schmale, A. and Namaste, S. (2021). AdolescentNutrition 2000–2017:DHS Data on Adolescents Age 15–19 [Internet]. *Rockville, Maryland*: ICF;2021.

Bénéfice, E. (1992a). Growth and motor performance of healthy SenegalesePreschool children. *American Journal of Human Biology,* 4:717–728.

Bénéfice, E. (1993). Physical activity, cardiorespiratory fitness, motor performanceand growth of Senegalese pre-adolescents. *American Journal of Human Biology,* 5:653–667.

Bénéfice, E.and Malina, R. M. (1996). Body size, body composition and motorperformance of mild-to-moderately undernourished Senegalese children. *Annals of Human Biology* 23:307–321.

Bénéfice, E., Cames, C.and Simondon, K. (1999). Growth and maturation ofSeerer adolescent girls (Senegal) in relation to seasonal migration forlabor. *American Journal of Human Biology,* 11:539–550.

Benítez,B. N., Suárez,L. J. P., Fuentes,F. M.*et al.*(2016). Relationship between mid-upper arm circumferenceand body mass index in inpatients. *Public Library of Science One,* 11: e0160480.

Berkley, J., Mwangi, I., Griffiths, K., Ahmed, I., Mithwani, S., English, M., Newton, C. and Maitland, K.(2005). Assessment of severe malnutrition among hospitalized children in rural Kenya: comparison of weight-for-height and mid-upper arm circumference. *Journal of American Medical Association,* 294(5):591–597.

Bielicki, T. and Waliszko, H. (1991). Urbanization-dependentgradients in stature among polish conscripts in1976 and 1986. *American Journal of Human Biology,3*, 419-424.

Black, R. E., Victora, C. G.,Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M.,Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R.*et al*. (2013). Maternaland child undernutrition and overweight in low-income and middle-incomecountries. *Lancet*, 382:427–451.

Bogin, B. (1999). Patterns of human growth. New York: *CambridgeUniversity Press*.

Bogin, B. and Beydoun, N. (2007). The relationship of sitting height ratio to bodymass index and fatness in theUnited States, 1988–1994.*Human Ecology Special issue,*15:1–8.

Bogin, B., Silva, M. I. V.and Rios, L. (2007). Life history trade-offs inhuman growth: adaptation or pathology? *American Journal of Human Biology*, 19:631–642.

Borghi, E., de Onis, M., Garza C., Van den Broeck, J., Frongillo, E. A., Grummer-Strawn, L. *et al*. (2006). Construction of the World Health Organization Child Growth Standards: selection of methods for attained growth curves. *Statistics in Medicine*, 25:247–265.

Bose, K. (1996). Generalised obesity and regional adiposity inadult white and migrant Muslim males from Pakistan inPeterborough. *Journal of Research in Social and Health Promotion*, 116:161–167.

Bose, K. (2001). The interaction of waist–hip ratio and conicityindex with subcutaneous adiposity in two ethnicgroups: native British and migrant Pakistani men. *AnthropologischerAnzeiger*, 59:275–282.

Bose, K., Bisai, S., Das, P.*et al*. (2007). Relationship of income withanthropometric indicators of chronic energy deficiency amongadult female slum dwellers of Midnapore town. *Journal of Human Ecology*, 22:171–176.

Bose, K., Chakraborty, F., Mitra, K.*et al*. (2006). Nutritionalstatus of adult Santal men in Keonjhar District, Orissa, India.*Food and Nutritional Bulletin*, 27, 353–356.

Braegger, C., Jenni, O., Konrad, D, *et al*. (2011). Neue Wachstumskurven fürdie Schweiz. *Schweizerische Ärztezeitung*, 92:229–31.

Brambilla, P., Bedogni, G.,Heo, M. and Pietrobelli, A. (2013). Waist circumference-to-heightratio predicts adiposity better than body mass index in childrenand adolescents. *International Journal of Obesity*, 37:943–6.

Briend, A. and Zimicki S. (1986). Validation of arm circumference as an indicatorof risk of death in one to 4-year-old children. *Nutrition Research*,6:249–61.

Briend, A., Garenne, M. and Maire, B.*et al*. (1989). Nutritional status,age and survival: the muscle mass hypothesis. *European Journal of Clinical Nutrition*, 43:715–726.

Briend, A., Maire, B., Fontaine, O. and Garenne, M. (2012). Mid-upper arm circumferenceand weight-for-height to identify high-risk malnourished under-fivechildren. *Maternal and Child Nutrition,*8:130–3.

Briend, A., Maire, B., Fontaine, O. and Garenne, M. (2012). Mid–upper arm circumferenceand weight-for-height to identify high-risk malnourished under-fivechildren. *Maternal and Child Nutrition,* 8(1):130 −133.

Briend, A., Wojtyniak, B. and Rowland, M. G. M. (1987). Arm circumference and otherfactors in children at high-risk of death in rural Bangladesh. *Lancet,*2:725–8.

Briend, A., Wojtyniak, B. and Rowland, M. M. (1987). Arm circumference and other factors in children at high risk of death in rural Bangladesh. *The Lancet,* 330 (8561):725 – 728.

Bundy, D. A. P., de Silva, N., Horton, S., Jamison, D. T. and Patton, G. C.(2017). Disease Control Priorities, 3rd ed.,Vol. 8: Child andAdolescentHealthand Development.*Washington (DC)*:World Bank.

Bustamante, A., Freitas, D., Pan, H., Katzmarzyk, P. T. and Maia, J. (2015). Centile curvesand reference values for height, bodymass, body mass index and waistcircumference of Peruvian children and adolescents. *International Journal of Environmental Resources and Public Health*, 12:2905–22.

Bustos, P., Amigo, H., Muñoz, S. R. and Martorell, R. (2001). Growth in indigenous and nonindigenous Chileanschool children from 3 poverty strata. *Amercian Journalof Public Health,* 91:1645−1649.

Butte, N. F., Garza, C. and de Onis, M. (2007). Evaluation of the feasibilityof international growth standards for school-aged children andadolescents. *Journal of Nutrition*, 137:153–7.

Calcaterra, V., Klersy, C., Muratori, T., Telli, S., Caramagna, C., Scaglia, F., Cisternino, M. and Larizza, D. (2008). Prevalence of metabolic syndrome (MS)in children and adolescents with varying degrees of obesity. *Clinical Endocrinology (Oxford),*68:868–72.

Caleyachetty, R., Thomas, G. N., Kengne, A. P., Echouffo-Tcheugui, J. B.,Schilsky, S., Khodabocus, J. and Uauy, R. (2018). The double burden of malnutritionamong adolescents: analysis of data from the Global School-BasedStudent Health and Health Behavior in School-Aged Childrensurveys in 57 low- and middle-income countries. *American Journal of Clinical Nutrition,*108:414–24.

Cameron, N. (1991). Human growth, nutrition and health status in sub-Saharan Africa. *Year book of Physical Anthropology,* 34:211–250.

Cameron, N. (2007). Growth patterns in adverse environments. *American Journal of Human Biology,* 19 (5): 615 – 621.

Cameron, N., Gordon-Larsen, P.and Wrchota, E. M. (1994). Longitudinal analysis ofadolescent growth in height, fatness, and fat patterning in rural SouthAfrican black children. *American Journal of Physical Anthropology,* 93:307–321.

Cameron, N., Kgamphe, J. S., Leschner, K. F., and Farrant, P. J. (1992). Urban-rural differencesin the growth of South African black children. *Annals of Human Biology* 19:23–33.

Cameron, N., Wright, M. M., Griffiths, P. L., Norris, S. A. and Pettifor, J. M. (2005). Stunting at 2 years in relation to body composition at 9years in African urban children. *ObesityResearch,* 13:131–136.

Cameron, W.M. (1986). Standards for human growth: Theirconstruction and use. *South African Medical Journal,*70:422−425.

Campbell, P. and Ulijaszek, S. J. (1994). Relationships betweenanthropometry and retrospective morbidity in poor men inCalcutta, India. *European Journal of Clinical Nutrition*, 48:507–512.

Centers For Disease Control and Prevention. CDC growth charts [Online]. 2000. http://www.cdc.gov/growthcharts/Default.htm. [Accessed 31 January, 2021].

Chakraborty, R., Bose, K. and Bisai, S. (2009). Use of mid-upper armcircumference as a measure of nutritional status and its relationshipwith self reported morbidity among adult Bengaleemale slum dwellers of Kolkata, India. In Appetite and NutritionalAssessment, pp. 377–385 [SJ Ellsworth and RC Schuster,editors]. New York: *NOVA Science Publishers*, Inc.

Chakraborty, R., Bose, K. and Koziel, S. (2011). Use of mid-upperarm circumference in determining undernutrition and illness inrural adult Oraon men of Gumla District, Jharkhand, India.*Rural Remote Health*, 11:1754.

Chatterjee, S. and Hadi, A. S. (2006). Regression Analysis byExample, 4th edn. *John Wiley, New York.*

Christian, P. and Smith, E. R. (2018). Adolescent undernutrition: global burden,physiology, and nutritional risks. *Annalsof Nutrition and Metabolism*, 72:316–28.

Clausen, T., Charlton, K. E. and Holmboe-Ottesen, G. (1996).Nutritional status, tobacco use and alcohol consumption ofolder persons in Botswana. *Journal of Nutrition and Health Aging*, 10:104–110.

Cnattingius, S. and Villamor, E. (2016). Weight change between successivepregnancies and risks of stillbirth and infant mortality: a nationwidecohort study. *Lancet,* 387:558–65.

Cole, T. J.(1986). Weight/height^{p}compared to weight/height^{2} for assessingadiposity in childhood: influence of age and bone age on *p* duringpuberty. *Annals of Human Biology*,13:433–51.

Cole, T. J. (1990). The LMS method for constructing normalizedgrowth standards. *European Journal of Clinical Nutrition*, 44(1):45–60.

Cole, T. J.(1991). Weight-stature indices to measure underweight, overweight,and obesity. In: Himes JH, editor. Anthropometric Assessment ofNutritional Status. *New York:Wiley-Liss*; p. 83–111.

Cole, T. J. and Green, P. J. (1992). Smoothing reference centile curves: theLMS method and penalized likelihood. *Statistics in Medicine*, 11:1305–1319.

Cole, T. J. and Lobstein, T. (2012). Extended international (IOTF) body mass indexcut-offs for thinness, overweight and obesity. *Paediatrics Obesity*, 7:284−94.

Collins, S. (1996). Using middle upper arm circumference toassess severe adult malnutrition during famine. *Journal of American Medical Association*, 276:391–395.

Copil, A., Yeste, D., Maciá J., Texidó, R., Maciá, J., Santana, S., Almar, J., Tokashiki, N., Abellán, C. and Cararascosa, A. (2006). Patrones antropométricos de losrecién nacidos a término de grupos étnicos de raza no caucásicaprocedentes de África sub-Sahariana, Marruecos y Sudamérica nacidos en Cataluña. *Anales de Pediatría*, 65 (5):454 – 460.

Cronk, C. E. and Roche, A. F. (1982) Race- and sex-specific reference datafor triceps and subscapular skinfolds and weight/stature. *American Journal of Clinical Nutrition*, 35(2):347–354.

Crookston, B., T., Forste, R., McClellan, C., Georgiadis, A. and Heaton, T. B. (2014). Factors associated with cognitive achievement in late childhood andadolescence: the Young Lives cohort study of children in Ethiopia,India, Peru, and Vietnam. *BioMed Central Paediatrics*, 14:253.

Daniel, W. W. (1999). Biostatistics: A Foundation for Analysis in the Health Sciences. 7th edition. *New York: John Wiley and Sons*.

Daniels, S. R. (2009). Complications of obesity in children and adolescents. *International Journal of Obesity*, 33 Suppl 1:S60–S65.

Daniels, S. R., Khoury, P. R. and Morrison, J. A. (1997). The utility of body mass indexas a measure of body fatness in children and adolescents: differencesby race and gender. *Paediatrics*, 99:804–7.

Das, J. K., Salam, R. A., Thornburg, K. L., Prentice, A. M., Campisi, S., Lassi, Z. S., Koletzko, B. and Bhutta, Z. A. (2017). Nutrition in adolescents: physiology,metabolism, and nutritional needs. *Annals of New York Academicof Science*, 1393:21–33.

Daymont, C., Hwang, W. T., Feudtner, C.*et al*. (2010). Head-circumferencedistribution in a large primary care network differs from CDC andWHO curves. *Paediatrics*, 126:e836–42.

de Onis, M. (2007). Development of aWHO growth reference for school-agedchildren and adolescents. *Bulletin of World Health Organization*, 85:660−7.

de Onis, M. (2007). WHO Multicentre Growth Reference Study Group.Assessment of differences in linear growth among populationsin the WHO Multicentre Growth Reference Study. *ActaPaediatrics*, 95:56–65.

de Onis, M. (2017). Child growth and development. In: de Pee S, Taren D. and Bloem, M., W.(editors). Nutrition and Health in a Developing World.Cham: *Springer International Publishing*; 2017. p. 119–41.

de Onis, M. and Habicht, J. P. (1996). Anthropometric reference data for international use:recommendations from a World Health OrganizationExpert Committee. *American Journal of Clinical Nutrition*, 64:650 – 8.

de Onis, M. and Onyango, A. W. (2003). The Centers for Disease Control and Prevention 2000 growth charts and the growth ofbreastfed infants. *Acta Paediatrics*, 92:413–9.

de Onis, M. and Yip, R. (1996). The WHO growth chart: historical considerationsand current scientific issues. In: Porrini, M. and Walter, P. (editors). Nutrition inpregnancy and growth. *Bibl Nutr Dieta*, 53:74−89.

de Onis, M., Blössner, M., Borghi, E. (2012). Prevalence and trendsof stunting among pre-school children 1990–2020. *PublicHealth Nutrition*, 15:142–148.

de Onis, M., Dasgupta, P., Saha, S., Sengupta, D. and Blossner, M. (2001). TheNational Center for Health Statistics reference and the growth ofIndian adolescent boys. *American Journal of Clinical Nutrition*,74:248–53.

de Onis, M.,Garza, C. and Habicht, J. P. (1997). Time for a new growth reference.*Paediatrics*, 100: E8.

de Onis, M.,Garza, C.,Victora, C. G.,Onyango, A. W., Frongillo, E. A. and Martines, J. (2004). The WHO multicentre growth reference study: planning, studydesign, and methodology. *Food and Nutrition Bulletin*, 25:S15–26.

de Onis, M. Wijnhoven, T., M., A. and Onyango, A. W. (2004). Worldwide practices in child growth monitoring. *Journal of Paediatrics*. 144:461–5.

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C. and Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of World Health Organization,* 85: 660–67.

de Onis, M., Onyango, A., Borghi, E., Siyam, A., Blössner, M. and Lutter, C. (2012). Worldwide implementation of the WHO Child Growth Standards. *Public Health Nutrition,*15:1603–10.

de Onis, M., Siyam, A., Borghi, E., Onyango, A. W., Piwoz, E. and Garza, C. (2011). Comparison of the World Health Organization growth velocity standards with existing US reference data. *Paediatrics*, 128:e18−26.

de Wilde, J. A., van Dommelen, P., van Buuren, S. and Middelkoop, B. J. (2015). Height of South Asian children in the Netherlands aged 0-20 years: secular trends and comparisons with current Asian Indian, Dutch and WHO references. *Annals of Human Biology*,42: 38–44.

Delpeuch, F., Cornu, A., Massamba, J. P.*et al*. (1994). Is bodymass index sensitivity related to socio-economic status andto economic adjustment? A case study from the Congo. *European Journal of Clinical Nutrition*, 48: Suppl. (3): S141–S147.

Demerath, E. W., Schubert, C. M, Maynard, L. M., Sun, S. S., Chumlea, W. C.,Pickoff, A., Czerwinski, S. A., Towne, B., Siervogel, R. M. (2006). Do changes in bodymass index percentile reflect changes in body composition in children?Data from the Fels longitudinal study. *Paediatrics*, 117: e487.

Dercon, S. and Sanchez, A. (2013). Height in mid childhood and psychosocialcompetencies in late childhood: evidence from four developingcountries. *Economics of Human Biology*, 11:426–32.

Deurenberg, P, Deurenberg,Y. M., Wang, J., Lin, F. and Schmidt, G. (1999). Theimpact of body build on the relationship between bodymass index andpercent body fat. *International Journal of Obesity*,23:537–42.

Deurenberg, P., Deurenberg-Yap, M. and Guricci, S. (2002).Asians are different from Caucasians and from each other intheir body mass index/body fat per cent relationship. *Obesity Review*, 3:141–146.

Deurenberg, P., Yap, M. and van Staveren, W., A. (1998). Bodymass index and percent body fat: a meta analysis amongdifferent ethnic groups. *International Journal of Obesity and Related Metabolic Disorders*, 22:1164–1171.

Di Angelantonio, E., Bhupathiraju, S. H. N., Wormser, D.*et al*. (2016). Global BMI Mortality Collaboration. Body-mass indexand all-cause mortality: individual-participant-data metaanalysisof 239 prospective studies in four continents.*Lancet*, 388:776–786.

Dibley, M. J., Staehling, N. W., Nieburg, P. and Trowbridge, F. L. (1987). Interpretation ofZ-score anthropometric indicators derived from the international growthreference. *American Journal of Clinical Nutrition*,46:749−762.

Dissanayake, D. S., Kumarasiri, P. V., R., Nugegoda, D. B. and Dissanayake, D. M. (2009). The association of iron status with educational performance andintelligence among adolescents. *Ceylon Medical Journal*, 54:75–9.

Dorlencourt, F., Priem, V. and Legros, D. (2000). Anthropometricindices used for the diagnosis of malnutrition in adolescentsand adults: review of the literature. *Bulletin of Social Pathology and Exot*, 93:321–324.

dos Santos, F. K., Maia, J. A. R., Gomes, T. N. Q. F., Daca, T., Madeira, A.,Katzmarzyk, P. T., *et al*. 2014. Secular trends in growth and nutritionalstatus of Mozambican school-aged children and adolescents. *Public Library of SciencesOne* 9:e114068.

Emergency Nutrition Network (2012). Mid-upper arm circumference and weight-for-height z-score as indicators of severe acute malnutrition: A consultation of operational agencies and academic specialists to understand the evidence, identify knowledge gaps and to inform operational guidance. Final review paper. ENN, SCUK, ACF, UNHCR

Eveleth, P. and Tanner, J., M. (1990). Worldwide Variation in Human Growth. 2nded. *Cambridge:Cambridge University Press*.

Fakier, A., Petro, G. and Fawcus, S. (2017). Mid-upper arm circumference:a surrogate for body mass index in pregnant women.*South African Medical Journal*, 107:606–610.

Fernald, L., C. and Neufeld, L., M. (2007). Overweight with concurrentstunting in very young children from rural Mexico: prevalenceand associated factors. *European Journal of Clinical Nutrition*, 61:623–632.

Fernandez, M. A., Delchevalerie, P. and Van, H. M. (2010). Accuracy of MUAC in the detection of severe wasting with the new WHO growth standards. *Paediatrics*, 126(1):e195–e201.

Ferro-Luzzi, A., Sette, S., Franklin, M.*et al*. (1992). A simplifiedapproach of assessing adult chronic energy deficiency. *European Journal of Clinical Nutrition*, 46:173–186.

Fichna, P. and Skowrońska, B. (2008). Obesity and metabolic syndromein children and youth. *Family Medicineand Primary Care Review*, 2:269–278.

Fink, G. and Rockers, P., C. (2014). Childhood growth, schooling, and cognitivedevelopment: further evidence from the Young Lives study. *American Journal of Clinical Nutrition*,100:182–8.

Fiorentino, M., Sophonneary, P., Laillou, A., Whitney, S., de Groot, R.,Perignon, M., Kuong, K., Berger, J., and Wieringa, F. T. (2016). Current MUAC cut-offsto screen for acute malnutrition need to be adapted to gender and age:tee example of Cambodia. *Public Library of Science One*, 11:e0146442.

Fleiss, J. L. (1986). The design and analysis of clinical experiments. *New York:John Wiley*. 236.

Forthun, I., Wilcox, A. J., Strandberg-Larsen, K., Moster, D., Nohr, E. A., Lie, R. T., Suren, P., Tollanes, M. C. (2016). Maternal pre-pregnancy BMI and risk ofcerebral palsy in offspring. *Paediatrics*, 138: e20160874.

Fredriks, A. M., van Buuren, S., Burgmeijer, R., J, *et al*. (2000). Continuingpositive secular growth change in the Netherlands 1955–1997.*Paediatrics Research*, 47:316–23.

Freedman, D. S., Dietz, W. H., Srinivasan, S. R. and Berenson, G. S. (2009). Risk factors andadult body mass index among overweight children: the Bogalusa HeartStudy. *Paediatrics*, 123:750–7.

Freedman, D. S., Serdula, M. K., Srinivasan, S. R. and Berenson, G. S. (1999). Relation of circumferences and skinfold thicknesses to lipid andinsulin concentrations in children and adolescents: the Bogalusa Heart Study. *American Journal of Clinical Nutrition*, 69:308 – 317.

Freedman, D. S., Wang, J., Maynard, L. M., Thornton, J. C., Mei, Z., Pierson, R. N., Jr., Dietz, W. H. and Horlick, M. (2004). Relation of BMI to fat and fat-free massamong children and adolescents. *International Journal of Obesity*, 29:1–8.

Frisancho, A. R. (1981). New norms of upper limb fat and muscle areas for assessmentof nutritional status. *American Journal of Clinical Nutrition*,34:2540−2545.

Frisancho, A. R. (2003). Reduced rate of fat oxidation: a metabolicpathway to obesity in the developing nations. *American Journal of Human Biology*,15:522–532.

Frisancho, R. A. (1990). Anthropometric Standards for the assessment of growth and nutritional status. Ann Arbor: *University of Michigan Press*. 691 p.

Frisanho, A. R. (2008). Anthropometric standards: an interactive nutritional reference of body size and body composition for children and adults. *University of Michigan Press.*

GAIN/WHO. Commitments on Adolescent Nutrition [Internet].Geneva: GAIN/WHO; (2018). Available from: https://www.gainhealth.org/wp-content/uploads/2018/05/Commitments-on-Adolescent-Nutrition.pdf.

Gallagher, D., Visser, M., Sepulveda, D., Pierson, R., N., Harris, T. and Heymsfield, S., B. (1996). How useful is body mass index for comparison of body fatness across age,sex, and ethnic groups? *American Journal of Epidemiology*, 143:228–39.

Garcia, M. and Mason, J. (1992). Second Report on the World Nutrition Situation – Volume I: Global and Regional Results. A Report Compiledfrom Information Available to the United Nations Agencies of theACC/SCN. Geneva:WHO.

Garn, S. (1991). Implications and applications of subcutaneous fat measurementto nutritional assessment and health risk evaluation. In: HimesJH, ed. Anthropometric assessment of nutritional status. *New York: Wiley-Liss*,123–50.

Garza, C. and de Onis, M. (2004). Rationale for developing a new internationalgrowth reference. *Food and Nutrition Bulletin*, 25:S5–14.

Gayle, H. D., Binkin, J. N., Staehling, W. N. and Trowbridge, L. F.(1988). Arm circumference versus weight-for-heightin nutritional assessment: are the findings comparable? *Journal of TropicalPaediatrics*, 34: 213−217.

Georgiadis, A. and Penny, M. E. (2017). Child undernutrition: opportunities beyondthe first 1000 days. *Lancet Public Health*, 2:e399.

Gibson, R. S. (2005). Principles of Nutritional Assessment, 2nded. Oxford: *Oxford University Press*.

Gokcay, G., Furman, A. and Neyzi, O. (2008). Updated growth curves for Turkishchildren aged 15 days to 60 months. *Child Care and Health Development*, 34:454–63.

Goldstein, H. and Tanner, J. M. (1980). Ecological considerations in the creation and the use of child growth standards. *Lancet* 1:582–585.

Gomez, F., Galvan, R. R., Cravioto, J. and Frenk, S. (1955). Malnutrition in infancyand childhood, with special reference to kwashiorkor. *Advancements in Paediatrics,*7:131−169.

Gomez, F., Galvin, R. R., Frenk, S., Cravioto, M. J., Chavez, R. and Vazquez, J. (1956). Mortality in second- and third-degree malnutrition. *Journal of Tropical Paediatrics,* 2:77−83.

Goodpaster, B. H. (2002). Measuring body fat distribution and contentin humans. *Current Opinionin Clinical Nutrition and MetabolicCare,* 5(5):481–487.

Grellety, E. and Golden, M. H. (2016). Weight-for-height and mid-upper-arm circumferenceshould be used independently to diagnose acute malnutrition: policyimplications. *BioMed Central Nutrition*,2:10.

Grellety, E., Krause, L. K., Shams, E. M., Porten, K. and Isanaka, S. (2015). Comparison ofweight-for-height and mid-upper arm circumference (MUAC) in atherapeutic feeding programme in South Sudan: is MUAC alone a sufficientcriterion for admission of children at high risk of mortality? *Public HealthNutrition*,18(14):2575–2581.

Griffiths, P. L. and Bentley, M. E. (2001). The nutrition transition isunderway in India. *Journal of Nutrition*, 131, 2692–2700.

Grummer-Strawn, L. M., Reinold, C. and Krebs, N. F. (2010). Use of World HealthOrganization and CDC growth charts for children aged 0–59months in the United States. *Morbidity and Mortality Weekly Report*, 55:1–15.

Guh, D. P., Zhang, W., Bansback, N., Amarsi, Z., Birmingham, C. L. and Anis, A. H. (2009). The incidence of co-morbidities related to obesity and overweight: asystematic review and meta-analysis. *BioMed Central Public Health*, 9:88.

Guo, S., Chumlea, W., Roche, A. and Siervogel, R. (1997). Age- andmaturity-relatedchanges in body composition during adolescence into adulthood: theFels Longitudinal Study. *International Journal of Obesity*, 21:1167–75.

Gurka, M. J., Kuperminc, M. N., Busby, M. G.*et al*. (2010). Assessment and correction of skinfoldthickness equations in estimating body fatin children with cerebral palsy. *Developmental Medicine and Child Neurology*,52:e35−e41.

Gustafson, P., Gomes, V. F. and Vieira, C. S. (2007). Clinical predictorsfor death in HIV-positive and HIV-negative tuberculosispatients in Guinea-Bissau. *Infection* 35, 69–80.

Haas, J. D. and Campirano, F. (2006). Interpopulation variation in height amongchildren 7 to 18 years of age. *Food and Nutrition Bulletin*, 27: S212–23.

Habicht, I. P, Martorell, R., Yarbrough, C., Malina, R. M. and Klein, R. E. (1974). Heightand weight standards for preschool children: how relevant are ethnicdifferences in growth potential? *Lancet*, 1(7858), 1:611− 614.

Hauspie, R. (1998*).* The genetics of child growth. In:Ulijaszek, S., J., Johnston, F., E. and Preece, M., A. (Eds.). TheCambridge Encyclopedia of Human Growth and Development(pp. 124-128). *Cambridge, UK: University Press*.

Hauspie, R., Das, S., R., Prece, M., A. and Tanner, J., M.(1982). Degree of resemblance of the pattern ofgrowth among sibs in families of West Bengal (India).*Annals of Human Biology*, 9(2): 171−74.

Healey, M. J. R., Rasbash, J. and Yang, M. (1988). Distribution-free estimation of age-related centiles. *Annals of Human Biology*, 15:17–22.

Henneberg, M., and Louw, G. J. (1998). Cross-sectional of growth of urban andrural Cape coloured school children : anthropometry and functionaltests. *American Journal of Human Biology* 10:73–85.

Heude, B., Scherdel, P., Werner, A., Le Guern, M., Gelbert, N., Walther, D., Arnould, M., Bellaïche, M., Chevallier, B., Cheymol, J., Jobez, E., N'Guyen, S., Pietrement, C., Reynaud, R., Salaün, J-F. *et al*., (2019). A big-data approach to producing descriptive anthropometric references: a feasibility and validation study of paediatric growth charts. *Lancet Digital Health*, 1: e413–23.

Heymsfield, S. B., Peterson, C. M., Thomas, D. M., Heo, M. and Schuna, J. M. (2015). Whyare there race/ethnic differences in adult body mass index–adiposityrelationships? A quantitative critical review. *Obesity Review*, 17:262–75.

Heyward, V. H, and Wagner, D. R. (2004).Applied BodyComposition. 2nd ed. *Champaign, IL:Human Kinetics*;49−66.

Himes, J., H. (1980). Subcutaneous fat thickness as an indicator of nutritionalstatus. In: Green LS, Johnston FE, eds. Social and biological predictorsof nutritional status, physical growth, and neural development. *NewYork, NY: Academic Press, Inc*,9–32.

Hjelmborg J, *et al*. (2006). Genetic influence on human lifespan and longevity. Human Genetics.119(3):312–21.

Hoffman, D. J., Sawaya, A. L., Coward, W. A., Wright, A., Martins, P. A.,de Nascimento, C., Tucker, K. L. and Roberts, S. B. (2000a). Energyexpenditure of stunted and non-stunted boys and girls livingin the shantytowns of Sao Paulo, Brazil. *American Journal of Clinical Nutrition*, 72:1025–1031.

Hoffman, D. J., Sawaya, A. L., Verreschi, I., Tucker, K. L. and Roberts, S. B. (2000b). Why are nutritionally stunted children at increasedrisk of obesity? Studies of metabolic rate and fat oxidation inshantytown children from Sao Paulo, Brazil. *American Journal of Clinical Nutrition*,72:702–707.

Hoffman,D., Cacciola, T., Barrios,P. and Simon, J. (2017). Temporal changes and determinants ofchildhood nutritional status in Kenya andZambia.*Journal of Health, Population and Nutrition*, 36:27.

Horlick, M. (2001). Body mass index in childhood-measuring a movingtarget. *Journal of Clinical Endocrinology and Metabolism*, 86:4059–60.

Isanaka, S., Guesdon, B., Labar, A. S., Hanson, K., Langendorf, C. and Grais, R. F. (2015). Comparison of clinical characteristics and treatment outcomes ofchildren selected for treatment of severe acute malnutrition using midupper arm circumference and/or weight-for-height Z-score. *Public Libraryof Science One*10(9):e0137606.

Izuora, A. N., Animasahun, B. A., Nwodo, U., Ibeabuchi N. M., Njokanma O. F. and Renner, J. K. (2008). Assessment of overweight and obesity among Nigerian children and adolescents using triceps skin-fold thickness and body mass index. *Clinical Obesity*. 3 (3 −4):103 – 111.

Jackson, A. S., Stanforth, P. R., Gagnon, J., Rankinen, T., Leon, A. S., Rao, D. C., Skinner,J. S., Bouchard, C. and Wilmore, J. H. (2002). The effect of sex, age and race on estimatingpercentage body fat from body mass index: The Heritage Family Study.*International Journal of Obesity Related Metabolic Disorders*,26:789–796.

James, W. P. T., Ferro-Luzzi, A. and Waterlow, J. C. (1988). Definitionof chronic energy deficiency in adults. Report of a WorkingParty of the International Dietary Energy Consultative Group.*European Journal of Clinical Nutrition*, 42:969–981.

James, W. P., Mascie-Taylor, G. C., Norgan, N. G.*et al*. (1994). Thevalue of arm circumference measurements in assessingchronic energy deficiency in Third World adults. *European Journal of Clinical Nutrition*, 48:883–894.

Jamison, P. L. and Ward R. E. (1993). Brief communication: measurement size, precision and reliability in craniofacial anthropometry: bigger is better. *American Journal of Physical Anthropology*. 90:495−500.

Jaworski,M., Kułaga,Z., Płudowski,P., Grajda,A., Gurzkowska,B., Napieralska,E., Świąder,A., Pan,H., Litwin,M.*et al.*, (2012). Population-based centile curves for triceps, subscapular,and abdominal skinfold thicknesses in Polish childrenand adolescents – theOLAF study. *European Journal of Pediatrics*, 171:1215 – 1221.

Jehn, M., L., Gittelsohn, J., Treuth, M., S. and Caballero, B. (2006). Prevalence of overweightamong Baltimore city school children and its associations withnutrition and physical activity. *Obesity (Silver Spring)*, 14:989–93.

Jelliffe, D. B. (1966). The assessment of nutritional status of the community(with special reference to field surveys in developing regions of theworld). *Monograph Series of World Health Organization*, [Internet].53:3–271.[AccessedJanuary 6, 2021].

Jensen, S. M., Molgaard, C., Ejlerskov, K. T., Christensen, L. B., Michaelsen,K. F. and Briend, A. (2015). Validity of anthropometric measurements to assess bodycomposition, including muscle mass, in 3-year-old children from theSKOT cohort. *Maternal and Child Nutrition* 11:398–408.

Johnston, F. E. (1986). Reference data for physical growthin nutritional anthropology. In Quandt S.A. and Ritenbaugh. C. (Eds.). *Training manual in nutritionalanthropology* (pp. 60-65). Washington, United States:*American Anthropologist Association*.

Júlíusson, P. B., Roelants, M., Hoppenbrouwers, K., Hauspie, R. and Bjerknes, R. (2011). Growth of Belgian and Norwegian children compared to the WHO growth standards: prevalence below −2 and above +2 SD and the effect of breastfeeding. *Archives of Diseases of Childhood*, 96: 916–21.

Karvonen, M., Hannila, M. L., Saari, A. and Dunkel, L. (2012). New Finnish reference for head circumference from birth to 7 years. *Annals of Medicine*,44: 369–74.

Keller, W. and Filmore, C. M. (1983). Prevalence ofprotein-energy malnutrition.*World Health Statistics Q*, 36: 129−67.

Kelly, S. J., Lilley, J. M. and Leonardi-Bee, J. (2010). Associationsof morbidity in the underweight. *European Journal of Clinical Nutrition*, 64:475–482.

Khadivzadeh, T. (2002). Mid upper arm and calf circumferencesas indicators of nutritional status in women ofreproductive age. *East Mediterranean Health Journal*, 8:612–618.

Khongsdier, R. (2002). Body mass index and morbidity inadult males of the War Khasi in Northeast India. *European Journal of Clinical Nutrition*, 56:484–489.

Khongsdier, R. (2005). BMI and morbidity in relation to bodycomposition: a cross-sectional study of a rural community inNorth-East India. *British Journal of Nutrition*, 93:101–107.

King, J. C. (2003). The risk of maternal nutritional depletion and poor outcomes increases in early and closely spaced pregnancies. *Journal of Nutrition*. 133:1732S–6S.

Kosti, I. R. and Panagiotakos, B. D. (2006). The epidemic of obesity in children and adolescents in the world. *Central European Journal of Public Health*,14 (4):151 – 159.

Krebs, N., Bagby, S., Bhutta, Z. A., Dewey, K., Fall, C.,Gregory, F., Hay, W., Jr,Rhuman, L., Caldwell, C. W. and Thornburg, K. L. (2017). International summit on thenutrition of adolescent girls and young women: consensus statement.*Annals of New York Academy of Science*, 1400:3–7.

Kuczmarski, R. J., Ogden, C. L., Guo, S. S., Grummer-Strawn, L. M., Flegal, K. M., Mei, Z., Wei, R., Curtin, L. R., Roche, A. F. and Johnson, C. L. (2002). 2000 CDCGrowth Charts for the United States: methods and development. *VitalHealth Statistics*, 11:246:1–190.

Kuhle, S., Ashley-Martin, J., Maguire, B. and Hamilton C. D. (2016). Percentile curves for skinfold thickness for Canadian children and youth. PeerJ 4:e2247; DOI10.7717/peerj.2247

Kułaga, Z., Grajda, A., Gurzkowska, B.*et al*. (2013). Polish 2012 growth references for preschool children. *European Journal of Paediatrics*,172:753–61.

Kułaga, Z., Litwin, M., Tkaczyk, M. *et al*. (2011). Polish 2010 growth references for school-aged children and adolescents. *European Journal of Paediatrics*,170:599–609.

Kulaga, Z., Litwin, M., Tkaczyk, M., Rozdzynska, A., Barwicka, K.,Grajda, A.,Swiąder, A., Gurzkowska, B., Napieralska, E. and Pan, H. (2010). The height-, weight- and BMI-for-age of Polish school-aged children and adolescentsrelative to international and local growth references. *BioMed Central PublicHealth*, 10:109.

Kulaga, Z., Mieczyslaw, L., Graida, A., Kulaga, K., Gurzkowska, B., Góźdź, M. and Huiqi, P. (2012). Oscillometric blood pressure percentiles for Polish normal-weight school-aged children and adolescents. *Journal of hypertension,* 30 (10): 1942 – 1954.

Kumar, R. and Indrayan, A., (2011). Receiver operating characteristic(ROC) curve for medical researchers. *Indian Paediatrics*, 48:277–287.

Kuzawa, C., W. (1998). Adipose tissue in human infancy and childhood:an evolutionary perspective. *American Journal of Physical Anthropology*, 107:177–209.

L'Abée, C., Visser, G. H., Liem, E. T., Kok, D. E., Sauer, P. J. and Stolk, R. P. (2010). Comparison of methods to assess body fat in non-obese sixto seven-year-old children. *Clinical Nutrition*, 29(3):317–322.

Laillou, A., Prak, S., de Groot, R., Whitney, S., Conkle, J., Horton, L. *et al*. (2014). Optimal screening of children with acute malnutrition requires a change in current WHO guidelines as MUAC and WHZ identify different patient groups. *Public Library of Science One* 9 (7): e101159.

Lasserre, A. M., Chiolero, A., Paccaud, F. and Bovet, P. (2007). Worldwide trends inchildhood obesity. *Swiss Medical Weekly*, 137(9-10):157–158.

Lassi, Z. S.,Moin, A. Das, J. K., Salam, R. A. and Bhutta, Z. A. (2017). Systematic review onevidence-based adolescent nutrition interventions. *Annalsof New York Academy of Science*, 1393:34–50.

Lemmer, C. E., Badri, M., Visser, M,*et al*. (2011). A lower bodymass index is associated with cardiomyopathy in peoplewith HIV infection: evidence from a case comparison study.*South African Medical Journal*, 101:119–121.

Leonard, W. R., Sorensen, M. V., Mosher, M. J., Spitsyn, V. and Comuzzie, A. G. (2009). Reduced fat oxidation and obesity risks among theBuryat of southern Siberia. *American Journal of Human Biology*, 21:664–670.

Li, H., Stein, A. D., Barnhart, H. X., Ramakrishnan, U. and Martorell, R. (2003). Associations between prenatal and postnatal growthand adult body size and composition. *American Journal of Clinical Nutrition*, 77:1498–1505.

Liu, E., Spiegelman, D. and Semu, H. (2011). Nutritional status andmortality among HIV-infected patients receiving antiretroviraltherapy in Tanzania. *Journal of Infectious Disease*, 204:282–290.

Lloyd, L. J., Langley-Evans, S. C. and McMullen, S. (2012). Childhood obesity andrisk of the adult metabolic syndrome: a systematic review. *International Journal of Obesity*, 36:1–11.

Lobstein, T., Baur, L. and Uauy, R. (2004). Obesity in children and young people: acrisis in public health. *Obesity Review*, 1:4–104.

Lohman, T. G., Roche, A. F. and Martorell, R. (1988). AnthropometricStandardization Reference Manual. *Chicago, IL: HumanKinetics Books*.

Lytle, L. A. (2002). Nutritional issues for adolescents. *Journal of American Dietetic Association*, 102:S8–12.

Mahmud,K. M., Hotchkiss, D. R., Berruti, A. A.*et al*. (2006).Geographic aspects of poverty and health in Tanzania:does living in a poor area matter? *Health Policy Plan*, 21:110–122.

Malina, R. M. and Bouchard, C. (1991). Growth, maturation and physical activity. Champaign, IL: Human Kinetics

Marrodán, M. D. (2005). Antropología de la nutrición. InRebato, E., Susanne, C. and Chiarelli. B. (Ed.). *Para comprenderla Antropología biológica. Evolución y biologíahumana* (pp. 595−607). *Navarra, España: EditorialVerbo Divino*.

Marshall, W. A. and Tanner, J. M. (1986). Puberty. In: Falkner FT, Tanner JM, editors.Human Growth: A Comprehensive Treatise. 2nd ed. *New York:Plenum Press*, p. 171–209.

Martin, A. C., Pascoe, E. M. and Forbes, D. A. (2009). Monitoring nutritional status accuratelyand reliably in adolescents with anorexia nervosa. *Journal of Paediatric ChildHealth*, 45(1-2):53−57.

Martorell, R. (1985). Child growth retardation: a discussion of its causes and itsrelationship to health. In: Blaxter, K., L. Waterlow, I., C. eds. Nutritionaladaptation in man. *London: John Libbey*,13−30.

Mascarenhas, M. Zemel, B. and Stallings, V. (1998). Nutritional assessment in paediatrics. *Nutrition*, 14:105 – 115.

Matkovic, V. Jelic, T., Wardlaw, G. M., Illich, J. Z., Goel, P. K., Wright J. K., Andon M. B., Smith, K. T. and Heaney R. P. (1994). Timing of peak bone mass in Caucasian females and its implication for the prevention of osteoporosis. Inference from a cross-sectional model. *The Journal of Clinical Investigation*, 93 (2): 799 – 808.

Maynard, L. M., Wisemandle, W., Roche, A. F., Chumlea, W. C., Guo, S. S.,Siervogel, R. M. (2001). Childhood body composition in relation to body massindex. *Paediatrics*, 107:344–50.

Mazicioglu, M. M., Yalcin, B. M. and Ozturk, A. (2010). Anthropometricrisk factors for elevated blood pressure in adolescentsin Turkey aged 11–17. *Paediatrics of Nephrology*, 25:2327–2334.

McDowell, M. A., Fryar, C. D., Ogden, C. L. and Flegal, K. M. (2008). Anthropometricreference data for children and adults: United States, 2003–2006. National Health Statistics Reports Number 10; October 22.http://www.cdc.gov/nchs/data/nhsr/nhsr010.pdf. [Accessed 3 September, 2020].

McKeigue, P. M., Marmot, M. G., Court, Y. D. S., Cottier, D. E., Rahman, S. and Riemersma, R. A. (1988). Diabetes, hyperinsulinemia, and coronary riskfactors in Bangladeshis in east London. *Heart*, 60:390−340.

Mehta, N. M., Corkins, M. R., Lyman, B., *et al*. (2013). Defining Paediatric malnutrition:a paradigm shift towards etiology-related definitions. *Journal for Pareteral and Enteral Nutrition*, 37(4):460−481.

Milani, S., Buckler, J.M., Kelnar, C.J., Benso, L., Gilli,G., Nicoletti, I. and Sartorio, A. (2012). The use oflocal reference growth charts for clinical use or a universalstandard: a balanced appraisal. *Journal of EndocrinologicalInvestigation*, 35(2):224−226.

Monden, C. W. S. and Smits, J. (2009). Maternal height and child mortality in 42developing countries. *American Journal of Human Biology*,21:305–11.

Monnier, C., Lepage, Y., Hauspie, R., Vercauteren, M.,Roelants, M., Cruz-Albornoz, J. and Cruz-Pierard, J.(2011). Estudio del crecimiento y desarrollo de niñosecuatorianos residentes en Quito, según su origen social.*Tsafiqui, 2*(2):127−141.

Monteiro, C. A., Conde, W. L. and Popkin, B. M. (2004). The burden ofundernutrition and overnutrition in countries undergoingrapid nutrition transition: a view from Brazil. *American Journal of PublicHealth*, 94:433–434.

Monyeki, K. D., Cameron, N., and Getz, B. (2000). Growth and nutritional status ofRural South African children 3–10 years old: the Ellisras Growth Study.*American Journal of Human Biology* 12:42–49.

Morrison, J. A., Barton, B. A., Biro, F. M., Daniels, S. R. and Sprecher, D. L. (1999). Overweight,fat patterning, and cardiovascular disease risk factors in blackand white boys. *Journal of Paediatrics*, 135:451–7.

Mueller, W.H. (1986). The genetics of size and shape inchildren and adults. In Falkner, F. and Tanner, J.M.(Eds.). Human growth, an encyclopedia of life supportsystems (EOLSS) comprehensive treatise (pp. 145−168).*New York and London: Plenum Press.*

Mukudi, E. (2003). Nutrition status, education participation, and schoolachievement among Kenyan middle-school children. *Nutrition*, 19:612–16.

Muller, W. H. and Martorell, R. (1988). Reliability and accuracy of measurement. In: Lohman T.G., Roche A.F., Martorell R. Editors. Anthropometric standardization reference manual. Champaign, IL. *Human kinetics,* 83−86.

Must, A., Dallal, G. E. and Dietz, W. H. (1991). Reference data forobesity: 85th and 95th percentiles of body mass index(wt/ht^2) and triceps skinfold thickness. *American Journal of Clinical Nutrition*,53:839–46.

Muthuri, S. K., Francis, C. E., Wachira, L-J. M., Leblanc, A. G., Sampson, M.,Sampson, M., *et al*. (2013). Evidence of an overweight/obesity transitionamong school-aged children and youth in sub-Saharan Africa: a systematicreview. *Public Library of Science One,* 9:e92846.

Myatt, M., Khara, T. and Collins, S. (2006). A review of methods to detect cases ofseverely malnourished children in the community for their admissioninto community-based therapeutic care programs. *Food Nutrition Bulletin*, 27:S7–23.

Naidu, A. N. and Rao, N. P. (1994). Body mass index: a measure ofnutritional status in Indian populations. *European Journal of Clinical Nutrition*, 48(3):S131–S140.

National Centre for Chronic Disease Prevention and Health Promotion:Nutrition and Physical Activity. Use and interpretation of the CDC growthcharts: an instructional guide. 2007. http://www.cdc.gov/nccdphp/dnpa/growthcharts/guide_intro.htm. [Accessed January 5, 2021].

National High Blood Pressure Education Program (1996). Update on the 1987 Task Force Report on High Blood Pressure inChildren and Adolescents: A working group report from the National High Blood Pressure Education Program.National High Blood Pressure Education Program Working Group on Hypertension Control in Children andAdolescents. *Paediatrics,* 98:649–58.

National Population Commission (2006).

NCSS Statistical Software (2016). One ROC Curve and Cut-offAnalysis. https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/NCSS/One_ROC_Curve_and_Cutoff_Analysis.pdf [Accessed August 11, 2020].

Neyzi, O., Gunöz, A., Furman, A., *et al*. (2008). Türk çocuklar_nda vücuta_g_rl__g_, boy uzunlu_gu, bas¸ çevresi ve vücut kitle indeksi referansde_gerleri. *Çocuk Sa_gl__g_ Hastal_klar_ Derg,* 51:1–14.

Nhantumbo, L., Maia, J. A. R., Dos Santos, F. K., Jani, I. V., Gudo, E. S., Katzmarzyk, P. T.,*et al*. (2013). Nutritional status and its association with physical fitness,physical activity and parasitological indicators indicators in youthsfrom Rural Mozambique. *American Journal of Human Biology*, 25:516–523.

NHLBI. Blood pressure tables for children and adolescents. http://www.nhlbi.nih.gov/guidelines/hypertension/child_tbl.htm. [Accessed 10 Jan 2021].

Nightingale, C. M., Rudnicka, A. R., Owen, C. G., Cook, D. G. and Whincup, P. H. (2011). Patterns of body size and adiposity amongUK children of SouthAsian,blackAfrican–Caribbean andwhite European origin: Childheartandhealth study in England (CHASE Study). *International Journal of Epidemiology*, 40:33−44.

Norgan, N. (1994a). Population differences in body composition in relationto the body mass index. *European Journal of Clinical Nutrition*, 48(Suppl 3):S10–25.

Norgan, N. G. (1994a). Population differences in body composition in relation to thebody mass index. *European Journal of Clinical Nutrition*,48:s10–25.

Norgan, N. G. (1994b). Relative sitting height and the interpretation of the bodymass index. *Annals of Human Biology*, 21:79–82.

Norgan, N. G. (1995). Body mass index and nutritional status: the effects of adjustingbody mass index for the relative sitting height on estimates of theprevalence of chronic energy deficiency, overweight and obesity. *Asia Pacific Journal of Clinical Nutrition*, 4:137–9.

Nube, M., Asenso-Okyere, W. K. and van den Bloom, G. J. M. (1998).Body mass index as an indicator of standard of living indeveloping countries. *European Journal of Clinical Nutrition*, 77:1186–1191.

Oliveira, I., Andersen, A. and Furtado, A. (2012). Assessment ofsimple risk markers for early mortality among HIV-infectedpatients in Guinea-Bissau: a cohort study. *British Medical Journal Open*, 2,e001587.

Olivieri, F., Semproli, S., Pettener, D.and Toselli, S. (2008). Growth and malnutritionof rural Zimbabwean children (6–17 years of age). *American Journal of Physical Anthropology*136:214–222.

Olukoya, A. A. (1990). Identification of underweight womenby measurement of the arm circumference. *International Journal of Gynaecology and Obstetrics*, 31:231–235.

Omwami, E. M., Neumann, C. and Bwibo, N. O. (2011). Effects of a schoolfeeding intervention on school attendance rates among elementaryschool children in rural Kenya. *Nutrition*, 27:188–93.

Ong, K. K. L. Ahmed, M. L. Emmett, P. M. Preece, M. A. and Dunger, D. B. (2000). Association between postnatal catch-up growth and obesity in childhood: prospective cohort study. *British Medical Journal.* 320:967−971.

Orden, A. B. and Apezteguía, M. C. (2016). Weight and height centiles of Argentinianchildren and adolescents: a comparison with WHO and nationalgrowth references. *Annals of Human Biology*,43:9–17.

Owen, C. G.,Whincup, P. H., Orfei, L., Chou, Q-A., Rudnicka, A. R.,Wathern, A. K., Kaye, S. J., Eriksson, J. G., Osmond, C. and Cook, D. G. (2009). Is body massindex before middle age related to coronary heart disease risk inlater life? Evidence from observational studies. *International Journal of Obesity*, 33:866–77.

Oyhenart, E. E., Torres, M. F., Garraza, M.,Cesani, M. F., Navazo, B., Castro, L. E., Alfaro, E., Bejarano, I. F., Carrillo, R., Dahinten, S. L., Lomaglio, D., Luis, M. A., Menecier, N., Quintero, F. A., Román, E. M., Zonta, M. L., Serrano, M. D. M. and Dipierri, J. E.2019. Reference percentiles formid-upper arm circumference, upper armmuscle and fat areas in the Argentine child andadolescent population (4-14 years old). *Archives ofArgentinian Paediatrics*,117(4):e347−e355.

Özaltin, E. and Hill, K. (2010). Subramanian SV. Association of maternal staturewith offspring mortality, underweight, and stunting in low- to middle-incomecountries. *Journal of American Medical Association*, 303:1507–16.

Pan, H. and Cole, T. J. (2004). A comparison of goodness of fit tests for age-relatedreference ranges. *Statistics in Medicine*, 23:1749–65.

Pantsiotou, S., Papadimitriou, A., Douros, K., Priftis, K., Nicolaidou, P., and Fretzayas, A. (2008). Maturational tempo differences in relation to the timing of the onset ofpuberty in girls. *Acta Paediatrics* 97:217−220.

Patton, G. C., Sawyer, S. M., Santelli, J. S., Ross, D. A., Afifi, R., Allen, N. B., Arora, M., Azzopardi, P., Baldwin, W., Bonell, C., Kakuma, R. *et al.* (2016). Our future: a Lancet

commission on adolescent health and well-being. *The Lancet*, 387 (10036):2423 – 2478.

Pawloski, L. R. (2002). Growth and development of adolescent girls fromthe Segou region of Mali (West Africa). *American Journal of Physical Anthropology*117:364–372.

Pelletier, D. (2006). Theoretical considerations related to cut-off points. *Food and Nutrition Bulletin*, 27:S224–36.

Perignon, M., Fiorentino, M., Kuong, K., Burja, K., Parker, M., Sisokhom, S., Chamnan, C., Berger, J. and Wieringa, F., T. (2014). Stunting, poor iron statusand parasite infection are significant risk factors for lower cognitiveperformance in Cambodian school-aged children. *Public Library of ScienceOne*, 9:e112605.

Perumal, N., Bassani, D. G. and Roth, D. E. (2018). Use and misuse of stunting as ameasure of child health. *Journal of Nutrition*, 148:311–15.

Popkin BM. 2004. The nutrition transition: an overview of world patternsof change. *Nutritional Review*, 62:S140–S143.

Popkin, B. M., and Gordon-Larsen, P. (2004). The nutrition transition: worldwideobesity dynamics and their determinants. *International Journal of Obesityand Related MetabolicDisorders* 28(Suppl 3):S2–S9.

Popkin, B. M., Richards, M. K. and Montiero, C. A. (1996). Stunting is associatedwith overweight in children of four nations that areundergoing the nutrition transition. *Journal of Nutrition*, 126:3009–3016.

Powell-Tuck, J. and Hennessy, E. M. (2003). A comparison of mid upper arm circumference,body mass index and weight loss as indices of undernutrition inacutely hospitalized patients. *Clinical Nutrition*, 22(3):307−312.

Prentice, A. M, Ward, K. A., Goldberg, G. R., Jarjou, L. M., Moore, S. E., Fulford, A. J. and Prentice, A. (2013). Critical windows for nutritional interventions againststunting. *American Journal of Clinical Nutrition*, 97:911–18.

Prista A, Maia JA, Damasceno A, Beunen G. 2005. Anthropometric indicatorsof nutritional status: implications for fitness, activity, and healthin school-age children and adolescents from Maputo, Mozambique.*American Journal of Clinical Nutrition*, 77:952–959.

Pryer, J. A., Rogers, A. and Rahman, A. (2003). Factors affectingnutritional status in female adults in Dhaka slums, Bangladesh.*Social Biology*, 50:259–269.

Rah, J., H. Christian, P. Shamim, A., A. Arju, U., T. Labrique, A., B. and Rashid, M. (2008). Pregnancy and lactation hinder growth and nutritional status of adolescent girls in rural Bangladesh. *Journal of Nutrition*.138(8):1505–11.

Rasmussen, J., Andersen, A., Fisker, A. B.*et al*. (2012). Mid-upper-arm-circumferenceand mid-upper-arm circumference z-score: the best predictor of mortality?*European Journal of Clinical Nutrition,*66(9):998−1003.

Reddy, B. N. (1998). Body mass index and its association withsocio-economic and behaviuoral variables among socio-economic allyheterogeneous populations of AndhraPradesh, India. *Human Biology*, 70:901–917.

Roberts, J. L. and Stein, A. D. (2017). The impact of nutritional interventions beyondthe first 2 years of life on linear growth: a systematic review and meta-analysis.*Advancements in Nutrition*, 8:323–36.

Roelants, M., Hauspie, R. and Hoppenbrouwers, K. (2009). References for growth and pubertal development from birth to 21 years in Flanders, Belgium. *Annals of Human Biology,*36: 680–94.

Rolland-Cachera, M. F., Cole, T. J., Sempe, M., Tichet, J., Rossignol, C. and Charraud, A. (1991). Body mass index variations: centiles from birth to 87 years. *European Journal of Clinical Nutrition*,45:13–21.

Royal College of Paediatrics and Child Health. UK–WHO growth chart 2–18 years (girls) 2013b. May 11, 2009.https://www.rcpch.ac. uk/sites/default/files/Girls_2-18_years_growth_chart.pdf [accessed Oct 25, 2020].

Royal College of Paediatrics and Child Health. UK–WHO growth chart 0–4 years (girls) 2013a. May 11, 2009. https://www.rcpch.ac.uk/sites/default/files/Girls_0-4_years_growth_chart.pdf [accessed Oct 25, 2020].

Rush, E. C., Freitas, I. and Plank, L. D. (2009). Body size, body composition and fatdistribution: comparative analysis of European, Maori, Pacific Islandand Asian Indian adults. *British Journal of Nutrition*, 102:632–41.

Saari, A., Sankilampi, U., Hannila, M. L., Kiviniemi, V., Kesseli, K. and Dunkel, L. (2011). New Finnish growth references for children and adolescents aged 0 to 20 years: length/height-for-age, weight-for-length/height, and body mass index-for-age. *Annals of Medicine*, 43:235–48.

Sachs, M., Dykes, F. and Carter, B. (2006). Weight monitoring of breastfed babies in the United Kingdom-interpreting, explaining and intervening. *Maternal and Child Nutrition,*2: 3–18.

Salam, R. A.,Hooda, M., Das, J. K., Arshad, A., Lassi, Z. S., Middleton, P. and Bhutta, Z. A. (2016). Interventions to improve adolescent nutrition: a systematic reviewand meta-analysis. *Journal of Adolescent Health*, 59:S29–39.

Save the Children Adolescent Nutrition (SCAN): Policy and Programmingin SUN+ Countries [Internet]. *London, UK: Save the ChildrenFund*; 2021.

Sawyer, S. M., Azzopardi, P. S.,Wickremarathne, D. and Patton, G. C. (2018). The age ofadolescence. *Lancet Child and Adolescent Health,* 2:223–8.

Scherdel, P., Botton, J., Rolland-Cachera, M. F.*et al*. (2015). Should the WHO growth charts be used in France? *Public Library of Science One,*10:e0120806.

Scherdel, P., Dunkel, L., van Dommelen, P., *et al*. (2016). Growth monitoring as an early detection tool: a systematic review. *Lancet Diabetes Endocrinol,*4: 447–56.

Schienkiewitz, A., Schaffrath, Rosario, A., Dortschy, R.*et al*. (2011). Germanhead circumference references for infants, children andadolescents in comparison with currently used national andinternational references. *Acta Paediatrics*, 100:e28–33.

Schisterman, E. F., Perkins, N. J. Liu, A.*et al*. (2005). Optimal cut-pointand its corresponding Youden Index to discriminateindividuals using pooled blood samples. *Epidemiology*, 16:73–81.

Schorrl, M., Dichtel, E. L., Gerweck, V. A., Valera, D. R., Torriani, M. Karen, K., Miller, K. K. and Bredella, A. M. (2018). Sex differences in body composition andassociation with cardiometabolic risk. *Biology of Sex Differences*, 9:28.

Schweizer, J. and Gerver, W. J. (2005). Mid–upper arm circumference is a reliablepredictor of body-mass index in healthy Dutch children. *Journal of Paediatrics, Gastroenterologyand Nutrition*, 40(5):695.

Sellen, W. S. (1999). Growth patterns among seminomadic pastoralists(Datoga) of Tanzania. *American Journal of Physical Anthropology,* 109:187–209.

Semproli, S.and Gualdi-Rossi, E. (2007). Childhood malnutrition and growth in arural area of western Kenya. *American Journal of Physical Anthropology,* 132:463–469.

Senbanjo, I. O., Oshikoya, K. A., Odusanya, O. O. and Njokanma, O. F. (2011). Prevalence of and risk factors for stunting among schoolchildren and adolescents in Abeokuta, southwest Nigeria. *Journal of Health, Population and Nutrition*, 29: 364−370.

Senbanjo, I. O. Oshikoya K. A. Njokkanma O. F. (2014). Helicobacter pylori associated with breastfeeding, nutritional status and recurrent abdominal pain in healthy Nigerian children. *The Journal of Infection in Developing Countries.* 8 (4): 448 – 453.

Seoane, N. and Latham, M. C. (1971). Nutritional anthropometry in the identificationof malnutrition in childhood. *Journal of Tropical and Paediatric Environment Child Health*,17:98−104.

Shetty, P., S. and James, W., P., T. (1994). Body mass index. A measure of chronic energydeficiency in adults. Food and Agricultural Organization.*Food and Nutrition Paper*,No 56. Rome 56:1–57.

Siervogel, R. M., Maynard, L. M., Wisemandle, W., Roche, A. F., Guo, S. S.,Chumlea, W. C. and Towne, B. (2006). Annual changes in total body fat and fat-freemass in children from8 to 18 years in relation to changes in bodymassindex: the Fels longitudinal study. *Annals of New York Academic Science*, 904:420–3.

Simondon, K. B., Simondon, F., Simon, I., Diallo, A., Bénéfice, E., Traissac, P., *et al*. (1998). Preschool stunting, age at menarche and adolescent height: alongitudinal study in rural Senegal. *European Journal of Clinical Nutrition* 52:412–418.

Singla, R., Sharma, S. K. and Mohan, A. (2010). Evaluation of riskfactors for antituberculosis treatment induced hepatotoxicity.*Indian Journal of Medical Research*, 132:81–86.

Skuse, D.H. (1998). Growth and psychosocial stress. InUlijaszek, S.J., Johnston, F. E. and Preece, M. A. (Eds.). TheCambridge encyclopaedia of human growth and development(pp. 341-342). *Cambridge, UK: University Press*.

So, H. K., Nelson, E. A. S., Sung, R., Y., T. and Ng, P. C. (2011). Implications of using WorldHealth Organization growth reference (2007) for identifying growthproblems in Hong Kong children aged 6 to 18 years. *Hong Kong Medical Journal*, 17:174–9.

Spear, B. A. (2002). Adolescent growth and development. *Journal of American Dietetics Association*, 102:S23–9.

SPRING. (2018). Report of the Stakeholders Consultation on AdolescentGirls' Nutrition: Evidence, Guidance and Gaps. Washington (DC):Strengthening Partnerships, Results and Innovations in NutritionGlobally (SPRING) project.

SPRING. (2018a). Adolescent Nutrition Call to Action: Better Data Nowto Drive Better Policies and Programs in the Future [Internet].Washington (DC): Strengthening Partnerships, Results andInnovations in Nutrition Globally (SPRING) project. Availablefrom: https://www.spring-nutrition.org/about-us/news/adolescentnutrition-call-action-better-data-now-drive-better-policies-andprograms.

Stein, A. D., Wang, M., Martorell, R., Norris, S. A., Adair, L. S., Bas, I.,Sachdev, H. S., Bhargava, S. K., Fall, C. H. D. and Gigante, D. P. (2010). CohortsGroup. 2010. Growth patterns in early childhood and finalattained stature: data from five birth cohorts from low- andmiddle-income countries. *American Journal of Human Biology*, 22:353–359.

Steinberger, J., Daniels, S. R., Eckel, R. H., Hayman, L., Lustig, R. H.,McCrindle, B. and Mietus-Snyder, M. L. (2009). American Heart AssociationAtherosclerosis, Hypertension, and Obesity in the Young Committeeof the Council on Cardiovascular Disease in the Young;Council on Cardiovascular Nursing; and Council on Nutrition, PhysicalActivity, and Metabolism. Progress and challenges in metabolicsyndrome in children and adolescents: a scientific statement from theAmerican Heart Association Atherosclerosis, Hypertension, andObesity in the Young Committee of the Council on

CardiovascularDisease in the Young; Council on Cardiovascular Nursing; andCouncil on Nutrition, Physical Activity, andMetabolism. *Circulation*, 119(4):628–647

Steinberger, J., Jacobs, D. R., Raatz, S., Moran, A., Hong, C. P. and Sinaiko, A. R. (2005). Comparison of body fatness measurements by BMI and skinfolds vsdual energy X-ray absorptiometry and their relation to cardiovascularrisk factors in adolescents. *International Journal of Obesity, (London)*, 29:1346–52.

Sterling, R., Miranda, J. J., Gilman, R. H, Cabrera, L., Sterling, C. R.,Bern, C. and Checkley, W. (2012). Early anthropometric indices predictshort stature and overweight status in a cohort of Peruviansin early adolescence. *American Journal of Physical Anthropology*, 148:451–461.

Subramanian, S. V., Ackerson, L. K., Smith, G. D. and John, N. A. (2009). Associationof maternal height with child mortality, anthropometric failure, andanemia in India. *Journal of American Medical Association*, 301:1691–701.

Suliga, E. (2006). Anthropometrical methods of assessing the nutritionalstatus of children and adolescents. *PaediatricsPolicy*, 81(10):739−746.

Sun, H., Ren, X. and Chen, Z. (2016). Association between bodymass index and mortality in a prospective cohort ofChinese adults. *Medicine*, 95:e4327.

Tang, A., M., Chung, M., Dong, K.*et al*. (2017). Determining aGlobal Mid-Upper Arm Circumference Cutoff to AssessUnderweight in Adults (Men and Nonpregnant Women).*Washington, DC: FHI 360/FANTA*.

Tanner, J. M. (1962). Growth at Adolescence; with a General Consideration of the Effects of Hereditary and Environmental Factors Upon Growth and Maturation from Birth to Maturity. Oxford: *Blackwell Scientific*.

Tanner, J. M. (1986). Growth as a mirror of the condition ofsociety: secular trends and class distinctions. In Demirjian,A and Taylor, R. (Eds.). *Human growth: a multidisciplinaryreview* (pp. 3-34). *London, UK: Taylor and Francis*.

Tinggaard, J., Aksglaede, L., Sørensen K, *et al*. (2014). The 2014 Danish references from birth to 20 years for height, weight and body mass index. *Acta Paediatr*ics, 103: 214–24.

Trowbridge, F. L. and Staeling, N. (1980). Sensitivity and specificityof arm circumference indicators in identifying malnourishedchildren. *AmericanJournal of ClinicalNutrition*, 33:687-696.

Tumilowicz, A. (2010). “Guide to Screening for Food and Nutrition Services Among Adolescents and Adults Living with HIV.” http://www.fantaproject.org/sites/default/files/resources/ Nutrition_Interventions_Screening_Guide_Final.pdf.

Tumilowicz, A. Beal, T. Neufeld, M. L. and Frongillo A. E. (2019). Perspective: Challenges in use of adolescentanthropometry for understanding the burden ofmalnutrition. *Advancements in Nutrition.* 10:563–575.

Unal, I. (2017). Defining an optimal cut-point value in ROCanalysis: an alternative approach. *Computational Mathematical Methods in Medicine,* 3762651.

United Nations Children's Fund (2011). The state of the world's children—adolescence: an age of opportunity. *New York.* p. 16.

van Buuren, S. and Fredriks, M. (2001). Worm plot: a simple diagnostic device formodelling growth referencecurves. *Statistics in Medicine*, 20:1259–77.

Varela-Silva, M. I., Azcorra, H., Dickinson, F., Bogin, B. and Frisancho, A. R. F. (2009). Influence of maternal stature, pregnancy age, andinfant birth weight on growth during childhood in Yucatan,Mexico: a test of the Intergenerational Effects Hypothesis.*American Journal of Human Biology*, 21:657–663.

Varela-Silva, M. I., Dickinson, F., Wilson, H. J., Azcorra, H., Griffiths, P. L. and Bogin, B. (2012). The nutritional dual-burden in developingcountries: how is it assessed and what are the health implications.*Coll Anthropology*, 36:39–45.

Vercauteren, M. (2005). Evolución secular en el siglo XX. In Rebato,E. Susanne, C. and Chiarelli. B. (Eds.). Para comprenderla antropologia biológica. Evolución y biologia humana(pp. 547-555). *Navarra, España: Editorial Verbo Divino.*

Ververs, M. *et al*. (2013). "Which Anthropometric Indicators Identify a Pregnant Woman as Acutely Malnourished and Predict Adverse Birth Outcomes in the Humanitarian Context*?" Public Library of Science, Current Disasters*. Edition 1.

Victora, C. G., Morris, S. S., Barros, F. C., de Onis, M. and Yip, R. (1998). The NCHS reference and the growth of breastand bottle-fedinfants. *Journal of Nutrition*, 128:1134–8.

Wagner, D., R. and Heyward, V., H. (1999). Techniques of body compositionassessment: a review of laboratory and field methods. *Research Q Exercise Sport*, 70(2):135–149.

Wang, Y. Moreno, L., A. Caballero, B. and Cole, T. J. (2006). Limitations of the current World Health Organization growth references for children and adolescents. *Food Nutrition Bulletin*, 27:S175–88.

Walker, R., Gurven, M., Hill, K., Migliano, A., Chagnon, N., De Souza, R., Djurovic, G., Hames, R., Hurtado, A. M., Kaplan, H., Kramer, K.,Oliver, W. J., Valeggia, C. and Yamauchi, T. (2006). Growth rates andlife histories in 22 small-scale societies. *American Journal of Human Biology*, 18:295–311.

Walker, S. P., Chang, S. M. and Powell, C. A. (2007). The associationbetween early childhood stunting and weight status in lateadolescence. *International Journal of Obesity*, 31:347–352.

Walker, S. P., Gaskin, P., Powell, C. A. and Bennett, F. I. (2002). The effectsof birth weight and postnatal linear growth retardation onbody mass index, fatness and fat distribution in mid and latechildhood. *Public Health Nutrition*, 5:391–396.

Wang, J., Freire, D., Knable, L., Zhao, W., Gong, B.,Mazzola, P., Ho, L., Levine, S. and Pasinetti, G., M. (2015). Childhood and adolescent obesity and long-termcognitive consequences during aging. *Journal of Computational Neurology*, 523:757–68.

Wang, J., Thornton, J. C., Kolesnik, S. and Pierson, R. N. (2000). Anthropometryin body composition. An overview. *Annals of New York of Academy of Science*, 904:317–326.

Wang,Y. and Chen, H-J. (2012). Use of percentiles and Z-scores in anthropometry. Preedy VR. (Ed).Handbook of Anthropometry: Physical Measures of Human Form in Health and Disease. *Springer Science*, 3107 (4):1 – 21.

Wang, Y., Moreno, L. A., Caballero, B. and Cole, T. J. (2006). Limitations of thecurrentWorldHealthOrganization growth references for children andadolescents. *Food and Nutrition Bulletin*, 27:S175–88.

Waterlow, J. C., Buzina, R., Keller, W., Lane, J. M., Nichaman, M. Z. and Tanner, J. M. (1977). The presentation and use of the height and weight data forcomparing the nutritional status ofgroups ofchildren under the ageof 10 years. *Bulletin of World Health Organization*, 55:489−98.

Wells, J. C. and Fewtrell, M. S. (2006). Measuring body composition. *Archives of Disease of Childhood*, 91(7):612–617.

Wells, J. C. K. (2010). The evolutionary biology of human body fatness:thrift and control. Cambridge: *Cambridge UniversityPress*.

Wen, C. P., David,C. T. Y., Tsai, S. P., Chan, H. T., Hsu, H. L., Hsu, C. C. and Eriksen, M. P. (2009). Are Asians at greater mortality risks for being overweightthan Caucasians? Redefining obesity for Asians. *Public Health Nutrition*, 12:497–506.

Werner, B. and Bodin, L. (2006). Head circumference from birth to age48 months for infants in Sweden. *Acta Paediatrics*, 95:1601–7.

Whitlock, G., Lewington, S., Sherliker, P.*et al*. (2009). ProspectiveStudies Collaboration: Body-mass index and causespecificmortality in 900, 000 adults: collaborative analyses of57 prospective studies. *Lancet*, 373:1083–1096.

WHO/UNICEF (2007). Community-based management of severe acutemalnutrition. *Geneva (Switzerland): World Health Organization*.

WHO/UNICEF/WHO child growth standards and the identification ofsevere acute malnutrition in infants and children (2009). *Geneva (Switzerland):World Health Organization*.

Wijnhoven, H. A. H., Schilp, J. and van Bokhorst-de van der S. M. A. E. (2012). Development and validation of criteriafor determining undernutrition in community-dwellingolder men and women: the Short Nutritional AssessmentQuestionnaire 65+. *Clinical Nutrition*, 31:351–358.

Willows, N. D., Sanou, D. and Bell, R. C. (2011). Assessment of Canadian Creeinfants' birth size using the WHO Child Growth Standards. *American Journal of Human Biology*, 23:126–31.

Wilson, H. J., Dickinson, F., Hoffman, D. J., Griffiths, P. L., Bogin, B. and Varela-Silva, M., I. (2012). Fat free mass explains the relationshipbetween stunting and energy expenditure in urban MexicanMaya children. *Annals of Human Biology*, 39:432–439.

Womersley, J. and Durnin, J. V. G. A. (1977). A comparison of the skinfold method withextent of overweight and various weight–height relationships in theassessment of obesity. *British Journal of Nutrition*,38:271–284.

Woodruff, B. A. and Duffield, A. (2002). Anthropometric assessment of nutritional status inadolescent populations in humanitarian emergencies. *European Journal of Clinical Nutrition*,56:1108–18.

World Health Organization (1995). Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. *WorldHealth Organzation Technical Report Series: Geneva*.

World Health Organization (1995). Physical Status: The Useand Interpretation of Anthropometry. Report of a WHOExpert Committee. WHO Technical Report Series no. 854.*Geneva: World Health Organization*.

World Health Organization (1995b). Physical status: the use and interpretation of anthropometry.Report of a WHO Expert Committee. World Health Organization Technical Report Series, 854.

World Health Organization (2008). Training Course on Child GrowthAssessment: WHO Child Growth Standards. *Geneva, Switzerland: WorldHealth Organization*. http://www.who.int/nutrition. [Accessed January 5, 2021].

World Health Organization (2011). Determining SD or Z-scores for an individualusing software. Lesson 3.2. http://www.unicef.org/nutrition/training/3.2/24.html. [Accessed January 5, 2021].

World Health Organization (2013). Guideline: updates on the management ofsevere acute malnutrition in infants and children. *Geneva (Switzerland):World Health Organization*.

World Health Organization (2017). Global Accelerated Action for theHealth of Adolescents (AA-HA): Guidance to Support CountryImplementation. *Geneva:World Health Organization*.

World Health Organization (2018). Guideline: Implementing Effective Actions for ImprovingAdolescent Nutrition. *Geneva*.

World Health Organization Multicentre Growth Reference Study Group (2006a). WHO child growth standards: length/height-for-age, weightforage, weight-for-length, weight-for-height and body mass index-for-age: Methods and development. Geneva: World Health Organization.

World Health Organization Multicentre Growth Reference Study Group (2006b). Assessment ofdifferences in linear growth among populations in the WHOMulticentre Growth Reference Study. *Acta Paediatrics Supply*, 450:56–65.

World Health Organization Working Group on Infant Growth (1994). An evaluation of infantgrowth. *Geneva: World Health Organization*.

WorldHealthOrganization.WHOChildGrowth Standards [Internet].WHO. [Accessed 15 January, 2021]. Available from: http://www.who.int/childgrowth/en/.

World Obesity Federation. Obesity Classification [Internet]. *WorldObesity Federation*. [cited 16 January, 2021]. Available from: https://www.worldobesity.org/about/about-obesity/obesity-classification.

World Health Organization. Determining SD or Z-scores for an individual using software. Lesson 3.2. http://www.unicef.org/nutrition/training/3.2/24.html [Accessed June 8, 2019].

Wright, K., O. Shogbamimu, Y. Akinbami, A., A. Adebisi, R. Senbanjo, I. O. and Ogbera, A. O. (2018). Nutrition status of children in a well-child clinic in Lagos Nigeria. *African Journal of Food, Agriculture, Nutrition and Development,* 18 (3): 13602 – 13616.

Zafon, C. (2007). Oscillations in total body fat content throughlife: an evolutionary perspective.*Obesity Review*, 8:525–530.

Zaki, M. E., Hassan, N. E. and El-Masry, S. A. (2008). Head circumference referencedata for Egyptian children and adolescents. *East Mediterranean HealthJournal*, 14:69–81.

Zemel, B. S., Riley, E. M. and Stallings, V. A. (1997). Evaluationof methodology for nutritional assessmentof children: anthropometry, bodycomposition, and energy expenditure. *Annual Review of Nutrition*, 17:211−235.

Zverev, Y.and Gondwe, M. (2001). Growth of urban children in Malawi. *Annals of Human Biology* 2:384–394.

APPENDIX I

INFORMED WRITTEN CONSENT

I……..... of…… agreed to participate in this study entitled **"Growth, Body Composition and Nutritional Status of Children and Adolescents in Lafia and Doma Local Government Areas of Nasarawa State, Nigeria".** The full procedure and the probable benefits of the study were fully explained to me.

I was informed that my socio-demographics and anthropometric measurements will be taken in the course of the study. If I so wish, the study results will be communicated to me in confidence.

I made this consent willingly without being subjected to any pressure.

Participant Name: ……. Signature: ……..……

Witness Name: …….. Signature: ……..

Researchers Name: ……Signature: ……..……

APPENDIX II

Questionnaire for the Study of Growth, Body Composition and Nutritional Status of Children and Adolescents in Lafia and Doma Local Government Areas of Nasarawa State, Nigeria

Please your cooperation is needed in completing this questionnaire. All efforts will be made to keep information you provided confidential. Where applicable, kindly choose an option by adding a check mark (✓) or circle (O) *in the appropriate letter where necessary below:*

Demographics of Participant

1. Name of School: …….

2. School type: (i) Public school [ ] (ii) Private school [ ] Class: …….. Sex: Male [ ] Female [ ]

3. Date of investigation: …….

4. Date of birth: DD/MM/YYYY: …..…/…..…/……..…

5. Number of younger: (i) Brothers: ……..... (ii) Sisters: ……

6. Number of elder: (i) Brothers: ……. (ii) Sisters: …….

7. Birthweight: ……. (kg)

8. Birth length: …… (cm)

9. Birth order: A. 1st born [ ] B. 2nd born [ ] C. 3rd born [ ] D. 4th born [ ]

10. State of origin: …….

11. Ethnic group: ……..

Parent's/guardian's assessment of health condition of the child:

12. General health condition: A. Normal [ ] B. Sickly [ ] C. Suffering from chronic [ ] Genetic diseases [ ] Others (specify) [ ]

13. Mother's level of education:

A. None [ ]
B. Primary [ ]
C. Secondary [ ]
D. Tertiary [ ]

14. Father's level of education:

A. None [ ]

B. Primary [ ]
C. Secondary [ ]
D. Tertiary [ ]

15. Mother's occupation

A. Professional [ ]
B. Executive officer [ ]
C. Administrative officer [ ]
D. Military/paramilitary/police/civil defense [ ]
D. Trading [ ]
E. Farming [ ]
F. Artisan [ ]
G. Others (specify): …….

16. Father's occupation:

A. Professional [ ]
B. Executive officer [ ]
C. Administrative officer [ ]
D. Military/paramilitary/police/civil defense [ ]
D. Trading [ ]
E. Farming [ ]
F. Artisan [ ]
G. Others (specify): …….

17. Monthly income of the family

A. Less than ₦ 5,000 [ ]
B. ₦ 5,000 to ₦ 19,000 [ ]
C. ₦ 20,000 to ₦ 40,000 [ ]
D. Greater than ₦ 40,000 [ ]

18. Questions on this section are for irls 9 y/o and above

"Have you already had your menstrual periods?"
a. No, I haven't yet [ ]
b. Yes, I have at the age of: …… (yrs.)
c. What year? ……
d. What month? …….

19. Anthropometric Measurements

i. Standing height: …… (cm)
ii. Body weight: …….. (kg)
iii. Sitting height: …….. (cm)
iv. Mid-upper arm circumference: …… (cm)
v. Total arm length: ……... (cm)
vi. Head circumference: ……. (cm)
vii. Head length: ……. (cm)
viii. Head breadth: ……..…. (cm)
ix. Biceps skinfold: ……..... (mm)
x. Triceps skinfold: ……... (mm)
xi. Subscapular skinfold: ……. (mm)

xii. Supraspinale skinfold: …… (mm)
xiii. Medial calf skinfold: ……(mm)
xiv. Biepicondylar breath of humerus: …..….(mm)
xv. Biepicondylar breadth of femur: ……..... (mm)
xvi. Calf girth: ……. (cm)
xvii. Subischial leg length: ……. (cm)

You have finished the questionnaire — *Thank you*

APPENDIX III

AHMADU BELLO UNIVERSITY, ZARIA
DIRECTORATE OF ACADEMIC PLANNING & MONITORING
Vice Chancellor *Prof. Ibrahim Garba, B.Sc. (Hons) Geology, M.Sc. (Mineral Exploration) A.R.I.C., Ph.D Geology (London), D.I.C., FNMGS*
Director: Prof. M.F. Ishiyaku, B.Sc. (Hons) Botany (ABU), M.Sc. Plant Breeding (Unilos), Ph.D Agriculture (University of Reading, U.K.), MASN, MBSN
Tel. Zaria + 234-069-551912 Fax. 234 (069) 550022 Telegram: UNIBELLO Zaria e-mail: dapm@abu.edu.ng

Appl No.: ABUCUHSR/2018/Human Anatomy/004 27th June, 2018

Approval No: ABUCUHSR/2018/004

Dr. B. Danborno
Department of Human Anatomy,
College of Health Sciences,
Ahmadu Bello University,
Zaria.

Sir,

PROVISIONAL APPROVAL OF RESEARCH TITLED "PHYSICAL GROWTH, BODY COMPOSITIN, AND NUTRINATIONAL STATUS OF CHILDREN AND ADOLESCENTS IN NASARAWA AND KADUNA STATES: IMPACT OF SOCIODEMOGRAPHIC FACTORS"

This is to convey the provisional approval of the ABUCUHSR to you for the aforestated study domiciled in Department of Human Anatomy of the Ahmadu Bello University. The approval is predicated on the assumption that you shall maintain and cater for the study subjects as indicated in your application.

Monitoring of the Research by spot checks, invitations, interactions with the subjects any other means the Committee deems fit shall be undertaken at the convenience of the Committee.

This approval can and shall be revoked should a significant breach in the terms and condition of the approval occur. It is hence your responsibility to ensure that the agreed terms are maintained to the end of the Study.

The said approval shall be posted on the ABUCUHSR Page on the University's website.

Note upon completion of the research, ethical clearance certificate will be issued.

Prof. I.H. Nock
ABUCUHSR Chairman

Cc. Director, DAPM
Director, IC &ICT
Provost, College of Health Sciences
HOD, Human Anatomy
Prof. J.A. Randawa

APPENDIX IV

NASARAWA STATE UNIVERSAL BASIC EDUCATION BOARD

Former Deputy Governor's Office,
State Secretariat, Shendam Road,
P.M.B 050, Lafia, Nasarawa State.
+234 813 255 4503,
+234 807 733 1440
nasarawasubeb@gmail.com,
nasarawasubeb@yahoo.com

All correspondences should be addressed to the Executive Chairman

Ref: NS/UBEB/OFF-253/VOL.I/74 Date: 6th January, 2021

Monday Nwankwo,
PI7MDHA9021
Department of Human Anatomy,
Faculty of Basic Medical Sciences,
Ahmadu Bello University Zaria,
Kaduna State of Nigeria.

RE: REQUEST FOR DEMOGRAPHIC OF SCHOOL IN LAFIA

Above is the subject matter.

2. Sequel to your letter in respect of the above underlined subject dated 30th December, 2020. I am directed to convey the Board's approval to enable you conduct your christened physical growth, Body Composition, Nutritional Status of School Children and Adolescents in Lafia LGEA.
3. Attached is the list of public primary schools in Lafia LGEA for your further necessary action.
4. Accept the assurances of Executive Chairman's esteem regards, please.

Haj. Hashiya Ahmed
Board Secretary
For: Executive Chairman

"Education for all is the responsibility of all"

APPENDIX V

Table 1: Socio-demographic characteristics of children and adolescents considered to be related to nutritional status

Socio-demographics	
Ethnicity	n (%)
Alago	2,415 (33)
Eggon	1,411 (19.3)
Hausa/Fulani	1,832 (25)
Others	1,663 (22.7)
Father's Level of Education	
No formal education	2,359 (32.9)
Primary	1,006 (14)
Secondary	1,247 (17.4)
Tertiary	2,569 (35.8)
Mother's Level of Education	
No formal education	2,960 (41.2)
Primary	1,756 (24.4)
Secondary	1,832 (25.5)
Tertiary	637 (8.9)
Father's Occupation	
Professionals	250 (3.4)
Civil Servants	576 (7.9)
Trading	885 (12.1)
Farming	1,518 (20.7)
Self-employed	446 (6.1)
Applicants	132 (1.8)
Mother's Occupation	
Professionals	71 (1)
Civil Servants	277 (3.8)
Trading	1,646 (22.5)
Farming	1,226 (16.7)
Self-employed	163 (2.2)
House wife	520 (7.1)
Applicants	45 (0.6)
Birth Order	
First Born	1,102 (16)
Second Born	1,024 (14.9)
Third Born	1,119 (16.2)
Fourth or Later Born	3,647 (52.9)

APPENDIX VI

Table 2: Prevalence of malnutrition according to anthropometric norm systems, z-scores of overall populations of children and adolescents aged 5 – 19 years from Nasarawa State

		HAZ					BAZ				
Age, yrs.	n	<–3	<–2	> +1	> +2	Mean ± SD	<–3	<–2	> +1	> +2	Mean ± SD
5	145	6.2%	17.2%	24.1%	10.3%	–0.11 ± 1.72	12.4%	26W4000.2%	1.4%	0.7%	–1.30 ± 1.29
6	372	3.0%	12.4%	18.0%	6.7%	–0.36 ± 1.43	11.3%	26.6%	3.5%	1.6%	–1.25 ± 1.34
7	387	2.8%	6.7%	18.9%	5.9%	–0.12 ± 1.38	13.8%	31.4%	2.3%	0.8%	–1.42 ± 1.34
8	493	1.0%	8.1%	12.6%	4.7%	–0.44 ± 1.31	16.6%	35.7%	3.7%	1.2%	–1.52 ± 1.47
9	590	1.0%	6.9%	9.8%	2.7%	–0.50 ± 1.12	18.1%	38.0%	2.7%	0.7%	–1.59 ± 1.46
10	677	1.8%	10.3%	8.9%	2.5%	–0.59 ± 1.18	19.4%	38.6%	1.4%	0.0%	–1.70 ± 1.32
11	545	4.4%	16.5%	5.9%	1.1%	–0.86 ± 1.21	18.0%	38.5%	0.9%	0.0%	–1.72 ± 1.29
12	635	5.8%	22.7%	4.6%	0.0%	–1.10 ± 1.17	12.0%	28.6%	1.3%	0.2%	–1.41 ± 1.26
13	694	8.8%	34.0%	2.4%	0.1%	–1.45 ± 1.21	13.5%	33.7%	6.0%	1.0%	–1.35 ± 1.48
14	612	15.7%	34.3%	2.3%	0.2%	–1.51 ± 1.34	16.3%	36.7%	3.8%	0.7%	–1.49 ± 1.41
15	592	9.8%	28.4%	2.4%	0.0%	–1.32 ± 1.22	14.0%	34.4%	4.8%	1.0%	–1.44 ± 1.42
16	480	11.5%	29.6%	4.0%	0.2%	–1.26 ± 1.40	11.8%	27.9%	1.3%	0.0%	–1.41 ± 1.24
17	322	9.0%	22.0%	6.8%	2.5%	–0.93 ± 1.39	7.5%	24.0%	0.9%	0.0%	–1.26 ± 1.11
18	189	7.9%	24.3%	8.5%	1.1%	–0.91 ± 1.45	5.3%	22.3%	1.6%	0.0%	–1.21 ± 1.07
19	123	13.8%	30.9%	25.2%	7.3%	–0.56 ± 1.91	2.4%	10.6%	0.0%	0.0%	–0.78 ± 0.96
Total	6,856	6.5%	20.3%	8.0%	2.1%	–0.89 ± 1.37	14.2%	32.6%	2.7%	0.6%	–1.46 ± 1.36

Severe stunting (HAZ < -3), moderate stunting (HAZ <-2), tall stature (HAZ > +2), severe thinness (< -3 BAZ), moderate thinness (< -2 BAZ), overweight
(> +1 BAZ), obesity (> +3 BAZ)

APPENDIX VII

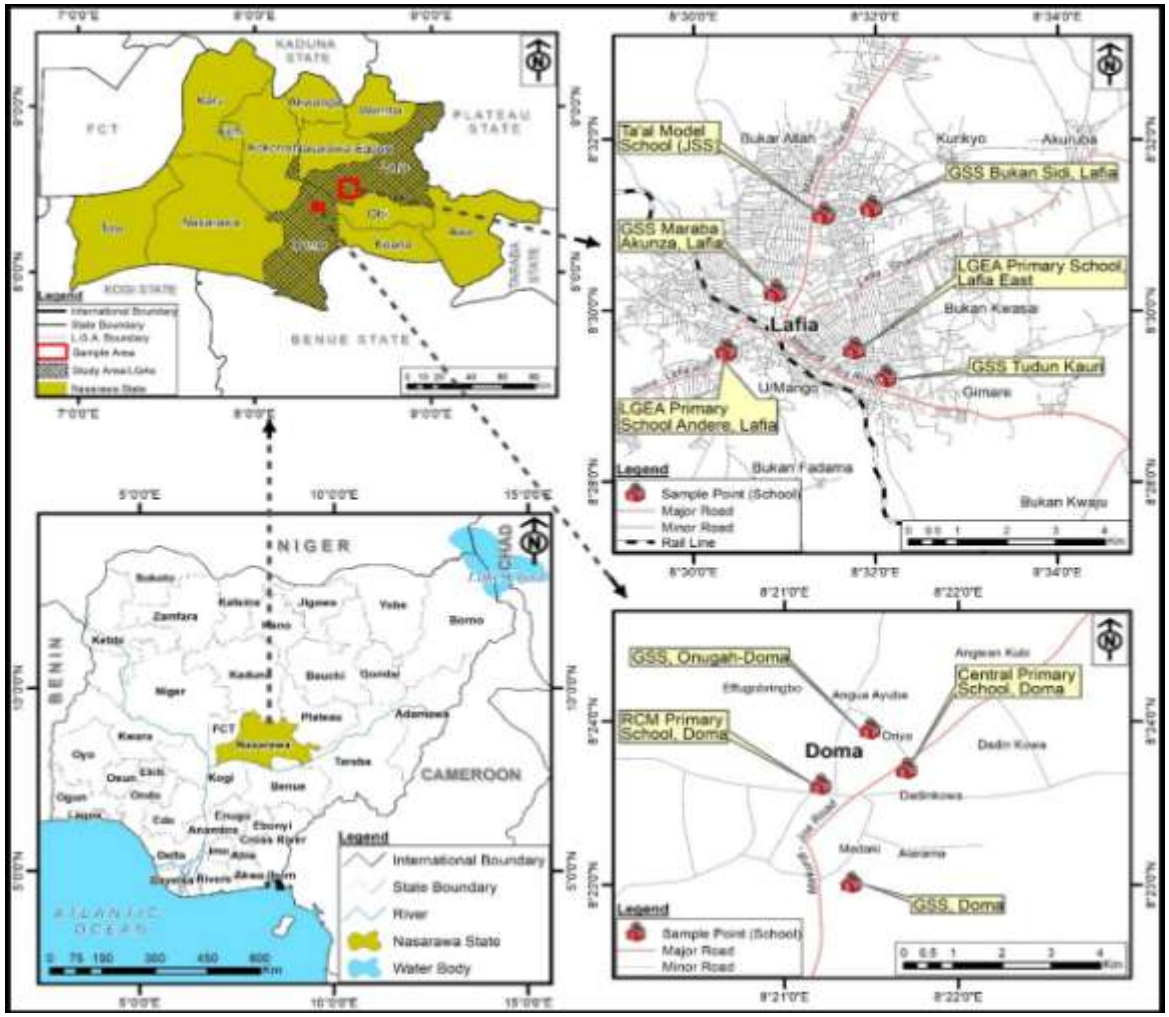

Figure 3.1: Sample Points in Doma and Lafia (Study Area)
Source: Modified from https://www.openstreetmap.org/#map=6/9.117/8.674