# THE EVALUATION OF POTENTIAL WEIGHT-ESTIMATION METHODS IN A PRIMARILY HIV POSITIVE COHORT IN BOTSWANA FOR USE IN RESOURCE LIMITED SETTINGS

by

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B.Sc., The University of British Columbia, 2010

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

The Faculty of Graduate Studies

(Human Nutrition)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

December 2012

## ABSTRACT

Appropriate drug dosing in children should be calculated based on a child's weight. In resource constrained settings however, inaccurate drug dosing is common due to the absence of working weight scales. Existing proxies for weight, such as those based on age or height, have been shown to be problematic, especially in populations in developing countries. Long bone measurements in children, such as ulna and tibia lengths, have yet to be studied as surrogate measures for weight.

The purpose of this study was 1) to examine the association between weight and a series of proxy anthropometric measurements including height, ulna and tibia lengths, mid-upper arm circumference (MUAC), and triceps skinfolds in a primarily HIV positive population of Botswana children (18 months – 12 years); 2) to determine what percentage of the study population has a predicted weight within 10% of their actual weight; and 3) to determine a simple weight-prediction method that would most accurately predict a child's weight (18 months – 12 years).

This study was a cross-sectional survey carried out in a clinical setting at the Botswana-Baylor Children's Clinical Center of Excellence in Gaborone, Botswana. We measured weight, height, mid-upper arm circumference (MUAC), triceps skinfolds, ulna length, and tibia length in 777 children between the ages of 18 months and 12 years. Univariate linear regression and multiple linear regression analysis were performed using SPSS and coefficients of determination ($R^2$) were calculated. Accuracy of the weight-prediction method was defined as having a predicted weight within 10% of the child's actual weight.

The MUAC-Tibia and the MUAC-Ulna weight-prediction models had the highest accuracy for predicting a child's weight with adjusted $R^2$ values of 0.95 and 0.94, respectively. Of the participants, 82% of weights were predicted to within 10% using the MUAC-Tibia method and 79% using the MUAC-Ulna method. Due to the high degree of accuracy, the MUAC-Tibia or MUAC-Ulna weight-prediction methods could potentially be used to estimate a child's weight. Studies are needed to confirm these findings in other resource poor settings where there is no access to working scales.

## PREFACE

This thesis is comprised of research conducted by myself, Roberta Wozniak, under the supervision of my graduate supervisor, Dr. Tim Green, as well as my supervisory committee members Dr. Judy McLean and Dr. Charles Larson. The study design was completed by Dr. Charles Larson, Dr. Tim Green, Dr. Judy McLean, and myself. I, along with Dr. Mia Pradinuk, completed the data collection that took place in Gaborone, Botswana.

My additional contributions to the research include setting up the study, compiling the survey questionnaire and training materials, and coordinating the data collection. The staff from the Botswana-Baylor Children's Clinical Center of Excellence was responsible for recruitment of participants and the translation of the consent form and survey into the local language of Setswana. The data analysis was primarily completed by me under the guidance and supervision of Dr. Tim Green. The writing in this manuscript is comprised primarily of my work. There will be sections of this thesis submitted to peer reviewed journals for publication.

Ethical approval for this study was provided by the UBC Children's and Women's Research Ethics Board (Certificate Number: H11-01052).

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| | |
|---|---|
| **LBW** | low birth weight |
| **WHO** | World Health Organization |
| **MDG** | Millennium Development Goal |
| **UN** | United Nations |
| **SAM** | severe acute malnutrition |
| **MUAC** | mid-upper arm circumference |
| **BMI** | body mass index |
| **IMCI** | integrated management of childhood illness |
| **ARV** | antiretroviral |
| **EML** | essential medicines list |
| **UNICEF** | United Nations Children's Fund |
| **HIV** | human immunodeficiency virus |
| **APLS** | Advanced Pediatric Life Support |
| **ARC** | Australian Resuscitation Council |
| **NCHS** | National Center for Health Statistics |
| **UK** | United Kingdom |
| **DWEM** | devised weight estimation method |
| **COE** | Botswana-Baylor Children's Clinical Center of Excellence |
| **HAART** | highly active antiretroviral therapy |
| **FANTA** | Food and Nutrition Technical Assistance |
| **USAID** | United States Agency for International Development |
| **PMTCT** | prevention of mother-to-child transmission |

## ACKNOWLEDGMENTS

First and foremost I would like to extend my sincerest gratitude to my supervisor, Dr. Tim Green, and my committee members Dr. Judy McLean and Dr. Charles Larson. Your expertise and encouragement were much appreciated. Thank you Dr. Green for all the countless hours you put into teaching me SPSS, I could not have done it without you.

Thank you to the staff at the Botswana-Baylor Children's Clinical Center of Excellence in Gaborone, Botswana. Your guidance and support throughout 10 weeks of data collection made it possible for us to reach our goal of measuring 800 children. Dr. Mia Pradinuk, my research partner, I could not have done it without your help and laughter. And to all the beautiful children we measured: your strength and optimism is inspiring.

It is hard to believe that my journey over the last 3 years began with an undergraduate course in international nutrition. Dr. Judy McLean introduced me to and ignited my passion for the fascinating world of international nutrition, and for that I will be forever grateful. From there, Judy gave me the opportunity to be involved in a study in Rwanda and assist her on a UN project in Cambodia. Judy's generosity, compassion, and support are endless and I am so thankful for everything she has done for me.

Finally, the support of my parents, Marilyn and Graham, has always been continual and unconditional. Whether it has been pursuing a professional career in dance or helping malnourished children in rural Rwanda, they have always encouraged me to follow my passion, work hard, and persevere.

# Chapter 1: INTRODUCTION

## 1.1. Background

Weight measurements in children are important for determining and tracking nutritional status as well as for appropriate drug dosing. A drug dose that is dependent on a child's weight should be calculated using a mg/kg body weight formula to determine the correct amount of medication the child should be administered. In ideal settings, a child is weighed on a calibrated weight scale in order to calculate the appropriate dose. Weight scales, however, are not always available to obtain an accurate body weight measurement for a child, such as in emergency situations or in resource limited settings. Therefore, a proxy measure for weight that can be used to estimate a child's weight is a necessity when weight scales are impractical or unavailable.

Proxy measures based on age or height have been developed and validated mostly on Western populations. Tools based on height like the Broselow tape may be more effective at estimating a child's weight compared to age-based formulas. However, there is concern of its validity in resource poor settings where malnutrition may be prevalent. Long bone measurements like ulna and tibia length are simple surrogate measures of height and may be more appropriate proxies for weight in populations where malnutrition is prevalent. Ulna and tibia lengths, as well as mid-upper arm circumference, should be examined as potential proxy measures for weight, especially in resource limited settings.

## 1.2. Purpose of the Study

The purpose of this study was to determine if a child's weight could be accurately estimated using a proxy anthropometric measure for weight in the absence of a working scale in children 18 months to 12 years in Botswana.

## 1.3. Research Objectives

### *1.3.1. Primary Objectives*

1) To examine the association between the weight of children aged 18 months to12 years and a series of proxy anthropometric measurements including height, ulna and tibia lengths, mid-upper arm circumference, and triceps skinfolds in a primarily HIV positive population in Botswana.
2) To determine what percentage of the study population would have a predicted weight within 10% of their actual weight.
3) To develop a simple weight-prediction method that would predict a child's weight with an acceptable degree of accuracy (18 months – 12 years).

### *1.3.2. Secondary Objectives*

1) To compare the accuracy of the devised weight-prediction method against common existing methods used to estimate weight in children.
2) To determine the accuracy of a tape compared to a validated caliper for measuring ulna and tibia lengths.
3) To describe the nutritional status of the study population in terms of rates of stunting, underweight, and body mass index-for age.

# Chapter 2: LITERATURE REVIEW

## 2.1. Importance of Measuring Weight and Height in Children

Measuring a child's weight and height is something that is often done from birth. Determining and tracking a child's weight and height allows health care providers to gain valuable information regarding the health of the child. There are many reasons for measuring a child's weight or height, such as for monitoring growth, determining nutritional status, and for formulating appropriate drug dosages.

### *2.1.1. Low Birth Weight*

A low birth weight (LBW) baby is defined by the World Health Organization (WHO) as an infant at birth who weighs less than 2,500 grams. (1) A LBW baby can have severe, if not fatal, health outcomes and they are at a much greater risk of dying than a baby born at a healthy weight. (1) Globally, 14% of children born each year are LBW, but they account for around 70% of all neonatal deaths. (2) In addition, being born with a low birth weight is closely linked to inhibited growth, reduced cognitive development, and an increased risk of chronic disease later in life. (1) Therefore, weighing a child at birth is important for determining whether a baby has an increased risk of death or complications, and thus appropriate actions can be taken.

On a population level, it is important to have data on birth weight for monitoring indicators for goals such as reducing child mortality rates as part of the Millennium Development Goals (MDGs), and goals set in 'A World Fit for Children', from the United Nations Declaration and Plan of Action. (1) While birth weight is one key health indicator, tracking height and weight over childhood can provide further information regarding health and nutrition status of the child.

### *2.1.2. Growth and Nutrition Monitoring*

Determining a child's height, weight, and age are important measurements for use in growth monitoring and indicators of malnutrition. On a global scale, the use of growth charts can help governmental, non-governmental, and United Nations (UN) agencies track the nutritional status of populations. This is important for formulating interventions and health policies, and being able to monitor the programs and assess their effectiveness. (3)

On an individual level, anthropometric measurements can be monitored over the course of childhood to assess whether a child is faltering in their growth. (4) The WHO Child Growth Standards, which were developed in 2006, are commonly used to identify children less than 5 years of age with malnutrition, including undernutrition and obesity. (5) In addition, the WHO established a growth reference for school-aged children and adolescents in 2007 for use in children 5-19 years. (6)

Indices for undernutrition including height-for-age, weight-for-height, and weight-for-age are used to identify nutritional conditions such as stunting, wasting, and underweight, respectively. Cut-off values used to classify low height-for-age (stunting), low weight-for-height (wasting), and low weight-for-age (underweight), are defined as a child being two standard deviations below the reference mean based on data from the WHO Child Growth Standards for children under 5 and the WHO growth reference for school-aged children and adolescents. (3,6) Severe undernutrition is defined as a Z-score value less than 3 standard deviations of the reference mean. (3)

#### *2.1.2.1. Low Length/Height-for-Age (Stunting)*

Stunting, or a low length/height-for-age, indicates a child with previous or chronic undernutrition. (7) The term length-for-age is used for children under 2 years of age, while height-for-age refers to children over 2 years of age. (3)

A low length/height-for-age is due to a slowed growth in the fetus and into early childhood meaning the child does not reach their expected height compared to a child of the same age who is healthy and well-nourished. (7) Stunting is a result of growth failure due to an insufficient diet, frequent or recurring infections, or a combination of both. (7) The lasting effects of stunting are often detrimental to a child's health and intellectual capacity, and it puts the child at an increased risk of illness or even death. (7) Moreover, the effects of stunting are often irreversible once a child has reached 2 years of age. (7) As stunting is not a measure of current nutrition status, it should not be used to measure short-term changes in a child's nutritional status. (7)

#### *2.1.2.2. Low Weight-for-Height (Wasting)*

Wasting, or low weight-for-length/height, indicates a child with current or acute undernutrition. (5) A child who is wasted has most likely either had severe weight loss or has experienced a failure to gain weight. (5) The child has a weight much lower than what a healthy child of the same height or length would be expected to have. (7) Unlike children experiencing stunting, wasting can occur quickly in children and is sensitive to changes in seasonal food availability, or shortages, and disease prevalence. (7) Whereas stunting is often irreversible once a child reaches 2 years, wasting is commonly short-term and can be treated. (5)

Severe acute malnutrition (SAM) is defined as a child being less than 3 standard deviations of the WHO growth standards for weight-for-height. (5) SAM can also be defined as a mid-upper arm circumference (MUAC) of less than 115 mm. (5) Being able to measure children's height and weight, and even MUAC in field settings, is important for the identification of SAM in populations. (5) The ability to determine the prevalence of SAM can help inform organizations when and where therapeutic feeding programs and other interventions are needed. (5)

Body mass index (BMI) is another index that uses weight and height (BMI= weight, kg/ height, $m^2$) and is often used for adults. (8) BMI in children, however, varies by age so the reference data are specific to age. (9) The weight-for-height index targets children under the age of 5, while the BMI-for-age index can be used for children 5-19 years.

#### *2.1.2.3. Low Weight-for-Age (Underweight)*

Underweight, or low weight-for-age, is an indicator of both past and present undernutrition but is more difficult to interpret. (3) Underweight is a composite measure of stunting and wasting, but it cannot distinguish between the two measures. (7)

Underweight is used as the indicator of undernutrition in the first goal of the UN's MDGs, but has stirred up controversy. (10) As mentioned above, there is more than one indicator using anthropometric data to assess nutrition status in children. (11) There can also be overlap among the 3 indicators. For instance, a child could be underweight and wasted, or a child could be stunted but not underweight, or a child could be all three: stunted, wasted, and underweight. (10) Therefore, only using one indicator may not accurately reflect the true presence of

undernutrition in populations, thus all three indicators are important for assessing nutrition status in children. (10)

### *2.1.3. Drug Dosing*

It is important that appropriate and correct administration of pediatric medications be given to children in order to treat illness and disease, and prevent death. Drug metabolism is correlated with lean body mass but for many pediatric drugs, correct dosages are calculated based on the child's weight. (12) The World Health Organization (WHO) and the integrated management of childhood illness (IMCI) guidelines state that drug dosing for pediatric medicines should be administered according to a child's weight or age. (13,14) Ideally, a child is weighed on an accurate scale and then a milligram per kilogram (mg/kg) body weight dose is administered, usually in the form of a syrup or portion of an adult fixed-dose. (14) Therefore, it is imperative for health workers to have a current and accurate weight for the child who is being prescribed a medication based on weight.

## 2.2. Drug Dosing Problems in Children

Globally, an estimated 25-75% of antibiotic dosages prescribed in teaching hospitals are inaccurate. (15) Recent studies conducted in Nigeria and other parts of sub-Saharan Africa found that over 50% of pediatric medications were being under or over dosed. (16) If recorded weights for children are inaccurate or unavailable, there is a risk of potentially under or over dosing medications. Over dosing of many pediatric medications can lead to toxicity. Underdosing a pediatric medication increases may result in the child not being treated for their illness or disease, or it could mean the child develops resistance to that drug. (17) While an inaccurate weight measurement may result in under or over dosing of a child, there are other problems that can arise when attempting to appropriately dose a child.

### *2.2.1. Adult Dose Extrapolation*

The WHO formulated an essential medicine list (EML) that could be adopted and reformulated to address the particular public health concerns of individual countries (Quick, 2002). The EML has been called a "successful public health initiative" (15); however, the EML concentrates on adult populations with minimal focus on pediatric formulations. (18)

Many pediatric medicines are scaled down from adult doses. (19) Extrapolation of adult doses may be safe and acceptable for children with any non-toxic drugs or drugs with wide therapeutic ranges, but drugs with narrower toxicity margins could be harmful to children if improperly dosed. (20) Children are physiologically different from adults and children absorb and metabolize drugs at different rates compared to adults. (21) For example, children under the age of 3 have low levels of acid in the stomach, which can affect the absorption of acid-sensitive drugs like penicillin by increasing absorption. (20) Absorption of rifampicin on the other hand, a drug used to treat tuberculosis, may be reduced in the low-acid environment of the child's stomach. (20) Therefore, extrapolating adult doses for children can increase the risk of inappropriately dosing a child. (22)

Manipulation of adult tablets like cutting or crushing the tablets can have other potentially harmful effects. (23) A protective coating usually ensures the contents of tablets are released in the small intestine (enteric coating) rather than the stomach; therefore, crushing or cutting tablets may increase a child's risk of stomach ulcers. (23) Cutting or crushing adult tablets also exposes the child to the unfavourable or bitter taste of the tablet's contents. (23)

In response to the problems associated with extrapolation from adult doses, work has been done to ascertain essential medicines and their optimal doses specific for children. The

WHO passed a resolution in 2007 called 'Better Medicines for Children', which includes addressing the need for improved dosage forms. (20) The resolution resulted in an EML for children, which was first published in 2007 with the latest version released in 2009. (23) Currently, the United Nations Children's Fund (UNICEF) and the WHO are advocating the use of dispersible tablets as the optimal dosage form for delivering drugs to children. (20,23)

### *2.2.2. Dispersible Tablets*

Dispersible tablets are solid tablets that disintegrate and dissolve when mixed with a small amount of water or breast milk. (24) Dispersible tablets are packaged in single doses in a solid state. When a dose is ready to be administered, it is ready within a few minutes after being added to liquid. (23) As a contrast to using adult doses, dispersible tablets have been specifically dosed for children ensuring that they are safe and appropriate for use in children of various ages and weights. (23) Some current drugs available in a dispersible tablet form for children include: rifampicin/isoniazid (tuberculosis), zinc sulfate (diarrhea), artemether/lumefantrine (malaria), lamivudine/stavudine (human immunodeficiency virus, HIV), amoxicillin (pneumonia), and paracetamol (pain and fever). (23)

One advantage of dispersible tablets is that they can be administered to infants who otherwise would not be able to swallow tablets. (24) Syrups are another way to administer drugs to very young children who have difficulty swallowing tablets. Syrup formulations, however, are difficult to administer at a correct dose. (24) Caregivers need to measure out a specific amount of syrup that has been calculated based on the child's weight, but measurement errors are common and can lead to an increased risk of over or under dosing. (24) On the contrary, dispersible tablets are dispensed as a fixed dose and thus require minimal manipulation which reduces the risk of dosage errors. (24,25)

Syrups are also difficult to transport and store due to refrigeration requirements. (24) Dispersible tablets are easily transported and are stable in blister packaging. (24) Another problem with syrups is that they are commonly in low concentrations so children may be required to swallow large volumes of syrup resulting in low compliance. (17,26) Dispersible tablets only require approximately 5-10 mL of liquid per dose, so minimal liquid is consumed even at higher doses. (24) In addition, dispersible tablets are relatively inexpensive in comparison to syrups. (24,26)

Dispersible tablets are easy to administer to children as they are prepared as fixed doses; however, this could also be seen as a potential disadvantage. One advantage of syrups over dispersible tablets is that a syrup dose can be easily altered depending on the weight of the child because syrup doses are calculated as a mg/kg body weight dose. (27) Dispersible tablets have a dose regime with only set doses (e.g. a 100 mg tablet of paracetamol divided into 4 doses: 0.5 tablet, 1 tablet, 1.5 tablets, 2 tablets), which means children of different weights could be administered the exact same dose. In order to guide a health care professional to which dose a child of a particular weight should receive, weight bands should be calculated for each drug being administered as dispersible tablets. (25)

### *2.2.3. Weight Banding*

The fixed-dose, scored tablets can be based upon weight bands in which a child who falls within a certain weight range would receive that fixed dose. (28) The use of weight bands with dispersible tablets eliminates dosage calculations, which can be time-consuming and susceptible to calculation errors. (26)

More research is needed to further understand optimal dosing formulations for pediatric populations including safety margins and therapeutic ranges for each pediatric drug. However, one thing remains constant: an accurate weight measurement is needed every time a weight-based drug dose is prescribed to a child.

## 2.3. When Weight Measurements are Unavailable

### *2.3.1. Emergencies*

Weighing a child using a scale is considered the 'gold standard' because it is the most accurate way to obtain the weight of a child. (29) However, calibrated weight scales are not always available or easily accessible in certain situations or settings. In emergency situations, obtaining an accurate weight for the child is one of the crucial first steps the clinician needs in order to progress with treatment. (30) Children undergoing resuscitation need the appropriate equipment size, defibrillation energy, fluid replacement rate, and medication dosage. (30-34) These critical steps in resuscitating a child require an accurate weight measurement. (28,30-34) However, delaying resuscitation in order to take a weight measurement using a scale is impractical, and often an estimated weight is used. (28,30-34) In addition, it may be difficult to move children to be weighed on a scale who are in the intensive care unit with severe trauma or pain. (12,35) Therefore, the need for a fast and reliable weight-estimation method is a necessity in pediatric emergencies and trauma when using a weight scale in unfeasible. (28,30-34)

### *2.3.2. Resource Limited Settings*

In many settings with limited resources, like rural health centers in developing countries, functioning or calibrated scales are lacking. (25) The WHO IMCI programs have been introduced in many developing countries to improve national health care systems, but recent

evaluations of these programs have exposed problems. (36) The Multi-Country Evaluation of IMCI Effectiveness, Cost and Impact identified problems in maintaining equipment, such as weight scales. (36,37) The cost of a simple electronic floor scale recommended by UNICEF is around US$90 and while some clinics may be able to afford the initial cost of the scale, maintaining the functionality of the scale does not occur. (7,25)

Therefore, there is urgency for the use of a proxy measure for weight that can be used in developing countries or other resource scarce settings in the absence of working scales.

## 2.4. Proxies for Weight

### *2.4.1. Existing Methods for Estimating Weight*

There is evidence suggesting visual assessment of weight by parents or clinicians is not accurate and methods to estimate a child's weight need to be based on a proxy for weight. (30,38-40) There have been many methods developed for estimating weight, mostly using age or height. (32-34)

#### *2.4.1.1. Age-Based Proxies for Weight*

Aged-based methods for estimating weight have been developed using formulas that allow for health care workers to simply put the child's age in years into a validated formula to get an estimated weight. (34) An advantage of using an age-based formula is that a health care worker can calculate a drug dose for a child without the child being present; so when the child visits the health clinic, a drug dose has already been prepared and is ready to be administered. (12,34) Another advantage of aged-based formulas is that it does not require any equipment, like a length board or tape measure. (12,34) In developing countries it can be difficult to purchase

and maintain expensive equipment used for anthropometric measurements. (34) A number of existing age-based formulas are listed in **Table 1**.

**Table 1. Existing age-based formulas for estimating weight in children**

| Source | Year | Location | Age Range, yrs | Calculation |
|---|---|---|---|---|
| Advanced Pediatric Life Support (APLS) (41) | 2005 | UK | 1 – 10 | $W = 2 (a + 4)$ |
| Luscombe (35) | 2007 | UK | 1 – 10 | $W = 3a + 7$ |
| Argall (29) | 2003 | UK | 1 – 10 | $W = 3a + 6$ |
| Theron (42) | 2005 | New Zealand | 1 – 10 | $W = e^{[2.197099 + (0.175571a)]}$ |
| Shann (42) | 2005 | New Zealand | 1 – 9 | $W = 2a + 9$ |
| | | | 10+ | $W = 3a$ |
| Nelson (43) | 2004 | USA | 1 – 6 | $W = 2a + 8$ |
| | | | 7 – 12 | $W = 0.5 (7a – 5)$ |
| Australian Recuscitation Council (ARC) (44) | 2006 | Australia | 1 – 9 | $W = 2a + 8$ |
| | | | 10+ | $W = 3.3a$ |

W = weight, kg
a = age in years

One of the most widely used age-based formulas for children 1-10 years is the advanced pediatric life support (APLS) formula. The original APLS formula was derived in 1977 using the National Center for Health Statistics (NCHS) data in the United States and is taught on the APLS course in the United Kingdom (UK). (12,45) The formula uses the child's age in years from their most recent birthday, and is as follows:

**Weight estimation, kg = 2 x (age in years + 4)**

The APLS formula has been a part of resuscitation training and guidelines for treatment in many countries globally. (46) For instance, the guidelines for the IMCI produced by the WHO recommend the use of the APLS formula for calculating drug doses and fluid volumes in children. (46,47) However, with the average weight of children on the rise and obesity rates increasing, there is concern in the scientific community that the APLS formula currently underestimates weight in pediatric populations in developed countries. (29,35,42,46,48)

Luscombe and Owens (35) conducted a large-scale study in 2005 with 17 244 children from the UK from 1-10 years of age. When the researchers tested the current APLS formula (weight = 2 x (age + 4)), they found that weight was underestimated by an average of 18.8%. (35) The authors worried that this underestimation would result in underdosing of pediatric drugs and fluids, which could result in complications and additional risks to the child's health. (35) Therefore, Luscombe and Owens derived a new, updated formula to correct for the increasing weights of the 'modern day child', which only found to underestimate weight by 2.5%. (35) The Luscombe and Owens formula is as follows:

**Weight estimation, kg = (3 x age in years) + 7**

Similar findings were observed in studies conducted in Australia and the UK in that the APLS formula underestimated weight in children. (48-51) On the contrary, weights are not increasing in children in developing countries like they are in children in developed countries, and a number of researchers have questioned the validity of the APLS formula in developing countries. (12,30,32,34,46,52,52) Several studies have validated the APLS formula, but they have been in Western countries including the study by Luscombe and Owens. (30,46,52) Only a

few studies have examined how accurate age-based formulas are at estimating weight in developing countries.

Varghese et al (53) found that the APLS formula overestimated weight by a mean of 2-3 kg in a study of 500 Indian children between the ages of 1 month and 12 years. A study conducted in South African children aged 1-10 years in 2010 found that the original APLS formula predicted weight better than the revised Luscombe and Owens formula. (12) Moreover, the authors found that the Luscombe and Owens formula overestimated weight by a mean of 12.4% in the study population. (12)

If the APLS formula has been developed in populations of well-nourished children, many researchers have hypothesized it will overestimate weight in populations in developing countries where children are more likely to have a low weight-for-age. (32,46,52,53) In addition to a possible overestimation of weight, another problem associated with age-based weight estimation methods in developing countries is that parents or caregivers may be unsure of the child's age, which is common in many low income countries. (32) The use of length-based methods for estimating weight has also been investigated as a proxy for weight and may be more accurate than age-based formulas.

#### *2.4.1.2. Length/Height-Based Proxies for Weight*

More and more countries are switching from recommending the use of age-based methods of estimating weight, such as the APLS formula, to length-based methods, like the Broselow tape. (12) Other methods using height include the devised weight estimation method (DWEM) (54), Traub-Johnson (55), Traub-Kichen (56), and Oakley (57). However, the Broselow tape is one of the most common weight estimation methods used for children. (30)

The Broselow tape was developed by James Broselow in 1986 using the National Center for Health Statistics (NCHS) data. (58) The NCHS data collected between 1963 and 1975 is from a nationwide sample of over 20 000 children up to age 18 living in the United States. (58) Broselow used this data and calculated the 50$^{th}$ percentile for weight-for-height. (58) The result was the Broselow tape: a tape measure for children between 46 cm and 143 cm with nine colour-coded zones representing ranges of weight estimates. (58) To use the Broselow tape, the child lays horizontal and one end of the tape is placed at the head with the colour-coded weight zones placed at the feet. (31) Each weight range provides drug dosages and the appropriate equipment sizes for children who fall into that particular weight range. (32)

Multiple studies have been conducted comparing different methods for estimating weight in children and results have shown that the Broselow tape more accurately predicts children's weights over age-based methods, such as the APLS formula. (28,30,31) Moreover, researchers have stated that age-based formulas should not be used when another method is available. (30,31) However, as obesity rates in children have increased, some recent studies conducted in developed countries have found that the Broselow tape underestimated weight, much like the APLS formula did in similar populations. (42,51,59-61) Most of these studies have had small sample sizes and have been in specific populations (e.g. First Nations children), (59) so further research is needed to determine if the Broselow tape has a tendency to underestimate weight. (32)

While the Broselow tape has been validated in many developed countries, there have been only 4 studies that have been conducted in children living in developing countries. (32) The first study, conducted in India by Varghese et al (53) and published in 2006, included a sample of 500 children between the ages of 1 month and 12 years. Overall, the Broselow tape accurately

predicted weight over the entire weight range and was a better predictor than the Argall, Nelson, and APLS formulas. (53) Although the Broselow tape performed the best, there was a slight tendency for it to overestimate weight in children weighing over 15 kg. (53)

The second study published in 2008 by Ramarajan et al (30), was also conducted in India. The 548 participants in the study were mostly poor and undernourished children between the ages of 1 month to 12 years. (30) The Broselow tape, on average, overestimated weight in children over 10 kg by at least 10%. (30) The authors added a 10% correction factor in order to adjust for the overestimation and better predict the weights of the children over 10 kg in their sample. (30)

The third study, published in 2011 by Geduld and colleagues (12), was conducted in 2 832 children aged 1-10 years in Cape Town, South Africa. Approximately 64% of the children had an estimated weight within 10% of their actual weight when the Broselow tape was used to estimate weight. (12) There was a slight tendency to underestimate weight, but overall the authors concluded that the Broselow tape was the most accurate method for estimating weight in their population. (12) However, the study took place in one hospital in Cape Town where average incomes are most likely higher than other parts of the country; therefore, the sample may not be representative of the entire country of South Africa. (12)

The final study to be conducted in a developing country took place in Kenya. House et al (32) published a study in 2012 that compared the Broselow tape to two age-based methods, APLS and Nelson's formula in 967 children under the age of 14 years. Findings were similar to those from previous studies in which the Broselow tape predicted weight better than the age-based formulas. (32) Approximately 66% of children were classified within the appropriate

colour zone for weight. (32) There was a small overestimation of weight using the Broselow tape with 24% of the children being misclassified by one colour zone, and this was mostly observed in children over 18 kg. (32) However, House et al recommended the use of the Broselow tape in the Kenyan population.

In summary, the Broselow tape was found to be the most accurate method for estimating weight in children in developing countries. The tape is easy to use and requires minimal training and education. (32) However, a potential obstacle of its acceptability and use is the cost of the tape. (30,53,32) Also, some populations showed a tendency for the Broselow tape to overestimate weight in pediatric populations. The Broselow tape was derived from weight-to-height correlations in well nourished, Western populations; therefore, its use may not be applicable to undernourished populations. If children are undernourished and have a low weight-for-height, the Broselow tape may overestimate weight and therefore adjustments or alternate methods should be developed and validated for these populations.

### *2.4.2. Other Proxy Measures for Weight*

#### *2.4.2.1. Long Bone Measurements*

Other proxy measures for weight may be needed as an alternative to the Broselow tape or age-based formulas; one that is not expensive or derived from Western populations. In populations where stunting (low height-for-age) is prevalent, height-based methods for estimating weight is most likely going to be a better predictor of weight compared to age-based formulas. When taking height measurements, it is recommended to use a calibrated stadiometer or recumbent length board in order to obtain accurate measurements. In developing countries however, access to these pieces of equipment is limited. If height is difficult to measure in

developing countries but is a strong predictor of weight, a possible proxy for height could be used.

Proxy measures for height have been examined in pediatric populations where a height measurement is difficult or impossible to measure like in children with cerebral palsy, spinal deformity, or children with an amputated lower limb. (62) Arm span has commonly been used as an alternative for height, but measuring a child's arm span can be difficult as it depends on exact positioning. (62)

Long bone measurements have been examined as an alternative to arm span for predicting height in children with cerebral palsy and children without disability. (62-64) Distal limb measurements including ulna and tibia lengths are easily accessible, and have landmarks that are easy to palpate meaning greater reproducibility. (63) Studies have found that ulna and tibia lengths are highly correlated with height and could be used as a proxy measure when height measurements are unavailable. (62-64)

There have been many studies exploring ulna and tibia lengths as proxies for height, but there have been no studies examining their role in estimating weight. In developing countries, using lone bone measurements as an alternative for height could potentially be more acceptable in weight-estimation methods based on height.

#### *2.4.2.2. Mid-Upper Arm Circumference*

Mid-upper arm circumference (MUAC) is commonly used as a quick screening tool for assessing nutritional status in children. (32,33) A child with a MUAC measurement below the cut-off of 11.5 cm is classified as being severely malnourished (5). Currently, MUAC is not being recommended or used for estimating children's weight in clinical settings. (33) However, a

recent study conducted in Hong Kong by Cattermole et al (33) determined that MUAC correlated the strongest with weight compared to other measurements like age, height, and foot-length. Cattermole et al (33) derived a weight-estimation formula, called the MAC formula, based on a study population of 1 391 children aged 1-11 years: weight, kg = (MUAC, cm – 10) x 3. This formula was found to be a better predictor of weight in older children (≥ 8 years) compared to the Broselow tape and the APLS formula. (33) Overall however, the MAC formula predicted weight within 10% in 44% of the population whereas the Broselow tape estimated weight within 10% of actual weight in 58% of the population. (33)

The Cattermole et al study is the first to test a MUAC-based formula. (33) More studies are needed in other populations to explore the potential of using MUAC as a predictor for weight in children. (32,33)

## 2.5. Summary

Weight measurements in children are imperative for tracking and monitoring a child's growth and nutritional status, as well as appropriately dosing medications based on body weight. However, taking a child's weight on a calibrated weight scale is not always practical or accessible. In particular, access to working equipment, like weight scales, is limited in developing countries; therefore, a simple and accurate proxy measure for weight is vital.

Age-based formulas like the APLS and the Luscombe formula have been shown to be ineffective at accurately estimating weight in children and the Broselow tape may be more effective. However, because the Broselow tape has been derived based on Western data, there has been some disagreement amongst researchers on its accuracy in populations in developing countries. Alternative proxy measures for weight should be examined in populations where

undernutrition is prevalent. Long bone measurements, like ulna and tibia lengths, as well as MUAC, have yet to be validated in developing countries as potential proxy measures for weight.

# Chapter 3: METHODOLOGY

## 3.1. Overview of Study Design

The present study was a cross-sectional survey of children (18 months to 12 years) conducted in a clinical setting at the Botswana-Baylor Children's Clinical Center of Excellence (COE), in Gaborone, Botswana. The research project was a non-experimental study and each participant was surveyed once during the two-month data collection time-frame from July to August, 2011. The sampling method was a convenience sample of the Baylor clinic population and their families as the first 800 children, whose caregiver agreed to have them participate in the survey, were selected for our sample. Caregivers who agreed to have their child participate were asked to: a) give health and demographic information of the child participating; and b) allow for a series of 6 anthropometric measurements to be taken of the child participant.

## 3.2. Ethics

Ethics approval was obtained from the three institutions involved in the study: the Institutional Review Board from UBC (H11-01052); the Baylor College of Medicine in Texas; and the Ministry of Health's Health Research Development Committee in Botswana. The anthropometric measurements carried out on the children were minimally invasive and the study was deemed very low risk. Verbal consent was obtained from the caregiver of the child by a trained study nurse in the preferred language of the caregiver. Remuneration equivalent to an average half of a day's income was given to the caregiver, which went towards travel and meal costs related to voluntarily participating in the study. Remuneration was established according to the Botswana Ministry of Health research guidelines and was fixed at 30 Pula for the caregiver

and another 30 Pula for the child if they were over 5 years old (60 Pula equals approximately $8.00 CDN). See **Appendix A** for the consent form.

## 3.3. Setting

Participants in this study were recruited from the Botswana-Baylor Children's Clinical Center of Excellence (COE) in Gaborone, the capital city of Botswana. The COE facility opened in 2003 following the launch of the country's nation-wide antiretroviral (ARV) treatment program. The COE provides free highly active antiretroviral therapy (HAART) to children with HIV. The COE provides care and treatment for over 4000 children and families infected with HIV.

HIV-exposed infants are tested for HIV at 18 months of age and if they test positive, the infant is enrolled in a treatment program at the COE. Regular check-up appointments are scheduled at 3 month intervals, on average. Standard appointments usually consist of weighing the child and recording their height, an account of remaining medication, refilling medications as necessary, and an appointment with a pediatrician. In addition, patients of the COE receive social support, adherence information classes for parents and caregivers, and nutrition and growth monitoring.

## 3.4. Subjects

The proposed study sample size of 800 was decided upon based on the time period during which the data collection could occur at the clinic and the average number of patients visiting the clinic per day.

Children were eligible to participate in the study if they were between the ages of 18 months and 12 years, inclusive. This age range was targeted because the IMCI guidelines are

provided for children up to 12 years, and children are screened for HIV at the Baylor clinic at age 18 months. Although the population of children at the clinic is primarily HIV positive, we did not exclude any children based on their HIV status. Both children with HIV and children without HIV were included in the study and their HIV status was recorded. Children were excluded from the study if their caregiver did not provide verbal consent, or if one or more measurements could not be completed.

## 3.5. Recruitment

Recruitment for study participants occurred between July 5, 2011 and August 24, 2011. Participants were recruited by a clinic nurse trained for our study in one of two ways. Participants were either recruited from the waiting room of the clinic or contacted from a patient list provided by the clinic. Children within the appropriate age range who were recruited from the waiting room were either a clinic patient, were accompanying a family member who was a clinic patient, or their caregiver had heard about the study from other clinic patients and they wanted their child to participate in the study. Caregivers contacted from a patient list and asked to participate had children within the targeted age range who were either current or past patients of the clinic, or were family members of current or past clinic patients.

## 3.6. Data Collection

### *3.6.1. Procedures*

Caregivers of children attending the COE were approached by a study nurse in the waiting room upon arrival and following being checked-in at the reception desk. The potential participants were asked if they had a child with them between 18 months and 12 years and if they would be willing to hear more about the study. If the caregiver and their child agreed, the study

nurse would bring them into the study procedures room and describe the study and the study objectives.

A consent form was read to the caregiver in either English or Setswana, the local language, and verbal informed consent was given. The study nurse and one of the two study investigators signed the form as witnesses, confirming verbal consent was given. Once the caregiver and their child agreed to participate, children were prepared for anthropometric measurements by removing shoes and outdoor or excess clothing.

The caregiver was asked health and demographic survey questions pertaining to the child participant while one of the study investigators performed a series of six anthropometric measurements on the child. Upon completion of the survey, the caregiver and child participant received their remuneration from the study treasurer and provided either a signature or finger print as confirmation of receiving the funds.

### *3.6.2. Health and Demographic Data*

A short survey consisting of seven health history and demographic questions were asked of each caregiver whose child was participating (see **Appendix B**). Information obtained included the child's birthdate, gender, HIV status, ARV use, caregiver's age, number of people living in the household, and the main reason for attending the clinic on the day of the study. The questions provided on the survey were obtained from the Demographic Health Survey, and have thus been validated.

### *3.6.3. Anthropometric Measures*

The anthropometric measurements included weight, height, ulna length, tibia length, mid-upper arm circumference (MUAC), and triceps skinfolds. All step-by-step procedures were

strictly followed according to the 2003 Anthropometric Indicators Measurement Guide published by Food and Nutrition Technical Assistance (FANTA) (7), which is a program funded by the US Agency for International Development (USAID); thus, all measurement techniques performed in this study have been previously validated. All measurements were performed at least twice by the same investigator to assess intra-observer reliability. In addition, inter-observer reliability was assessed on 30 participants to test the agreement of measuring between the two study investigators on the same child.

#### *3.6.3.1. Weight*

Weight was obtained from a calibrated digital floor scale to the nearest 0.1 kg. No shoes or excess clothing was worn during weighing. If a child could not stand on the scale unassisted due to physical conditions or deformities, or if they were too young or frightened, the child was weighed indirectly. Indirect weighing was done by getting the caregiver to hold the child in his/her arms and recording a combined weight. The child was then passed to another family member or the study investigator and the caregiver was weighed on their own. The difference between the two weights was recorded as the child's weight. (7)

#### *3.6.3.2. Length/Height*

Length was taken using a recumbent length-board for children under 2, or if the child could not stand upright long enough to be accurately measured. The recumbent length-board could measure children up to 120 cm. Children were laid flat on the center of the board with their head at the top of the board and their feet pressed flat against the sliding base. (7)

Height was measured using a standing stadiometre for children over 2 years or those who could stand upright with minimal assistance. Children stood with their head, shoulders, back, and

feet against the board and legs straight with the child looking straight ahead. (7) Measurements were recorded to the nearest 0.1 cm. If the two repeat measurements were not within 0.5 cm of each other, a third measurement was taken.

#### *3.6.3.3. Ulna Length*

Ulna length measurements were taken with a long bone caliper as well as a measuring tape. The purpose of using two different measuring tools was to validate the use of the tape against the caliper, which is considered the gold standard for long bone measurements. The child's left arm was placed in front of the body on a flat surface with approximately a 90 degree bend in the elbow. With the fingers extended and together and palm flat against the surface, the length of the ulna was measured from the proximal end of the ulna to the tip of the styloid process at the wrist. (62) Measurements with each the tape and the caliper were recorded to the nearest 0.1 cm. If the two repeat measurements were not within 0.5 cm of each other, a third measurement was taken.

#### *3.6.3.4. Tibia Length*

Tibia length measurements were also taken with a long bone caliper as well as a measuring tape. The child's right leg was crossed over the left with the right ankle flexed over the left knee. The tibia length was measured from the proximal aspect of the right tibial plate and the distal end of the tibia at the ankle bone. Measurements with each the tape and the caliper were recorded to the nearest 0.1 cm. If the two repeat measurements were not within 0.5 cm of each other, a third measurement was taken.

#### *3.6.3.5. Mid-Upper Arm Circumference*

Mid-upper arm circumference (MUAC) was taken using a validated head circumference measuring tape. The midpoint of the child's left upper arm was located by measuring the length from the tip of the child's shoulder to the base of the elbow, found by bending the child's arm at a 90 degree angle. (7) With the arm relaxed at the child's side, the tape was wrapped with correct tension around the midpoint, marked at the triceps with a pen. (7) Measurements were recorded to the nearest 0.1 cm. If the two repeat measurements were not within 0.5 cm of each other, a third measurement was taken.

#### *3.6.3.6. Triceps Skinfolds*

Triceps skinfolds were taken by a validated caliper. With the left arm relaxed at the child's side, a vertical fold of skin was gently pulled away from the muscle right above the mark at the triceps made during the MUAC measurement. The caliper jaws were applied to the marked midpoint at a right angle. Measurements were recorded to the nearest millimetre. If the two repeat measurements were not within 3 mm of each other, a third measurement was taken.

## 3.7. Data Analysis

Statistical analyses were performed using SPSS, version 20.0.0 for Windows (SPSS Inc., Chicago, IL). Data was entered into Microsoft Excel 2010 by both study investigators on site, following each day data collection occurred. Participant responses were number coded prior to analysis and any identified entry or measurement errors were corrected or removed before any statistical analyses were conducted.

The multiple values for each of the anthropometric measurements were consolidated and the average for each measurement was used during analysis. Intra-rater variability was

determined by assessing the average variability within each of the two study investigators measurements. The data from the first 30 participants was used to determine inter-rater variability between the measurements of the two study investigators, as these 30 participants were measured by each of the two investigators.

The following forms of analyses were executed:

- Descriptive and summary statistics on the demographics of the study sample.
- Descriptive statistics using the World Health Organization's (WHO) Anthro Plus statistics program (version 1.0.4) to determine rates of underweight (low weight-for-age), stunting (low height-for-age), and BMI-for-age. Participants with a Z-score below 2 standard deviations of the mean were classified as moderately undernourished, and those below 3 standard deviations of the mean were classified as severely undernourished.
- Univariate General Linear Models were produced to determine weight-prediction regression equations using each of the 5 anthropometric measurements as independent variables and measured, or actual, weight as the outcome (dependent) variable.
- The coefficient of determination, $R^2$, was used to see how much of the total variability of the outcome (weight) could be accounted for by the predictor variable. A high $R^2$ value indicates that a large proportion of the variability in weight can be explained by the predictor variable being investigated.
- Multivariate General Linear Models were produced to determine if the addition of potential covariates like age and cofactors such as gender, HIV status, and ARV treatment significantly improved the weight-prediction models. Pairing of anthropometric measures was also included in the models to see if two predictor variables could give a better estimation of actual weight (e.g. MUAC and ulna length).

- Bland-Altman analysis (65) was conducted to determine the strength of agreement between the actual weight and the predicted weight using each of the weight-prediction models.
- Accuracy of the weight-prediction models were defined as having a predicted weight within 10% of the child's actual weight.
- The weight-prediction equations were validated by randomly dividing the study population into 2 samples (Sample 1 and Sample 2), and testing the accuracy of the regression equation developed from Sample 1 on Sample 2.
- The accuracy of existing weight-estimation methods were determined using the present study sample and compared against the accuracy of the weight-estimation methods derived in this study.

All correlation analyses and other results were considered significant if the p-value was less than 0.05 ($p<0.05$).

# Chapter 4: RESULTS

## 4.1. Recruitment

A total of 817 children were invited to take part in the study, of which 807 completed the survey. Nine caregivers declined consent to have their child measured, and one child was not surveyed due to a suspected measles infection. Therefore, the response rate was 807/817 or 98.8%. The pilot testing included the first 30 participants enrolled in the study during the first two days of the surveying period, and this data was used to measure inter-rater reliability between the two study investigators. These 30 participants were not included in the overall analysis. Seven-hundred and seventy-seven participants were included in the analysis.

## 4.2. Participant Characteristics

Participant characteristics, including gender and age demographics, participant HIV status and Antiretroviral (ARV) therapy use, relationship of caregiver, and the participant's reason for attending the clinic are presented in **Table 2**. The majority of participants were over 5 years (74%), and almost 32% of participants were between 10 and 12 years. About 80% of the study population was HIV positive, with 95% of those children receiving ARV therapy treatment. Almost three quarters of the participants were recruited on a day he/she had a scheduled follow-up appointment with the medical staff at the COE. Other reasons for the participant attending the clinic during the study period included: accompanying a family member (n=62); heard about the study and wanted to participate (n=54); were phoned and invited to participate (n=71); refilling of medications (n=10); and screening for HIV (n=10).

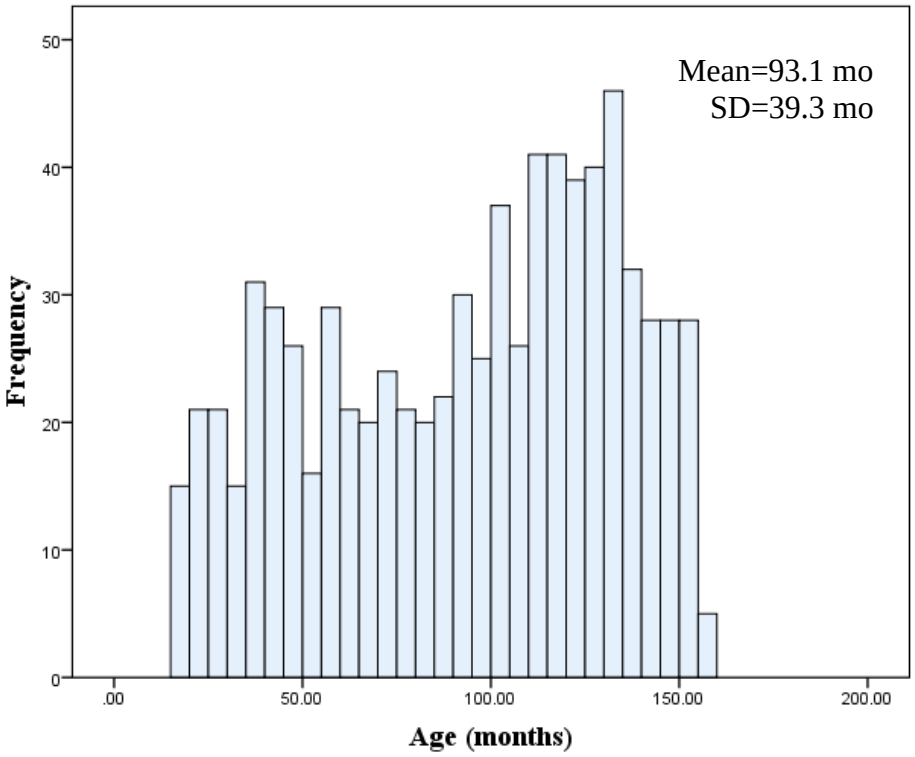
**Table 2. Participant characteristics**

| | Frequency, n | Percent |
|---|---|---|
| **Gender** | | |
| Male | 403 | 51.9% |
| Female | 374 | 48.1% |
| Total | 777 | 100% |
| **Age** | | |
| <24 months | 30 | 3.9% |
| 24 - <60 months | 173 | 22.3% |
| 60 - <120 months | 328 | 42.2% |
| 120 - <156 months | 246 | 31.7% |
| **HIV Status** | | |
| Negative | 129 | 16.6% |
| Positive | 625 | 80.4% |
| Unknown | 23 | 3.0% |
| **If HIV positive, on Antiretroviral therapy** | | |
| No | 31 | 5.0% |
| Yes | 594 | 95.0% |
| **Relationship of caregiver** | | |
| Mother | 481 | 61.9% |
| Father | 64 | 8.2% |
| Aunt/Uncle | 100 | 12.9% |
| Grandparent | 59 | 7.6% |
| Sibling/Cousin | 57 | 7.4% |
| Foster Parent | 12 | 1.5% |
| Not Specified | 4 | 0.5% |
| **Reason for attending clinic** | | |
| Check-up/Follow-up | 570 | 73.4% |
| Other | 207 | 26.6% |

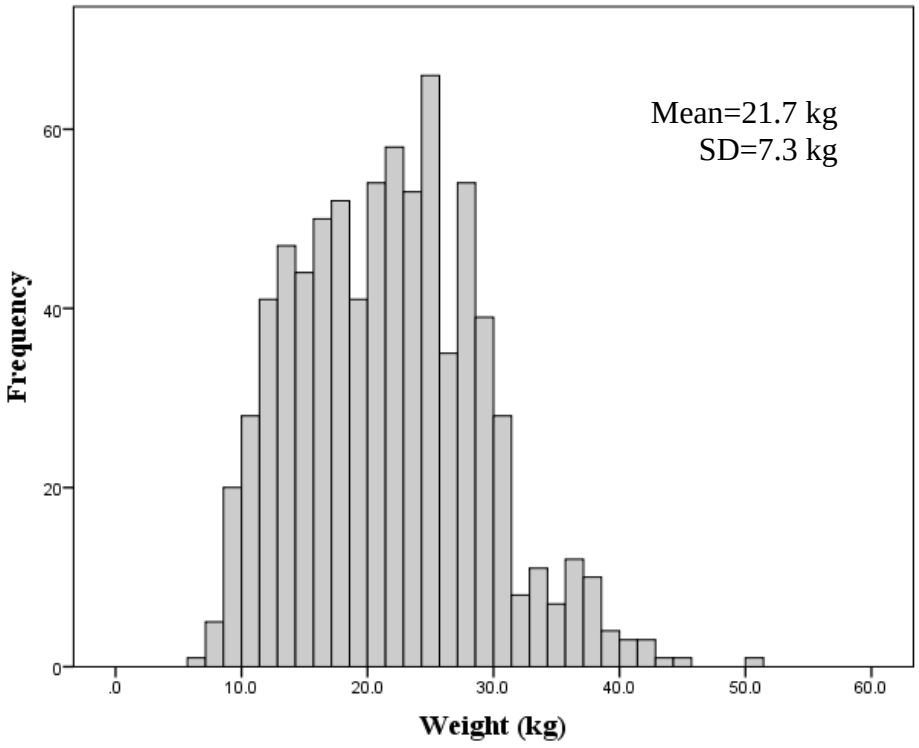
The distribution of participants by age, weight, and height are represented in **Figure 1**. Ages ranged from 18 months to 155 months (mean=93 months), weight ranged from 6.9 kg to 50.3 kg (mean=21.7 kg), and height ranged from 61.4 cm to 162 cm (mean=117.7 cm). The number and age distribution of participants categorized into eight weight groups is shown in **Table 3**.

**Figure 1. Distribution of participants by age (a), weight (b), and height (c)**

**(a) Age**



**(b) Weight**




**(c) Height**

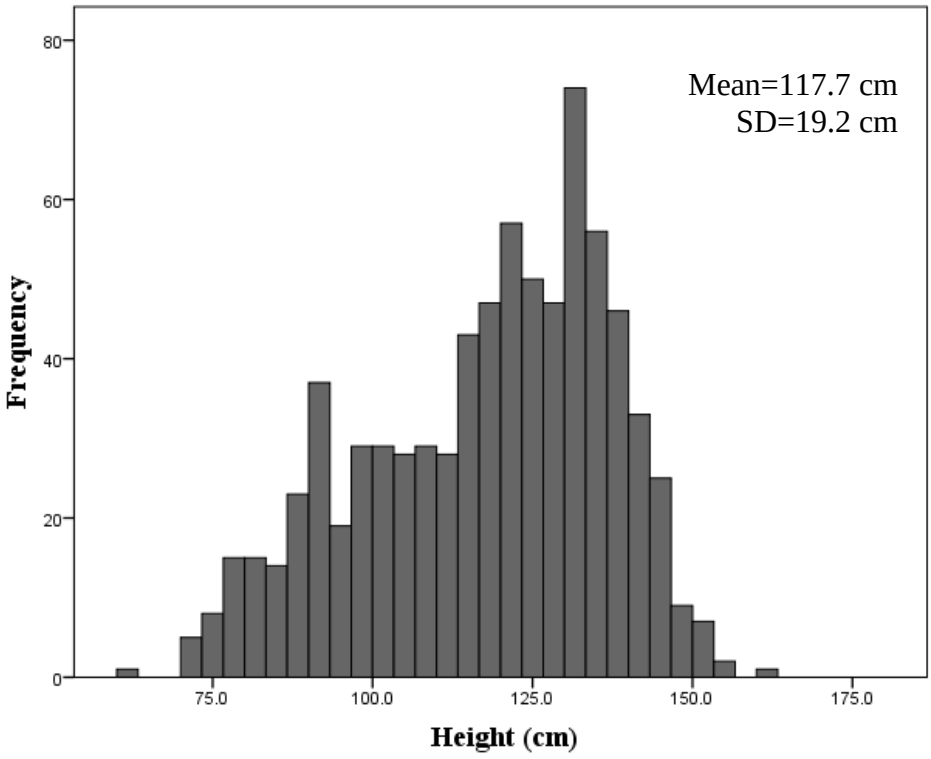


**Table 3. Age range and number of participants by weight group**

| Weight group *n* (kg) | Number in group | Median age in months | Minimum age in months | Maximum age in months |
|---|---|---|---|---|
| ≤10.0 | 28 | 21.65 | 17.16 | 37.22 |
| 10.1-15.0 | 139 | 40.96 | 18.15 | 91.43 |
| 15.1-20.0 | 164 | 70.83 | 26.73 | 137.26 |
| 20.1-25.0 | 193 | 107.08 | 52.11 | 152.02 |
| 25.1-30.0 | 165 | 126.74 | 56.88 | 155.64 |
| 30.1-40.0 | 80 | 139.96 | 111.06 | 155.84 |
| ≥40.1 | 8 | 138.94 | 128.88 | 154.45 |

Weight-for-age (**Table 4)**, length/height-for-age (**Table 5**), and BMI-for-age (**Table 6**) statistics were analyzed using the WHO Anthro Plus program (version 1.0.4). Data on the children less than 61 months of age are values based on the WHO standards and for children 61 months to 12 years, values based on the 2007 WHO reference data are used. Moderate undernutrition is defined as a Z-score of less than two standard deviations. Severe undernutrition is defined as a Z-score of less than three standard deviations. The number and percent of the study population who have a low weight-for-age (underweight), length/height-for-age (stunted), and BMI-for age are shown in **Table 7**. The severity of underweight was medium (19%) but was very high for stunting (42%). The severity of BMI-for-age was relatively low at 10%. For children under 5, approximately 11% were moderately stunted, 8% were underweight, and 12% had a low BMI-for-age.

**Table 4. Prevalence of low weight-for-age (underweight) in predominately HIV positive children (18 mo to 10 yrs) who are patients of the Botswana-Baylor Children's Clinic in Gaborone, Botswana**

| Age in months | Number (N) | % < -3 SD | 95% CI (%) | % <-2 SD | 95% CI (%) | Mean | Standard Deviation (SD) |
|---|---|---|---|---|---|---|---|
| 12-23 | 31 | 0 | (0, 1.6) | 0 | (0, 1.6) | 6.38 | 2.67 |
| 24-35 | 48 | 2.1 | (0, 7.2) | 6.3 | (0, 14.1) | 3.12 | 3.54 |
| 36-47 | 64 | 1.6 | (0, 5.4) | 6.3 | (0, 13) | 2.37 | 2.61 |
| 48-60 | 64 | 9.4 | (1.5, 17.3) | 10.9 | (2.5, 19.4) | 0.99 | 2.67 |
| 61-71 | 48 | 22.9 | (10, 35.8) | 33.3 | (19, 47.7) | -0.76 | 2.34 |
| 72-83 | 48 | 31.3 | (17.1, 45.4) | 35.4 | (20.8, 50) | -0.82 | 2.67 |
| 84-95 | 62 | 25.8 | (14.1, 37.5) | 32.3 | (19.8, 44.7) | -1.06 | 2.23 |
| 96-107 | 73 | 35.6 | (23.9, 47.3) | 42.5 | (30.4, 54.5) | -1.8 | 2.19 |
| 108-119 | 95 | 1.1 | (0, 3.6) | 1.1 | (0, 3.6) | -0.11 | 0.57 |

**Table 5. Prevalence of low length/height-for-age (stunting) in predominately HIV positive children (18 mo to 12 yrs) who are patients of the Botswana-Baylor Children's Clinic in Gaborone, Botswana**

| Age in months | Number (N) | % < -3 SD | 95% CI (%) | % <-2 SD | 95% CI (%) | Mean | Standard Deviation (SD) |
|---|---|---|---|---|---|---|---|
| 12-23 | 31 | 0 | (0, 1.6) | 0 | (0, 1.6) | 12.2 | 4.87 |
| 24-35 | 48 | 4.2 | (0, 10.9) | 6.3 | (0, 14.1) | 6.19 | 5.69 |
| 36-47 | 64 | 9.4 | (1.5, 17.3) | 9.4 | (1.5, 17.3) | 4.61 | 4.86 |
| 48-60 | 64 | 15.6 | (5.9, 25.3) | 20.3 | (9.7, 31) | 2.19 | 4.36 |
| 61-71 | 48 | 33.3 | (19, 47.7) | 33.3 | (19, 47.7) | -0.46 | 3.84 |
| 72-83 | 48 | 33.3 | (19, 47.7) | 35.4 | (20.8, 50) | -0.67 | 3.7 |
| 84-95 | 62 | 29 | (16.9, 41.1) | 35.5 | (22.8, 48.2) | -1.26 | 3.35 |
| 96-107 | 73 | 35.6 | (23.9, 47.3) | 42.5 | (30.4, 54.5) | -1.99 | 2.91 |
| 108-119 | 95 | 38.9 | (28.6, 49.3) | 51.6 | (41, 62.2) | -2.97 | 3.1 |
| 120-131 | 93 | 59.1 | (48.6, 69.7) | 73.1 | (63.6, 82.7) | -4.1 | 2.87 |
| 132-143 | 85 | 69.4 | (59, 79.8) | 85.9 | (77.9, 93.9) | -4.75 | 2.75 |

**Table 6. Prevalence of low BMI-for-age in predominately HIV positive children (18 mo to 12 yrs) who are patients of the Botswana-Baylor Children's Clinic in Gaborone, Botswana**

| Age in months | Number (N) | % < -3 SD | 95% CI (%) | % <-2 SD | 95% CI (%) | Mean | Standard Deviation (SD) |
|---|---|---|---|---|---|---|---|
| 12-23 | 31 | 0 | (0, 1.6) | 6.5 | (0, 16.7) | -0.43 | 1.07 |
| 24-35 | 48 | 2.1 | (0, 7.2) | 8.3 | (0, 17.2) | -0.5 | 1.27 |
| 36-47 | 64 | 1.6 | (0, 5.4) | 6.3 | (0, 13) | -0.03 | 2.73 |
| 48-60 | 64 | 0 | (0, 0.8) | 1.6 | (0, 5.4) | -0.09 | 1.04 |
| 61-71 | 48 | 0 | (0, 1) | 8.3 | (0, 17.2) | -0.31 | 1 |
| 72-83 | 48 | 0 | (0, 1) | 0 | (0, 1) | -0.17 | 0.81 |
| 84-95 | 62 | 1.6 | (0, 5.6) | 4.8 | (0, 11) | -0.13 | 1.5 |
| 96-107 | 73 | 0 | (0, 0.7) | 5.5 | (0, 11.4) | -0.53 | 0.91 |
| 108-119 | 95 | 1.1 | (0, 3.6) | 11.6 | (4.6, 18.5) | -0.72 | 1.03 |
| 120-131 | 93 | 3.2 | (0, 7.4) | 18.3 | (9.9, 26.7) | -1.16 | 0.97 |
| 132-143 | 85 | 2.4 | (0, 6.2) | 24.7 | (14.9, 34.5) | -1.4 | 0.86 |

**Table 7. Total percent of the study population who are underweight (low weight-for-age), stunted (low height-for-age), and low BMI-for-age**

| Indicator | Total N | % <-3SD (*n*) | % <-2SD (*n*) |
|---|---|---|---|
| Weight-for-age | 533 | 14.4% (77) | 18.6% (99) |
| Height-for-age | 711 | 34.3% (244) | 41.9% (298) |
| BMI-for-age | 711 | 1.3% (9) | 10.0% (71) |

## 4.3. Inter-rater and Intra-rater Variability

Inter-rater variability was assessed on 30 participants. The 30 participants were surveyed twice, once by each of the two study investigators (R, M). Inter-rater variability is presented in **Table 8**. The average variability between the two investigators did not exceed 1% for weight, height, tibia (tape), and the mid-upper arm circumference (MUAC) measurement. Tibia (caliper), ulna (caliper), and ulna (tape) measurements were under an average of 2.5% variability. The triceps skinfolds measurement using a caliper had the greatest inter-rater variability with an average variability of 5.67%.

The intra-rater variability, presented in **Table 9**, assessed the variability within each of the two study investigators (R, M). Seven of the measurements were measured at least twice by the same investigator. Weight was not analyzed for intra-rater variability because only one weight measurement was taken for each child. The average variability did not exceed 1% for height, ulna (tape and caliper), tibia (tape and caliper), and MUAC measurements for both investigators. The triceps skinfolds measurement had a higher variability for both investigators compared to the other six measurements, but the average variability was still under 5%.

**Table 8. Inter-rater variability**

| Measurement | Average variability (%) | Minimum variability (%) | Maximum variability (%) |
|---|---|---|---|
| Weight | 0.14 | 0 | 0.49 |
| Height | 0.19 | 0 | 0.71 |
| Ulna (tape) | 1.47 | 0 | 5.32 |
| Ulna (caliper) | 2.17 | 0 | 6.54 |
| Tibia (tape) | 0.92 | 0 | 4.40 |
| Tibia (caliper) | 1.20 | 0 | 8.43 |
| MUAC | 0.98 | 0 | 3.23 |
| Triceps skinfolds | 5.67 | 0 | 28.57 |

**Table 9. Intra-rater variability**

| Surrogate Measure | [R] Average (range) % variability | [M] Average (range) % variability |
|---|---|---|
| Weight | - | - |
| Height | 0.28 (0-1.13) | 0.16 (0-6.48) |
| Ulna (tape) | 0.31 (0-3.75) | 0.76 (0-4.60) |
| Ulna (caliper) | 0.53 (0-7.79) | 0.78 (0-5.13) |
| Tibia (tape) | 0.39 (0-38.73) | 0.46 (0-6.57) |
| Tibia (caliper) | 0.41 (0-5.61) | 0.83 (0-31.81) |
| MUAC | 0.20 (0-3.00) | 0.42 (0-5.92) |
| Triceps skinfolds | 3.70 (0-28.57) | 4.08 0-50.00) |

## 4.4. Correlation between Caliper and Tape Measurements

Using univariate regression, a coefficient of determination ($R^2$) was calculated to determine the strength of the relationship between a tape and a caliper, the gold standard, for taking ulna and tibia lengths. Both ulna tape and caliper and tibia tape and caliper measurements were strongly correlated with an $R^2$ value of 0.993 for the ulna measurements, and $R^2$= 0.988 for the tibia measurements. The graphs and regression equations are depicted in **Figures 2** and **3**. Due to the high correlation between the tape and caliper, ulna and tibia measurements using the tape values were chosen to be used for the remainder of the analyses.

**Figure 2. Correlation between ulna lengths using a caliper vs. a tape**

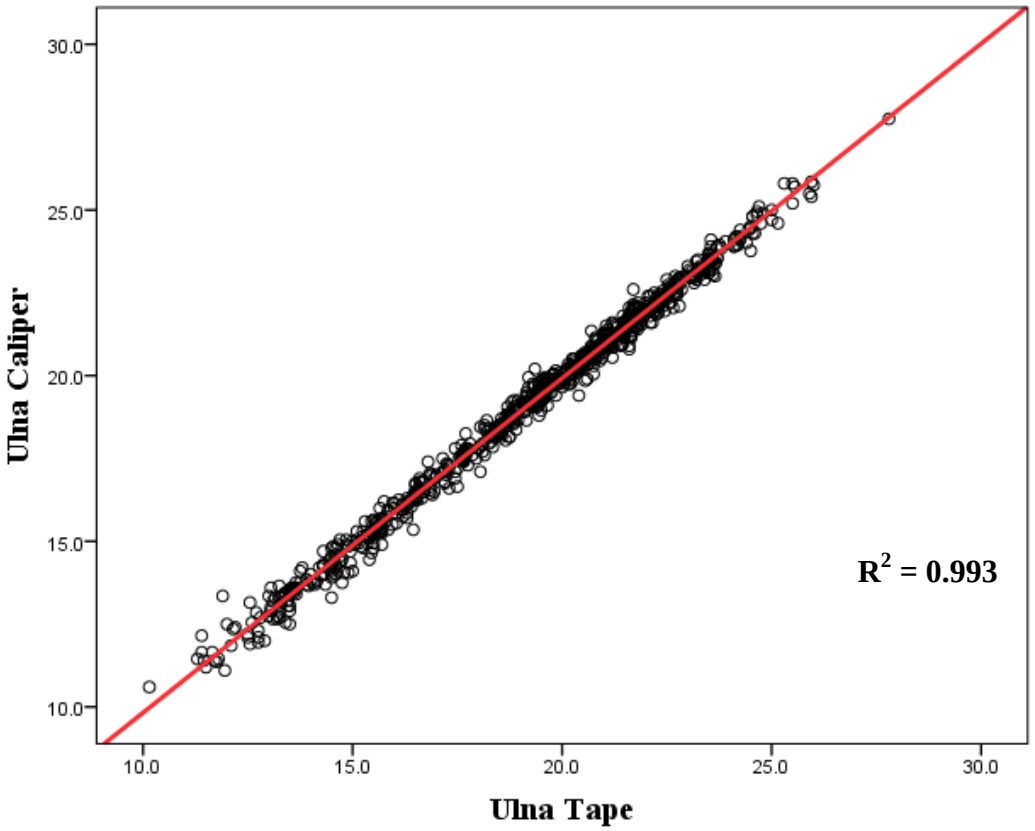
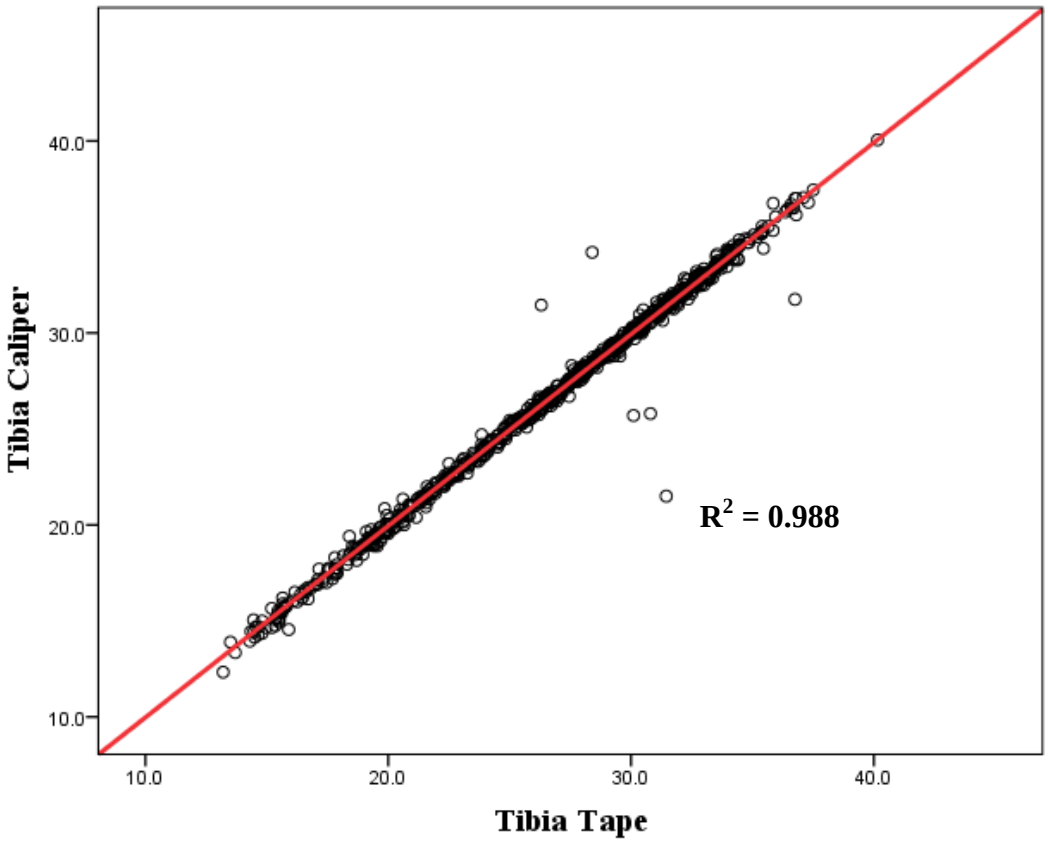


**Figure 3. Correlation between tibia lengths using a caliper vs. a tape**




## 4.5. Univariate Analysis Using Weight and Anthropometric Measurements

Using univariate linear regression analysis, prediction equations for weight with each of the anthropometric measurements were determined. The weight-prediction equations, along with the adjusted $R^2$ values and the root mean square of the error are presented in **Table 10**. Height, ulna length, and tibia length, were moderately strong predictors of weight with adjusted coefficients of determination ($R^2$) equating to 0.87, 0.86, and 0.84, respectively. The triceps skinfolds measure did not predict weight (p=0.152).

**Table 10. Univariate analysis of prediction equations for weight estimation**

| Surrogate Measure | Prediction equation for weight | Adjusted $R^2$ | RMSE |
|---|---|---|---|
| Age | W=0.162*A*+6.589 | 0.764 | 12.533 |
| Height | W=0.355*H*-20.116 | 0.870 | 6.885 |
| Ulna | W=2.026*U*-17.056 | 0.859 | 7.494 |
| Tibia | W=1.215*T*-10.869 | 0.841 | 8.439 |
| MUAC | W=3.271*M*-33.684 | 0.656 | 18.251 |
| Triceps | W=0.126*S*+20.647 | 0.001 | 53.029 |

*RMSE, root mean square of the error; W, weight (kg); A, age (months); G, gender; H, height (cm); U, ulna length (cm); T, tibia length (cm); M, mid-upper arm circumference (cm); S, triceps skinfold (mm)*

## 4.6. Accuracy of the Univariate Weight-Prediction Models

How well the univariate weight-prediction model accurately predicted actual weight was measured by percentage agreement. The proportion of the study population who had a predicted weight within 5%, 10%, and 15% of their actual weight, using each of the six univariate linear regression models, are presented in **Table 11.** The weight-prediction models using height, ulna length, and tibia length had the greatest percentage agreement with 60.5% of the children having a predicted weight within 10% of their actual weight using the height model; 61.3% using the ulna model; and 55.7% using the tibia model.

**Table 11. Percentage agreement between the predicted weight and the actual weight for each univariate weight-prediction model**

| Weight-Prediction Model (Univariate) | Percentage in agreement within: | | |
|---|---|---|---|
| | 5% of actual weight (*n*) | 10% of actual weight (*n*) | 15% of actual weight (*n*) |
| Age | 26.9 (209) | 52.2 (406) | 69.5 (540) |
| Height | 35.1 (273) | 60.5 (470) | 81.3 (632) |
| Ulna | 30.9 (240) | 61.3 (476) | 80.3 (624) |
| Tibia | 30.4 (236) | 55.7 (433) | 76.8 (597) |
| MUAC | 18.4 (143) | 36.2 (281) | 56.0 (435) |
| Triceps | 10.6 (82) | 20.7 (161) | 32.2 (250) |

## 4.7. Multivariate Analysis Using Weight, Anthropometric Measures, and Other Potential Confounding Variables

Additional potential covariates like age, and cofactors like gender, HIV status, and ARV therapy use, were included in the linear regression models for each of the anthropometric measurements (height, ulna length, tibia length, MUAC, and triceps skinfolds) to determine if accuracy of the weight prediction could be improved. The β values (slopes) and the p-values for each of the added confounders are shown in **Table 12**. HIV status and ARV therapy use were not significant predictors of weight for any of the anthropometric measures (p-values>0.05). Age was found to be a significant predictor of weight in the ulna, tibia, MUAC, and triceps skinfolds weight-prediction models. In addition to age, gender was also a significant predictor of weight for the MUAC and triceps skinfolds models.

**Table 12. Examination of the effects of cofactors and covariates on the relationship between proxy measures for weight and actual weight**

| Surrogate Measure | β values (95% CI) | *P* value |
|---|---|---|
| **1) Height (per cm)** | 0.362 (0.333, 0.390) | <0.0001* |
| Age (per month) | -0.001 (-0.016, 0.013) | 0.849 |
| Gender<br>Male (n=403) vs. Female (n=374) | 0.264 (-0.106, 0.634) | 0.162 |
| HIV<br>Negative or Unknown (n=152) vs. Positive (n=625) | 0.838 (0.661, 1.014) | 0.090 |
| ARV<br>No (n=183) vs. Yes (n=594) | -0.317 (-1.189, 0.554) | 0.475 |
| **2) Ulna Length (per cm)** | 1.773 (1.622, 1.925) | <0.0001* |
| Age (per month) | 0.025 (0.012, 0.039) | <0.0001* |
| Gender<br>Male (n=403) vs. Female (n=374) | -0.207 (-0.591, 0.176) | 0.289 |
| HIV<br>Negative or Unknown (n=152) vs. Positive (n=625) | 0.755 (-0.225, 1.735) | 0.131 |
| ARV<br>No (n=183) vs. Yes (n=594) | -0.191 (-1.093, 0.712) | 0.678 |
| **3) Tibia Length (per cm)** | 1.055 (0.949, 1.162) | <0.0001* |
| Age (per month) | 0.026 (0.011, 0.041) | 0.001* |
| Gender<br>Male (n=403) vs. Female (n=374) | 0.353 (-0.054, 0.761) | 0.089 |
| HIV<br>Negative or Unknown (n=152) vs. Positive (n=625) | 0.850 (-0.190, 1.891) | 0.109 |
| ARV<br>No (n=183) vs. Yes (n=594) | -0.339 (-1.299, 0.620) | 0.487 |
| **4) MUAC (per cm)** | 1.887 (1.784, 1.989) | <0.0001* |
| Age (per month) | 0.114 (0.108, 0.119) | <0.0001* |
| Gender<br>Male (n=403) vs. Female (n=374) | 0.372 (0.068, 0.675) | 0.017* |

| | | |
|---|---|---|
| HIV<br>Negative or Unknown (n=152) vs. Positive (n=625) | -0.183 (-0.962, 0.696) | 0.645 |
| ARV<br>No (n=183) vs. Yes (n=594) | 0.243 (-0.471, 0.957) | 0.504 |
| **5) Triceps Skinfolds (per mm)** | 0.578 (0.500, 0.655) | <0.0001* |
| Age (per month) | 0.173 (0.167, 0.180) | <0.0001* |
| Gender<br>Male (n=403) vs. Female (n=374) | 0.740 (0.292, 1.188) | 0.001* |
| HIV<br>Negative or Unknown (n=152) vs. Positive (n=625) | 0.911 (-0.213, 2.035) | 0.112 |
| ARV<br>No (n=183) vs. Yes (n=594) | -0.271 (-1.308, 0.765) | 0.608 |

*Significant at $p<0.05$

The insignificant confounders were excluded from further analysis and only the significant confounders ($p<0.05$) were included in the models. The linear regression equations and adjusted $R^2$ values for each of the weight-prediction models, also separated by gender, are presented in **Table 13**. A comparison of adjusted $R^2$ values between the simple univariate regression model and the model including the significant confounders are shown in **Table 14**. Age improved the model only a minimal amount for both the ulna and tibia models. The addition of age and gender into the MUAC and triceps skinfolds regression equations improved both models: a 26% improvement in the MUAC $R^2$ value, and an 82% improvement in the triceps skinfolds $R^2$ value.

**Table 13. Regression equations for predicting weight using weight-estimation models**

| Surrogate Measure | Prediction equation for weight | Adjusted $R^2$ | RMSE |
|---|---|---|---|
| **Both genders (*n*=777)** | | | |
| Height | W=0.355*H*-20.116 | 0.870 | 6.885 |
| Ulna | W=1.784*U*+0.022*A*-14.495 | 0.861 | 7.393 |
| Tibia | W=1.059*T*+0.023*A*-8.870 | 0.843 | 8.347 |
| MUAC | W=1.888*M*+0.113*A*+0.366*G*-21.018 | 0.913 | 4.611 |
| Triceps | W=0.587*S*+0.171*A*+0.751*G* | 0.817 | 9.735 |
| **Males (*n*=403)** | | | |
| Height | W=0.345*H*-18.799 | 0.873 | 6.240 |
| Ulna | W=1.580*U*+0.038*A*-12.170 | 0.859 | 6.904 |
| Tibia | W=0.959*T*+0.034*A*-7.038 | 0.848 | 7.450 |
| MUAC | W=1.792*M*+0.115*A*-19.175 | 0.907 | 4.546 |
| Triceps | W=0.494*S*+0.170*A*+2.125 | 0.818 | 8.937 |
| **Females (*n*=374)** | | | |
| Height | W=0.360*H*-20.800 | 0.855 | 8.334 |
| Ulna | W=2.048*U*-17.332 | 0.864 | 7.807 |
| Tibia | W=1.244*T*-11.859 | 0.840 | 9.218 |
| MUAC | W=1.962*M*+0.112*A*-22.198 | 0.919 | 4.669 |
| Triceps | W=0.662*S*+0.170*A* | 0.817 | 10.526 |

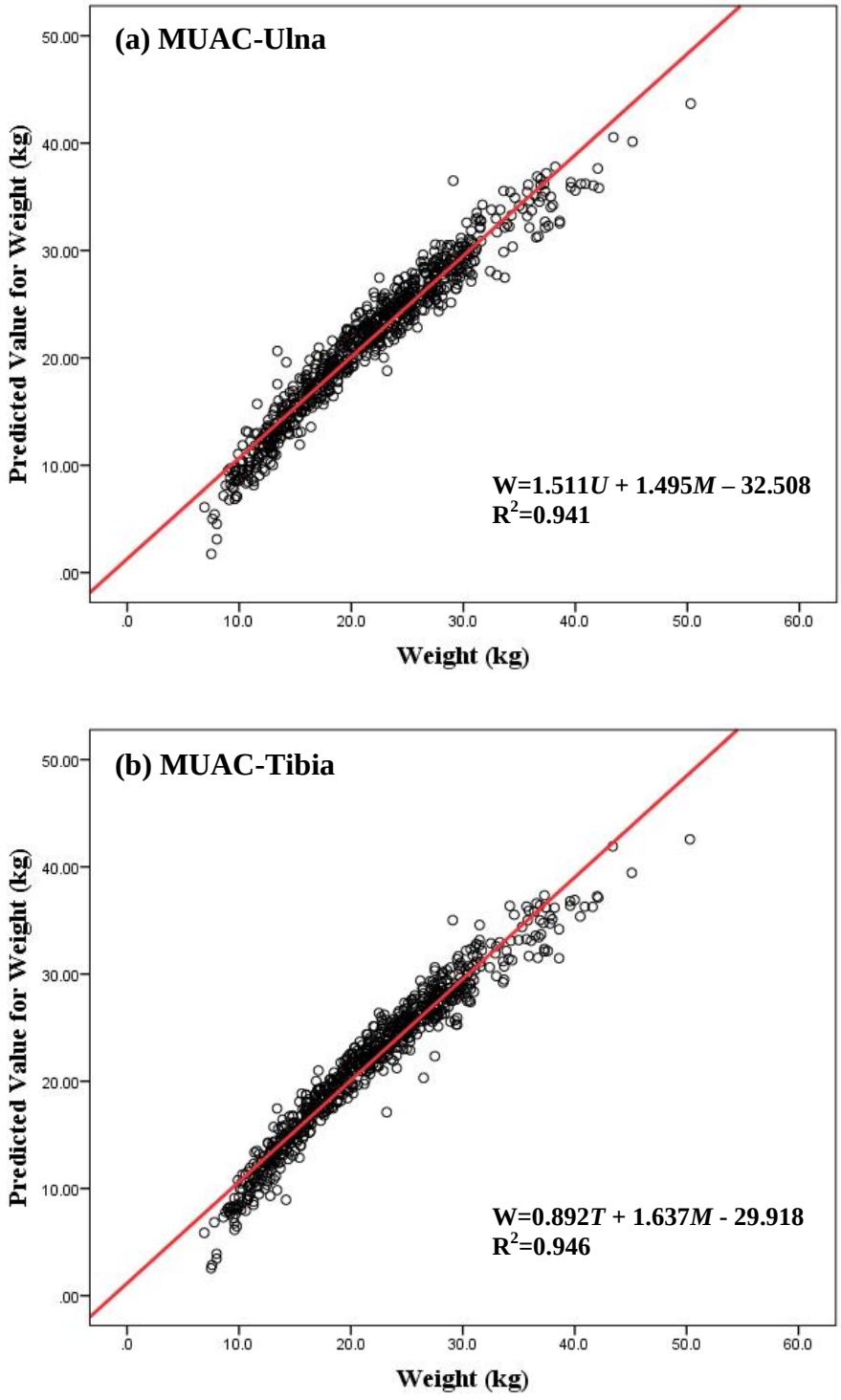
*RMSE, root mean square of the error; W, weight (kg); A, age (months); G, gender; H, height (cm); U, ulna length (cm); T, tibia length (cm); M, mid-upper arm circumference (cm); S, triceps skinfold (mm)*

**Table 14. Comparison of Adjusted $R^2$ values between the univariate weight-prediction model and the multivariate weight-prediction model**

| Measure | Simple univariate model, Adjusted $R^2$ | Model including significant confounding variables, Adjusted $R^2$ | Improvement in Adjusted $R^2$ |
|---|---|---|---|
| Height | 0.870 | - | - |
| Ulna | 0.859 | 0.861 | 0.002 |
| Tibia | 0.841 | 0.843 | 0.002 |
| MUAC | 0.656 | 0.913 | 0.257 |
| Triceps | 0.001 | 0.817 | 0.816 |

Replacing the age and gender variables with ulna length in the MUAC weight-prediction model resulted in a similar improvement to the adjusted $R^2$ value. The weight-prediction regression equation including ulna length in the MUAC weight-prediction model is as follows: $W=1.511U + 1.495M – 32.508$ ($R^2=0.941$). The relationship between the predicted weight using the MUAC-Ulna model and the actual weight is represented graphically in **Figure 4a.** Tibia length also had a similar effect as ulna length on the MUAC weight-prediction model ($W=0.892T + 1.637M -29.918$; $R^2=0.946$). The relationship between the predicted weight using the MUAC-Tibia model and the actual weight is shown in **Figure 4b.**

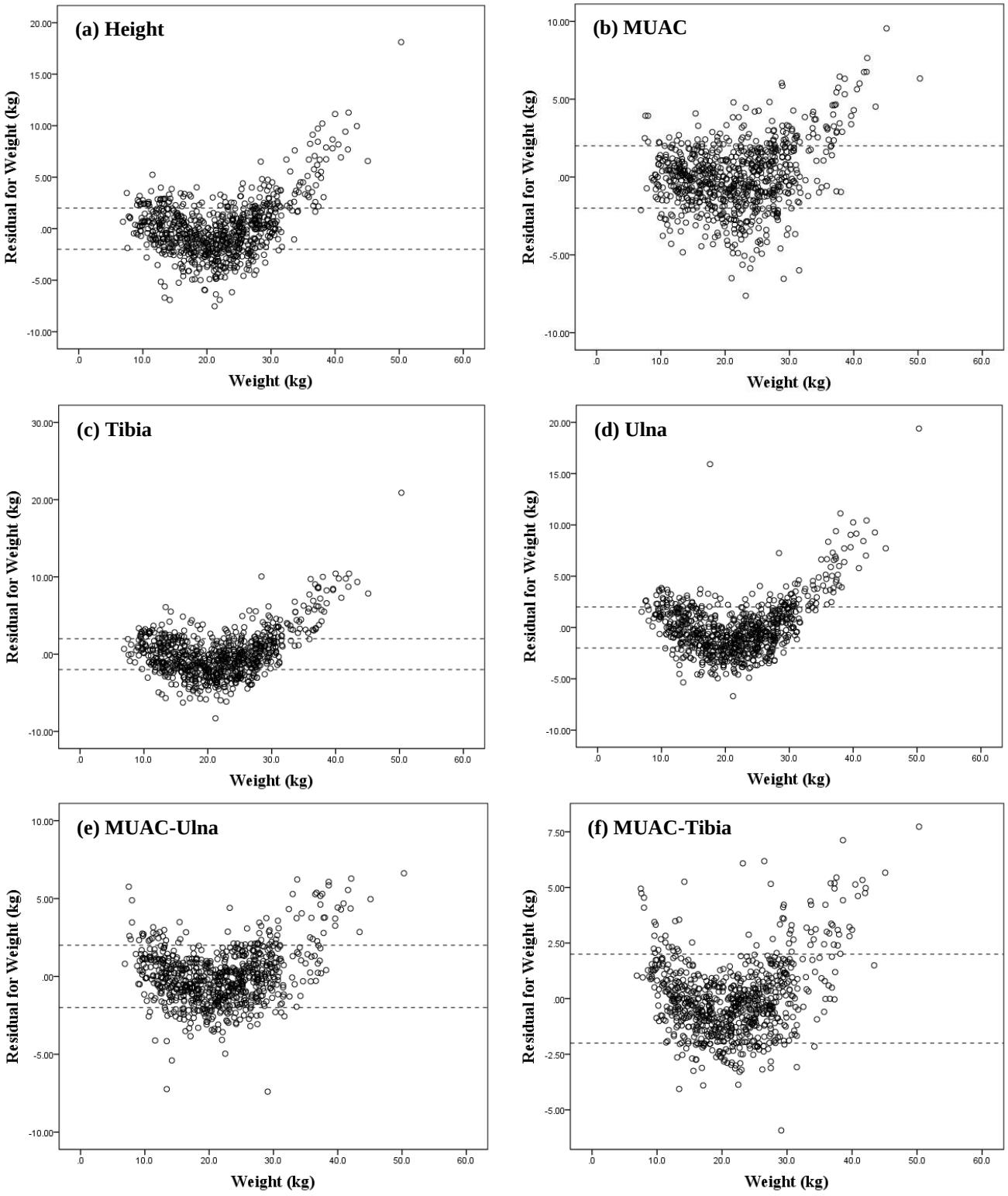
**Figure 4. Linear regression equations for the MUAC-Ulna (a) and the MUAC-Tibia (b) weight-prediction models**



## 4.8. Accuracy of the Multivariate Weight-Prediction Models

Modified Bland-Altman analysis was conducted to assess the agreement between the actual weight and the predicted weight using six of the weight-prediction models (height, MUAC, ulna length, tibia length, MUAC-Ulna, and MUAC-Tibia) (shown in **Figure 5**). The difference between the predicted weight and actual weight (actual – predicted), or the residuals, were plotted against the actual weight. The upper and lower "limits of agreement" were set at 2.0 kg and -2.0 kg.

**Figure 5. Modified Bland-Altman plots for predictive accuracy of six weight-prediction models. The dotted lines represent a residual weight of 2.0 kg and -2.0 kg**



Because a misclassification of 2 kg is more critical in a smaller child who weighs 10 kg compared to one that weighs 40 kg, percentage agreement was also calculated. The percentage agreement of the predicted weight within 5%, 10%, and 15% of the actual weight for the multivariate linear regression models are shown in **Table 15**. The weight-prediction models that had the greatest percentage agreement were the MUAC-Ulna model and the MUAC-Tibia model. A total of 79% of the children were classified as having a predicted weight within 10% of their actual weight when using the MUAC-Ulna model, and 82% of children for the MUAC-Tibia model. Weight was underestimated by greater than 10% in 10.6% of the population using the MUAC-Ulna model and in 10.0% of the population using the MUAC-Tibia model. Weight was overestimated by greater than 10% in 10.8% of the population using the MUAC-Ulna model and in 8.5% of the population using the MUAC-Tibia model.

Graphical representation of the percentage agreement of the MUAC-Ulna and MUAC-Tibia models are shown in **Figures 6 and 7**. As the variance changes over the range of weights, the percentage agreement within 10% for the MUAC-Ulna and the MUAC-Tibia weight-prediction models are separated by weight group in **Table 16**. The weight group of 25.1-30 kg had the highest percentage of children with a predicted weight within 10% of their actual weight. Approximately 95% of children between 25.1 kg and 30 kg had a predicted weight within 10% of their actual weight using the MUAC-Ulna model and 93% of children were within 10% when using the MUAC-Tibia model.

**Table 15. Percentage agreement between the predicted weight and the actual weight for each multivariate weight-prediction model**

| Weight-Prediction Model (Multivariate) | Percentage in agreement within: | | |
|---|---|---|---|
| | 5% of actual weight (*n*) | 10% of actual weight (*n*) | 15% of actual weight (*n*) |
| Height | 35.1 (273) | 60.5 (470) | 81.3 (632) |
| Ulna | 32.9 (256) | 62.0 (482) | 80.8 (628) |
| Tibia | 30.6 (238) | 56.6 (440) | 77.0 (598) |
| MUAC | 42.1 (327) | 72.1 (560) | 87.6 (681) |
| Triceps | 30.5 (237) | 55.5 (431) | 75.3 (585) |
| MUAC-Ulna | 45.6 (362) | 78.8 (612) | 91.2 (709) |
| MUAC-Tibia | 51.1 (397) | 81.5 (633) | 93.7 (728) |

**Figure 6. Percentage agreement between predicted weight and actual weight for the MUAC-Ulna weight-prediction model**

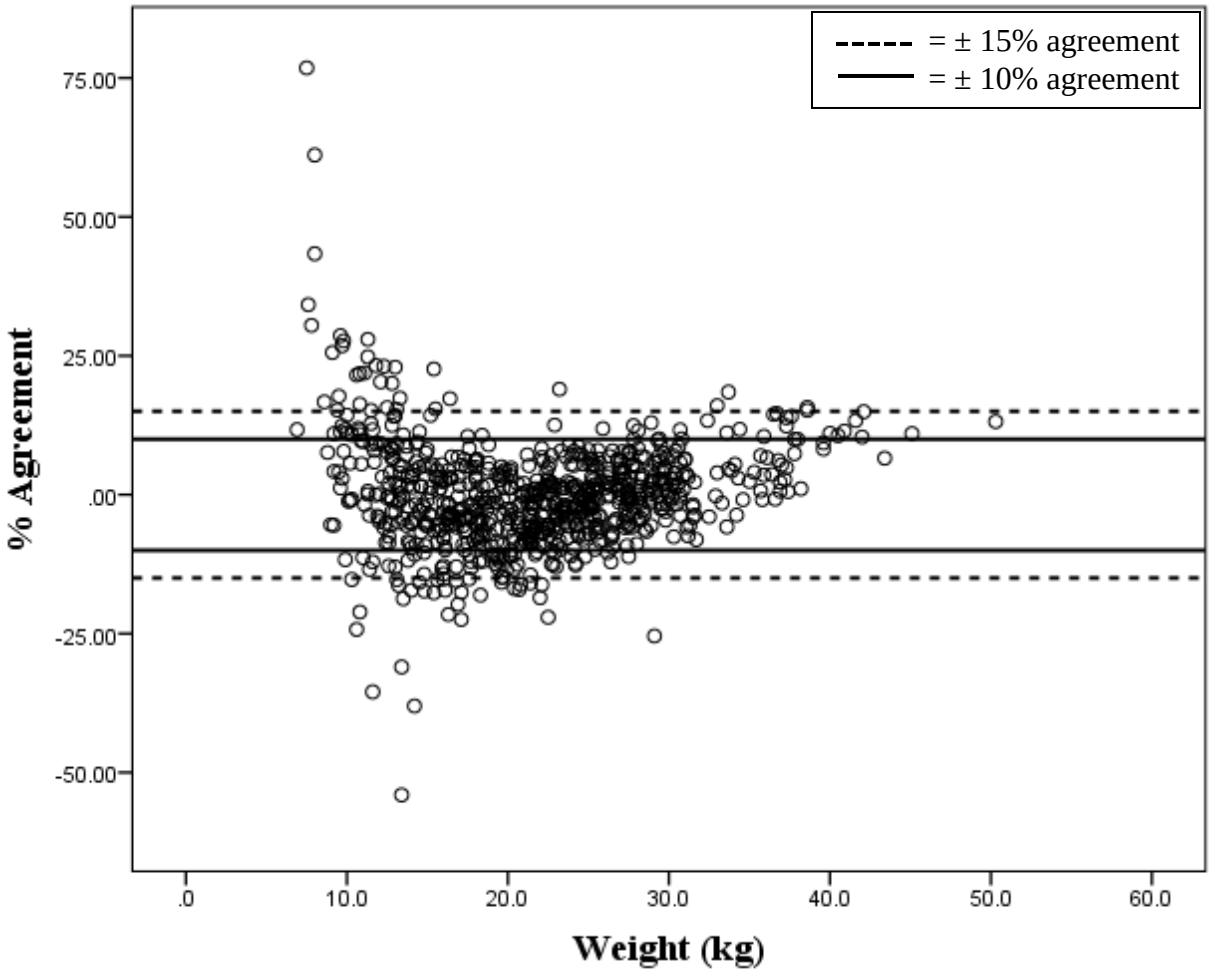


**Figure 7. Percentage agreement between predicted weight and actual weight for the MUAC-Tibia weight-prediction model**

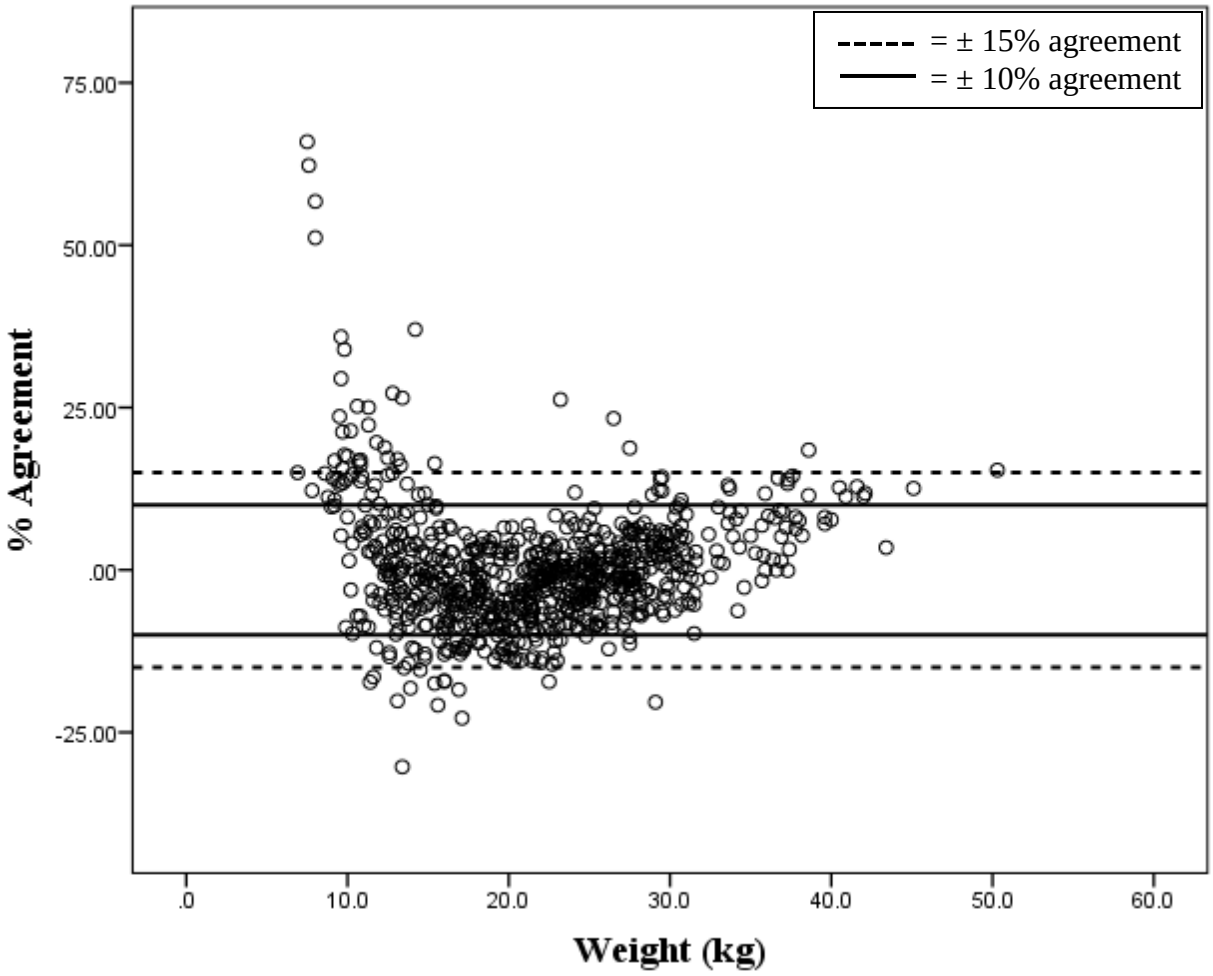


**Table 16. Percentage agreement within 10% between the predicted weight and the actual weight for the MUAC-Ulna and MUAC-Tibia weight-prediction models, separated by weight group**

| Weight group *n* (kg) | Number in group, *n* | MUAC-Ulna, % (*n*) | MUAC-Tibia, % (*n*) |
|---|---|---|---|
| ≤10.0 | 28 | 28.6 (8) | 17.9 (5) |
| 10.1-15.0 | 139 | 65.5 (91) | 69.8 (97) |
| 15.1-20.0 | 164 | 76.8 (126) | 82.3 (135) |
| 20.1-25.0 | 193 | 86.0 (166) | 89.1 (172) |
| 25.1-30.0 | 165 | 94.5 (156) | 93.3 (154) |
| 30.1-40.0 | 80 | 80.0 (64) | 86.3 (69) |
| ≥40.1 | 8 | 12.5 (1) | 12.5 (1) |

## 4.9. Validation of MUAC-Ulna and MUAC-Tibia Weight-Prediction Equations

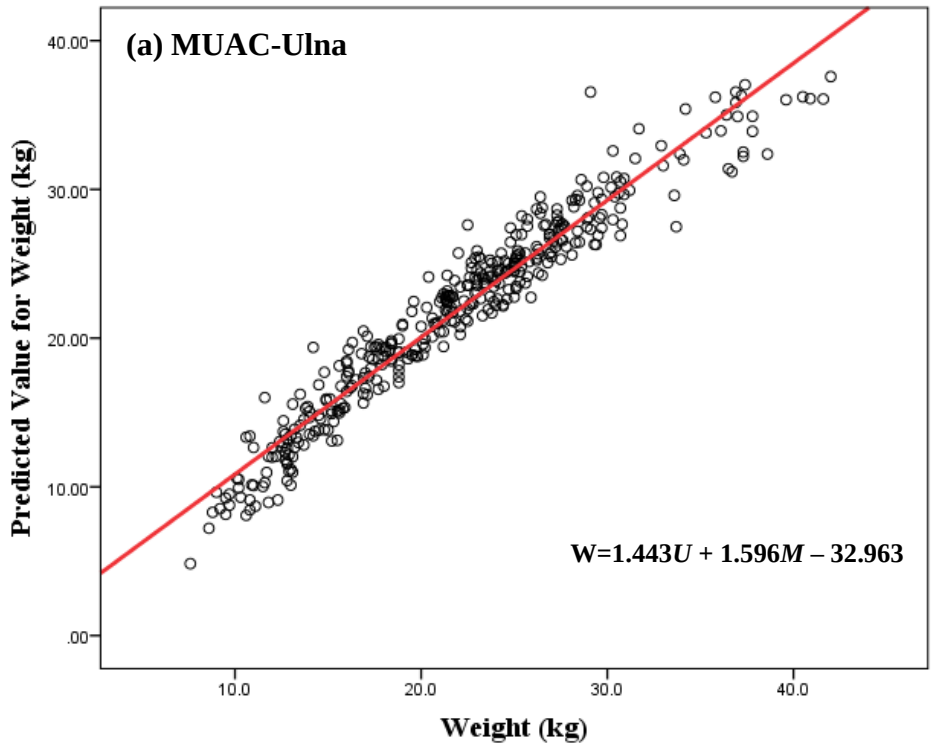
In order to validate the MUAC-Ulna and MUAC-Tibia weight-prediction equations depicted in Figure 4, a random sample of approximately half of the data set was removed from analysis (Sample 2, n=391). The remaining data (Sample 1, n=386) underwent linear regression analysis to produce regression equations for predicting weight (**Table 17**). These equations were used on a 'new' sample (Sample 2, n=391) that were used to validate the prediction equations and see how accurate the equations are at predicting weight. The predicted weight versus actual weight is plotted in **Figure 8** for the MUAC-Ulna and MUAC-Tibia weight-prediction equations using Sample 2 (n=391).

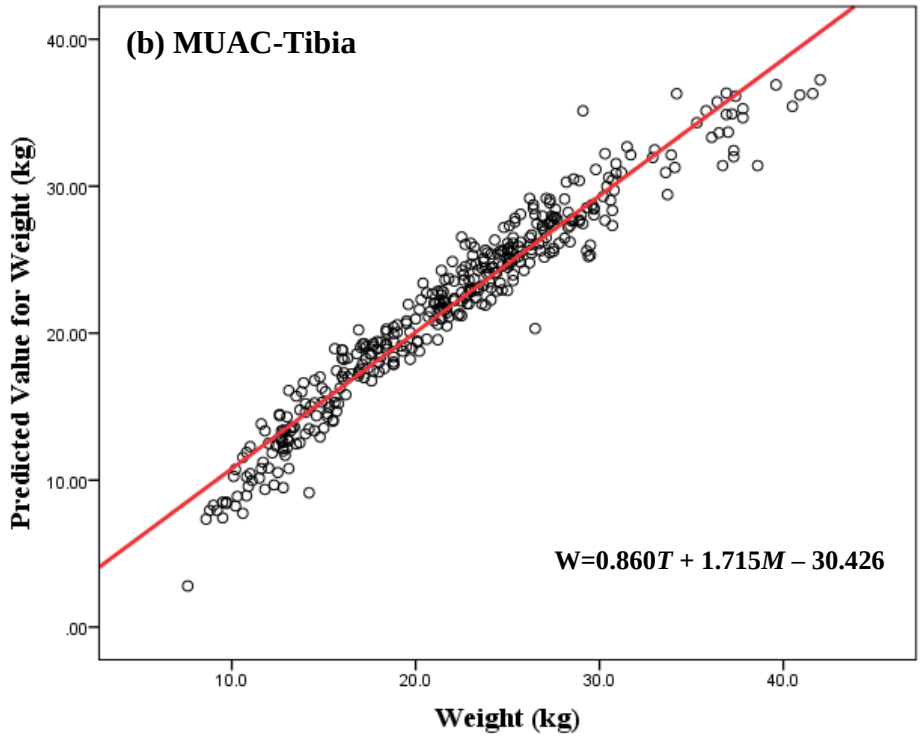
**Table 17. Regression equations for predicting weight using MUAC-Ulna and MUAC-Tibia weight-prediction models on a random sample of approximately 50% of the data (Sample 1, n=386)**

| Surrogate Measure | Regression Equation | Adjusted $R^2$ | RMSE |
|---|---|---|---|
| MUAC-Ulna | W=1.443*U*+1.596*M*-32.963 | 0.942 | 3.266 |
| MUAC-Tibia | W=0.860*T*+1.715*M*-30.426 | 0.950 | 2.799 |

*RMSE, root mean square of the error; W, weight (kg); U, ulna length (cm); T, tibia length (cm); M, mid-upper arm circumference (cm)*

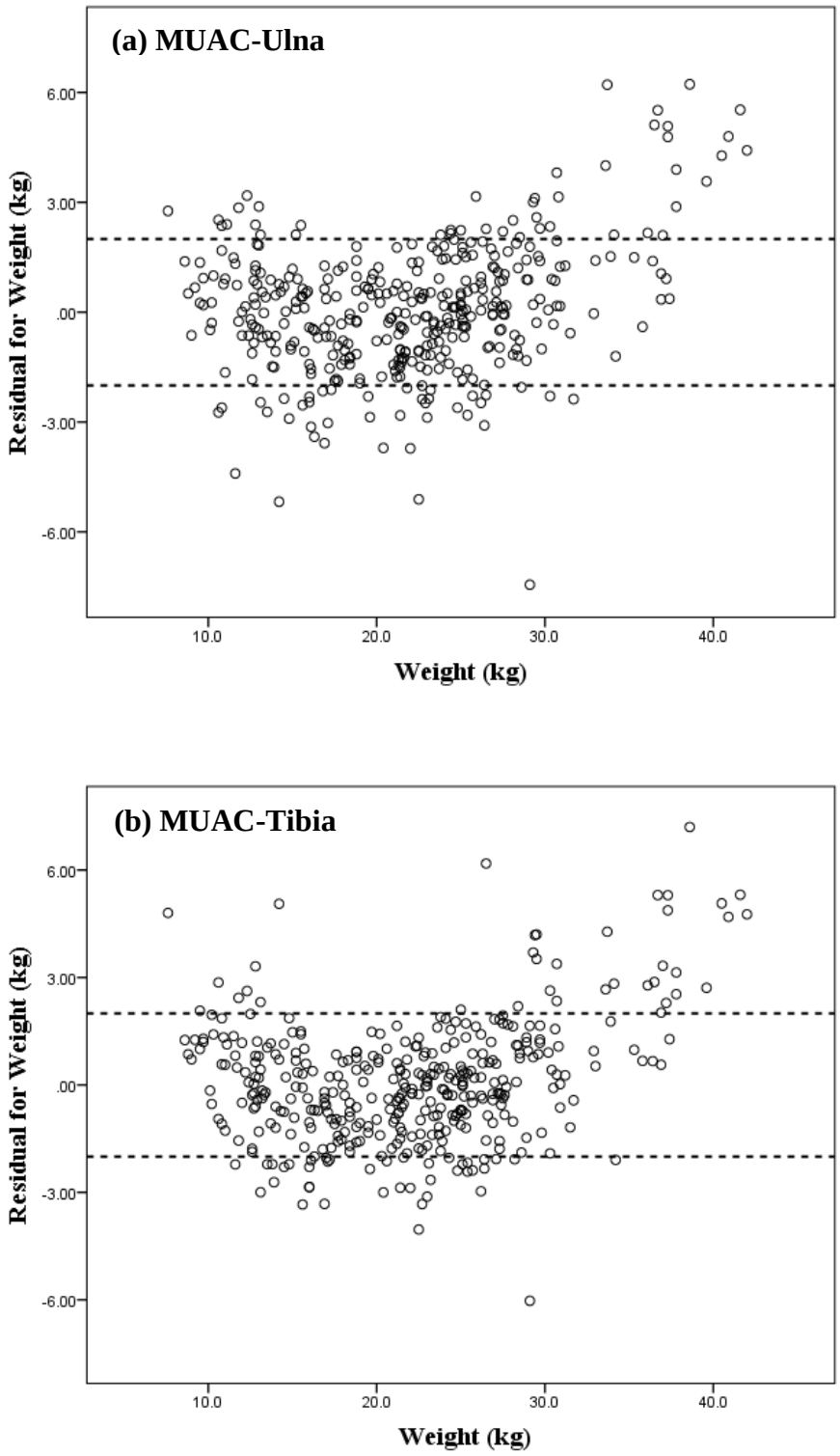
**Figure 8. Linear regression equations for the MUAC-Ulna (a) and MUAC-Tibia (b) weight-prediction models using approximately half the data set (Sample 2, n=391)**






To determine how accurate the MUAC-Ulna and MUAC-Tibia regression equations were at predicting actual weight over the range of weights, modified Bland-Altman analyses were conducted for Sample 2 (n=391). The two plots are shown in **Figure 9** with the difference between the predicted weight and actual weight (residuals) plotted against the actual weight. The upper and lower "limits of agreement" were set at 2.0 kg and -2.0 kg.

**Figure 9. Modified Bland-Altman plots for predictive accuracy of the MUAC-Ulna (a) and the MUAC-Tibia (b) weight-prediction models using approximately half the data set (Sample 2, n=391). The dotted lines represent a residual weight of 2.0 kg and -2.0 kg**



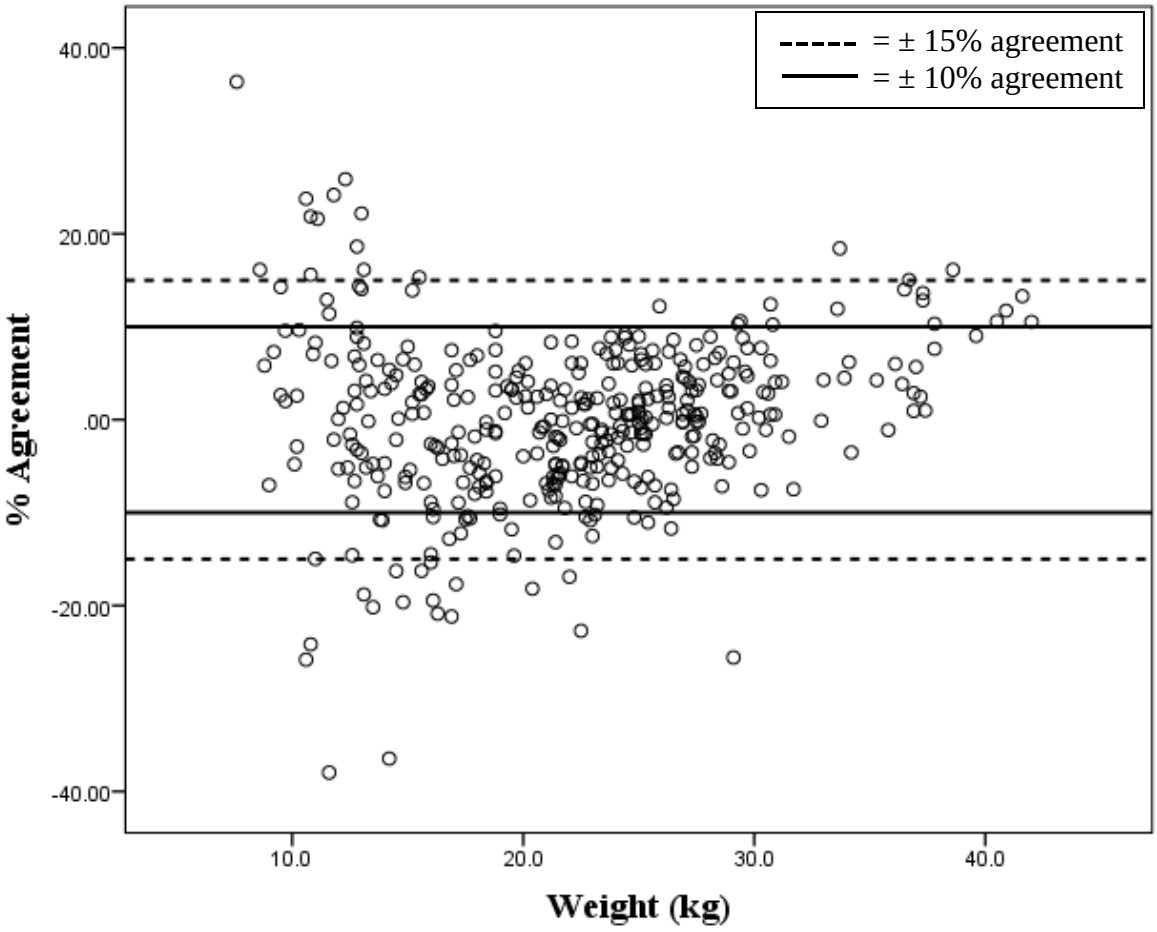
Percentage agreement for the MUAC-Ulna and MUAC-Tibia weight-prediction models within 5%, 10%, and 15% of the actual weight are shown for both samples (Sample 1, n=386; and Sample 2, n=391) in **Table 18**. Eighty-one percent (81%) of the children had a predicted weight within 10% of their actual weight using both models (MUAC-Ulna and MUAC-Tibia) for Sample 2 (n=391). The percentage agreements for the two models are presented graphically in **Figure 10**.

**Table 18. Percentage agreement between the predicted weight and the actual weight for the MUAC-Ulna and MUAC-Tibia weight-prediction models**

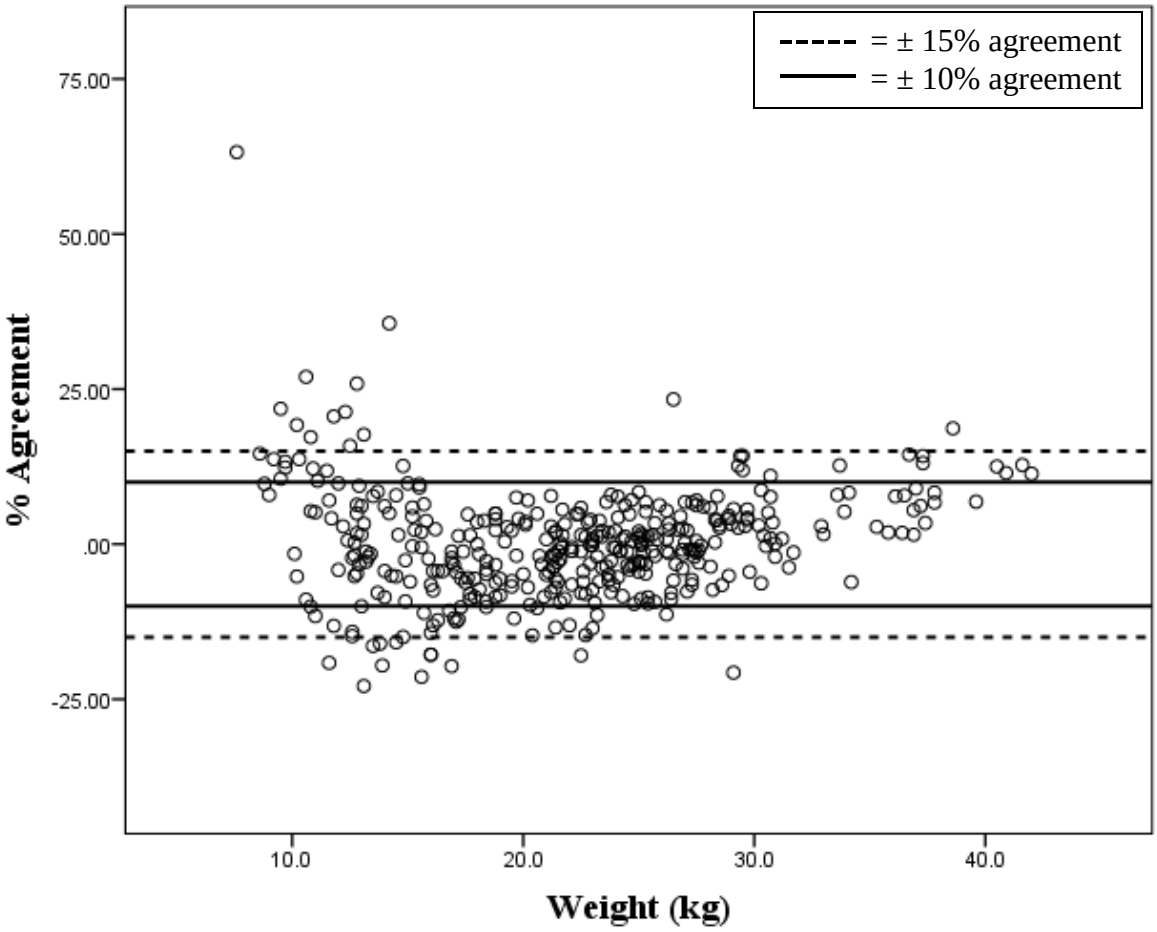
| Weight-Prediction Model | Percentage in agreement within: | | |
|---|---|---|---|
| | **5% of actual weight (*n*)** | **10% of actual weight (*n*)** | **15% of actual weight (*n*)** |
| Sample 1 (n=386) | | | |
| MUAC-Ulna | 46.4 (179) | 76.4 (295) | 91.5 (353) |
| MUAC-Tibia | 50.6 (199) | 80.1 (309) | 94.3 (364) |
| Sample 2 (n=391) | | | |
| MUAC-Ulna | 48.3 (189) | 80.8 (316) | 91.6 (358) |
| MUAC-Tibia | 50.6 (198) | 81.1 (317) | 93.6 (366) |

**Figure 10. Percentage agreement between predicted weight and actual weight for the MUAC-Ulna (a) and the MUAC-Tibia (b) weight-prediction models (Sample 2, n=391)**

**(a) MUAC-Ulna**



**(b) MUAC-Tibia**


= ± 15% agreement
= ± 10% agreement
75.00
50.00
25.00
.00
-25.00
% Agreement
10.0
20.0
30.0
40.0
Weight (kg)

## 4.10. Comparison of Existing Weight-Prediction Methods and the MUAC-Ulna and MUAC-Tibia Weight-Prediction Models

A number of validated weight-prediction methods were tested to assess the accuracy of each method on the population being examined, including the advanced pediatric life support (APLS) formula, the Luscombe formula, the Theron formula, and the Broselow tape. The percentage agreement for the MUAC-Ulna and MUAC-Tibia, as well as three previously validated weight-prediction methods based on age, are presented in **Table 19**. Using the APLS weight-estimation method, approximately 37% of the children in the sample had a predicted weight within 10% of their actual weight. The Luscombe and Theron formulas only estimated weight within 10% of actual weight in approximately 7% and 9% of the study population, respectively. The APLS formula overestimated actual weight by more than 10% in 55% of the population. The Luscombe and Theron formulas both had a strong tendency to overestimated actual weight by more than 10%: 92% of the population using the Luscombe formula and 91% of the population using the Theron formula. The MAC formula (weight = (MAC – 10) + 3) devised by Cattermole et al predicted weight within 10% of actual weight in approximately 32% of the population. The MAC formula had a very slight tendency to underestimate weight with 41% of the population having an estimated weight less than their actual weight by more than 10%, and 26% of the population had an overestimated weight greater than 10%.

**Table 19. Percentage agreement between the predicted weight and the actual weight for the MUAC-Ulna and MUAC-Tibia weight-prediction models and three existing weight-prediction methods based on age**

| Weight-Prediction Method | N | Percentage in agreement within: | | |
|---|---|---|---|---|
| | | 5% of actual weight | 10% of actual weight | 15% of actual weight |
| MUAC-Ulna | 777 | 45.6 | 78.8 | 91.2 |
| MUAC-Tibia | 777 | 51.1 | 81.5 | 93.7 |
| APLS | 531 | 21.3 | 37.3 | 55.0 |
| Luscombe | 531 | 3.6 | 7.2 | 13.6 |
| Theron | 531 | 3.8 | 8.5 | 12.8 |
| MAC | 777 | 15.7 | 32.2 | 49.4 |

In addition to the three age-based weight-prediction methods and the MAC formula, the accuracy of the Broselow tape was also determined. The Broselow tape correctly predicted approximately 55% (420/758) of the population within the correct colour zone for children between 46 cm and 143 cm. In addition, the Broselow tape overestimated actual weight in 39% (n=295) of the population by at least one colour zone and underestimated actual weight in 6% (n=43) of the population.

# Chapter 5: DISCUSSION

## 5.1. Overview

The purpose of this study was to determine if a child's weight could be accurately estimated using a proxy anthropometric measure for weight in the absence of a working scale in children 18 months to 12 years in Botswana. In this chapter, the results of the study are discussed and the weight-estimation methods are examined with relation to accuracy, practicality, and generalizability. A review of the current methods used for estimating weight in children is also discussed and a comparison to the weight-estimation methods from this study is examined.

## 5.2. Participant Characteristics

The majority of the study population was HIV positive because recruitment of participants took place in a clinic for children receiving treatment for HIV. In addition, the HIV rate in Botswana is one of the highest in the world, with over 16 000 children under the age of 14 infected with HIV. (66) Furthermore, it is highly likely that many of the participants who were HIV negative were HIV exposed, meaning they were born to HIV-infected mothers. The high proportion of children infected with HIV or exposed to HIV may contribute to the high rate of malnutrition observed in this study.

Numerous studies have reported that children infected with HIV have poor growth including stunting and wasting. (67-72) Reasons for weight loss, failure to gain weight, and poor linear growth in HIV positive children are related to malabsorption of nutrients, increased energy expenditure, or decreased food intake. (73) In addition, children who were born to HIV positive mothers have been found to have mean birth weights and lengths significantly lower than those infants born to mothers who were HIV negative. (74)

On the other hand, some studies have shown that children who are receiving highly active antiretroviral therapy (HAART) have improved growth with regards to both weight and height. (75-79) In the present study, the majority of the children with HIV were receiving ARV treatment, yet many children were stunted, underweight, or both. However, the benefits of HAART on growth are observed when children receive the treatment early. (67) Most likely, many participants in the study did not receive a timely initiation of HAART, which could have contributed to the stunted growth and low weights-for-age observed in the study population. (67)

Study participants tended to be in the older age range, with the majority of the participants over the age of 5. A likely reason for the age demographics of the study population is that the incidence rate of mother-to-child transmission of HIV in Botswana is declining due to the widespread use of HAART. (80) In Botswana, everyone has access to free HIV treatment programs, a first of its kind in Africa. (81) Moreover, the Ministry of Health has prioritized the prevention of mother-to-child transmission (PMTCT) program by increasing $CD4^+$ cell count testing and treatment referrals for HAART initiation in pregnant women. (81) As part of the PMTCT program, mothers receive HIV prophylaxis (Zidovudine) and a 12-month supply of formula for the HIV exposed infant. (82) The scaling up of the PMTCT program has resulted in the drastic reduction of the transmission of HIV since 2003. (80) In 2003, 20.7% of infants born to HIV infected mothers were born HIV positive, and that percentage dropped to 4.8% by 2008 and 3.8% by 2010. (82) Therefore, this drop in the mother-to-child transmission rate could mean that fewer younger children are attending the Botswana-Baylor Children's Clinical Center of Excellence (COE).

## 5.3. Devised Weight-Prediction Methods

The weight-prediction models devised in this study with the highest accuracy were the MUAC-Ulna and the MUAC-Tibia models, which support the recommendation of using height-based methods of estimating weight in children in developing countries compared to age-based formulas. (12,32,53) Height-based methods for estimating weight have shown to be less variable with body habitus compared to age-based formulas, especially in populations with prevalent stunting and low weights-for-age. (12,28,31,32,83) Proxy measures of height, such as ulna and tibia length, were used in this study because they have been shown to be well correlated with height and are simple to measure. (62) Also, height is a difficult measure to execute with accuracy in resource limited settings without proper equipment. (63)

Moreover, the addition of MUAC to the ulna and tibia length weight-estimation equations greatly improved the accuracy of predicting children's weight. Mid-upper arm circumference (MUAC) has previously been reported as a strong correlate of weight in a study conducted by Cattermole et al in 2010, (33) but it is not currently being used in any weight-estimation methods. Our study suggests that the combination of a proxy for height, like ulna or tibia length, and MUAC, an indicator of muscle mass and subcutaneous fat, may be used to accurately estimate a child's weight.

In addition to their accuracy level, another benefit of the MUAC-Ulna and MUAC-Tibia weight-prediction models is their simplicity of use. Tibia length, ulna length, and MUAC are easy areas to measure with a tape measure. In a clinical or field setting where scales may be unavailable, the only equipment needed to estimate a child's weight is a tape measure and a MUAC-Ulna or MUAC-Tibia weight-estimation chart (**Appendices C and D**). A health worker simply measures the child's ulna or tibia length to the nearest centimeter and MUAC to the

nearest half a centimeter, and finds the estimated weight value in kilograms on the chart. Similar to the Broselow tape, there are no calculations required meaning the risk of calculation errors are minimal. Age was found to be a statistically significant predictor of weight; however, age was not included in the MUAC-Ulna and MUAC-Tibia models because increasing the number of variables would complicate the model and make it more difficult to use in a clinical or field setting. More importantly, age may have been statistically significant, but it was not clinically significant as it did not impact the accuracy of the models.

In particular, the MUAC-Ulna and MUAC-Tibia weight-prediction models predicted weight with high accuracy for the children weighing 20-30 kg. The majority of children within this weight range had a predicted weight within 10% of their actual weight. Some studies from developing countries showed that particular existing weight-estimation methods poorly predicted weight in children in the higher weight or age ranges. For example, in the Ramarajan et al study (30) in a population of undernourished Indian children, the authors found the Broselow tape to be less accurate at predicting weight in children over 18 kg. Only 34% of the population weighing more than 18 kg had an estimated weight within 10% of their actual weight compared to 53% of those weighing less than 10 kg. (30)

However, the Broselow tape was devised based on Western populations and the MUAC-Ulna and MUAC-Tibia models have been devised on a highly stunted population. This might explain why the Broselow tape has been shown to be less accurate in older children in studies conducted in developing countries, where there is a significant divergence in height-for-weight correlations from Western populations. (30,53) Stunting was more pronounced in the older children ($\geq$ 9 years) compared to the younger children ($\leq$ 5 years) in our study; therefore, the MUAC-Ulna and MUAC-Tibia weight-prediction models may be more accurate for use in

developing countries where stunting in children is more widespread, particularly in children 20-30 kg.

However, findings from this study show that the two weight-prediction equations did not predict weight with the same accuracy across the entire weight range; therefore, the MUAC-Ulna and MUAC-Tibia weight-estimation charts should be used with caution. A high proportion of children under 15 kg did not have an estimated weight within 10% of their actual weight. In addition, there were significant outliers amongst this weight group, especially in the children weighing less than 10 kg. Therefore, the devised weight-prediction models may not be applicable for children weighing less than 15 kg.

In previous studies conducted in developing countries, there were contradictory findings with regards to children in the lower weight categories. For instance, a study conducted in India by Varghese et al (53) that examined the accuracy of the Broselow tape, found that it predicted weight better in children weighing less than 15 kg compared to children over 15 kg. However, more than 90% of the study population weighed less than 15kg, making it difficult to draw conclusions on children weighing over 15 kg. (32) Similarly, another study in India conducted by Ramarajan et al (30) found that the accuracy of the Broselow tape decreased as weight increased in participants. Weight was predicted with the highest accuracy in children weighing less than 10 kg with 53% of children in this weight category having an estimated weight within 10% of their actual weight. (30) These findings suggest that the Broselow tape may predict weight better in smaller children in developing countries compared to the MUAC-Ulna and MUAC-tibia weight-prediction methods. However, a possible reason for the low accuracy in the small weight group in our study could be because of the small sample size. As mentioned earlier, it was difficult to recruit many children under the age of 5 from the COE and therefore there are fewer participants

in the lower weight range. Furthermore, the weight-prediction models did not accurately predict weight in children weighing more than 40 kg. Again, the sample size was too small to draw any conclusions. Before any conclusions can be drawn on which weight-estimation method is the most accurate for smaller children, further studies need to be conducted in children in developing countries who weigh less than 15 kg.

## 5.4. Comparison of Existing Weight-Prediction Methods

The Broselow tape, three age-based weight-prediction formulas, and the MAC formula, were applied to this study population to compare the accuracies of the different weight-prediction methods. The Broselow tape, the APLS formula, and the MAC formula predicted weight better than the Luscombe and Theron formulas.

A study conducted in South Africa by Geduld et al (12) found that the APLS method predicted weight within 10% of actual weight in 58% of the population. The APLS formula was more accurate in predicting weight in the South African population compared to our Botswana study population. However, participants in the Geduld study were from a range of socioeconomic backgrounds and therefore rates of undernutrition may not have been as high as in our study. The APLS formula was devised based on Western data and therefore it may be more applicable to the population in the Geduld study. The children in the Geduld study were most likely more similar to Western populations compared to the moderately underweight population in our Botswana study. Also, it was to be expected that the Luscombe formula would be less accurate in our study population compared to the APLS formula. The Luscombe formula was an ‘improvement’ to the APLS formula to adjust for the growing obesity rates in Western populations, an issue not applicable in most undernourished populations.

A study conducted in India in a malnourished population found that the APLS method tended to overestimate weight. (53) Results from our study support these findings as the APLS formula poorly predicted weight in children with a tendency to overestimate weight. The reason for the overestimation is most likely due to the fact that the APLS formula is devised based on weight-for-age data from the United States and our study population had much lower weights-for-age with approximately 19% of our study population classified as underweight.

Results from our study were also similar to a study conducted by House et al (32) in children in Kenya. The APLS method had a high degree of variability and tended to overestimate weight. (32) Similar to the Varghese study in India and our Botswana study, children in the Kenyan study were also malnourished. (32) On the contrary, even though the Broselow tape outperformed the age-based formulas, results from the study did suggest that the APLS formula could be used to estimate weight in Kenyan children. (32) The reason the APLS formula may have worked slightly better in the Kenyan population compared to our Botswana population or the Varghese study population, could be because the Kenyan children were malnourished in a different context. (32) The population in the Kenyan study was most likely suffering from protein energy malnutrition with edema. (32) The presence of edema might have caused the children to be not as underweight compared to children suffering from malnutrition in the absence of edema, such as in our study and the Varghese et al study. (32)

The Broselow tape predicted weight with the greatest accuracy out of all the existing weight-estimation methods examined in this study population. As previously mentioned, this comes as no surprise as height-based methods have been repeatedly shown to be better predictors of weight compared to age-based methods. (12,30,32,53) However, some researchers have expressed concern over the potential overestimation of weight in developing country populations

where stunting may be prevalent. (30) Results from this study support this concern as a significant percent of children had an overestimated weight by at least one colour zone in our study.

There have been no studies validating the MAC formula devised by Cattermole et al (33) in children in Hong Kong. Our study is the first to examine the accuracy of the MAC formula on an independent sample. The MAC formula predicted weight in children with low accuracy in our study and was outperformed by the APLS method and the Broselow tape. However, our univariate weight-prediction model using only MUAC as the independent variable provided similar results to the MAC formula devised by Cattermole et al. (33) The addition of ulna length or tibia length into the MUAC formula in our study greatly increased the accuracy of predicting weight. This suggests that a MUAC measurement on its own is not a sufficient predictor of weight in children, but can be used together with a surrogate measure for height like ulna or tibia length to better predict weight in children aged 18 months to 12 years.

The MUAC-Ulna and MUAC-Tibia weight-prediction models were the best predictors of weight compared to any other weight-estimation method explored – both existing and devised in this study. However, interpretation should be exerted with caution as the MUAC-Ulna and MUAC-Tibia weight-prediction regression equations are best fitted for this study population, thus correlations are expected to be strong.

In order to validate the MUAC-Ulna and MUAC-Tibia regression equations in this study population, the data was split into two random samples. The ‘independent’ sample predicted weight within 10% of actual weight with similar accuracy as the sample from which the regression equations were derived from. This suggests that the MUAC-Ulna and MUAC-Tibia

weight-prediction models could potentially predict weight to similar degrees of accuracy in other similar populations. This is a unique step in our study as none of the researchers conducting studies examining weight-prediction methods included this step in their analyses. However, it is understood that while the data from the 'independent' sample was not used to devise the regression equations, the sample is not truly independent as the children were selected from the same population. Validation of the MUAC-Ulna and MUAC-Tibia models should be done in child populations in other developing countries.

## 5.5. Correlation between Caliper and Tape Measurements

Ulna and tibia lengths were measured with both a long bone caliper and a tape measure to validate the use of the tape in clinical or research study settings. The tape measurements for both the ulna and tibia lengths correlated almost perfectly with the caliper measurements, meaning the tape measure could be used in place of the caliper in future studies. In addition, inter-rater (degree of agreement between investigators) and intra-rater (degree of agreement among multiple measurements conducted by a single investigator) of the tape and caliper measurements were similar with minimal average variability between raters and measures.

Calipers are considered the 'gold standard' and have metal prongs that are perpendicular to a ruler that can be adjusted to the exact length of the ulna or tibia to the nearest millimeter. However, these pieces of measuring equipment are difficult to transport and are extremely expensive (Rosscraft Campbell 20 caliper, CND$524). The use of a tape measure to take long bone measurements instead of a caliper would significantly reduce costs.

## 5.6. Study Limitations

It is important to acknowledge and discuss limitations of the study and the interpretation of the results, such as issues with the study design and participant demographics.

The study was a convenience sample and was conducted at a single facility: the Botswana-Baylor Children's Clinical Center of Excellence (COE). Therefore, the study sample may not be representative of the entire population of Botswana. Another limitation of the study was that the participants' ages were not evenly distributed. For instance, the majority of the participants were over the age of 5, particularly between the ages of 9 and 13. Very few participants were under the age of 5, particularly under the age of 2 years. In addition, because there were fewer children under 5, there were fewer children were in the lower weight range. Due to the small sample size for children under 15 kg, it was difficult to draw any conclusions for the accuracy of the weight-prediction methods in children pertaining to this weight group. Furthermore, the estimated weights listed in the MUAC-Ulna and MUAC-Tibia weight-prediction charts should be interpreted with caution as they are most likely not accurate across all the measurements. The two charts should be validated in other populations before they can be considered as replacements for current weight-estimation methods.

Moreover, limited demographic and health data was collected in the survey. Without additional information, we were unable to describe the severely misclassified children or describe the outliers. Also, children who were HIV negative were most likely born to HIV positive mothers given the demographics of the patients at the COE; however, it was unknown in our sample whether an HIV negative child was HIV exposed because they were not differentiated in the study. As similar poor growth outcomes has been observed in both HIV positive children and HIV exposed children, it would have been beneficial to separate HIV

negative from the HIV exposed children. Also, the sample size for HIV negative children was small and direct comparisons to the children who were HIV positive should be limited. Similar sample sizes are needed for a comparison between how well the MUAC-Ulna and MUAC-Tibia weight-prediction methods performed in HIV positive children versus HIV negative children.

In addition, most studies validating weight-estimation methods, especially those based on age did not include children over 10 years. (31) In our study however, we included children who were in their twelfth year and some children therefore may have already entered into puberty. Pubertal status was not recorded and these children may have negatively influenced results because growth spurts and a large increase in weight variability can be observed in children in this age category. (31)

Lastly, despite splitting the population and internally validating the weight-prediction equations, results from this study need to be externally validated. The MUAC-Ulna and MUAC-Tibia weight-prediction equations should be tested in other populations in developing countries before any conclusions can be made on the accuracy and generalizability of the two equations.

## 5.7. Generalizability

The results of this study primarily apply to well-monitored HIV positive children receiving ARV treatment in Botswana who are moderately underweight with moderate to severe stunting. It should be noted that the HIV positive children in this study had access to the best medical facility for the treatment of HIV in the country with some children receiving treatment since birth. Therefore, results from this study may not be transferable to other HIV positive cohorts of children, especially in populations with no or limited access to treatment. In addition, measurements were taken with trained study investigators in a facility fully equipped with

calibrated measuring equipment. Therefore, study results may differ in settings with untrained staff or improper measuring equipment.

## 5.8. Implications of Findings

There is no single weight-estimation method that is recommended for use across all populations. (12) In particular, there is concern regarding the applicability of existing weight-estimation methods in developing countries that have been derived from Western populations. Results from this study suggest that using ulna or tibia length along with MUAC in children over 15 kg could potentially predict weight in children in developing countries. Furthermore, implications of these findings could mean that health clinics in limited resource settings without access to working scales may be able to dose pediatric medications with an accurate, simple, and inexpensive weight-prediction method that would reduce dosing errors.

## 5.9. Directions for Further Research

Validation of the MUAC-Ulna and MUAC-Tibia weight-prediction methods is needed in various populations in other developing countries. In particular, repeat studies need to be conducted in children weighing less than 15 kg, or under the age of 5 years including children less than 18 months. Future studies also need to be conducted in less ideal settings to examine the effectiveness of the MUAC-Ulna and MUAC-Tibia weight-prediction charts. These studies are needed to assess the usability and practicality of the charts in real-life settings.

Further research also needs to include applying weight-bands to the MUAC-Ulna and MUAC-Tibia weight-prediction charts for use in drug dosing of fixed-dose dispersible tablets. Colour-coding the charts into weight-bands for each fixed-dose would make dosing pediatric

medications easy and quick. Weight-bands would need to be devised and corresponding dosages would then be determined for each band.

In addition, ulna and tibia length were only two long bone measurements that were examined in this study; however, addition long bone measurements should also be explored for the use in weight-estimation models. For example, humerus length could be an alternative measurement to ulna to tibia length. In a study exploring proxy measures for height in children with cerebral palsy, researchers found that humerus length was easier to measure compared to ulna length. (64) Moreover, using humerus length would require one less measurement when estimating weight because in order to correctly locate the mid-point of the upper arm for a MUAC measurement, the humerus length needs to be determined.

## 5.10. Conclusion

This study suggests that a weight-estimation method based on mid-upper arm circumference (MUAC) and a surrogate measure for height, like ulna or tibia length, could potentially be used in developing country populations with high rates of undernutrition as a way to accurately estimate a child's weight in the absence of a working scale. The MUAC-Ulna and MUAC-Tibia weight-prediction methods estimated children's weight (18 months – 12 years) with the highest accuracy compared to other commonly used weight-prediction methods.

Although these two weight-prediction models worked well in this study population, they need to be externally validated in other populations. If the two equations predict children's weight in other populations to the same degree of accuracy seen in this study, they could potentially replace the use of other existing weight-prediction methods currently being used in developing country populations and improve the dosing of pediatric medications.

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# APPENDICES

## Appendix A. Participant Consent Form

**Information and Consent Agreement Form for the Evaluation of Potential Weight Proxies for Use in Drug Dosing Determination in Gaborone, Botswana**

Hello. My name is _____ and I am a (student, medical resident, research assistant) working with Botswana-Baylor Children's Clinical Center of Excellence and the University of British Columbia in Vancouver, Canada. We are asking your permission to allow us to measure your child's weight, height, mid-upper arm circumference, and length of forearm or length of lower leg. The reason for taking these measurements is because we are determining simple and accurate substitute measures of weight for children, as weight scales are often unavailable. These measurements will tell us what dose of a drug to treat a child with.

Your child's participation is entirely voluntary and you may refuse to participate or may withdraw your child from this study at any time and without providing a reason for your decision. If you should withdraw, you have the choice not to permit the research team to use any information obtained from your child.

By entering this study there is no known harm to your child.

If you agree to participate, whatever information you provide will be kept strictly confidential, and will not be shared with anyone other than the survey team. Your participation is voluntary, and you can stop participating at any time and without providing a reason for your decision. If you decide not to participate it is your decision and we respect your decision. There are no consequences if you say no and your decision will not be shared with anyone, including government officials.

Do you have any questions about the study? If you have any questions or concerns in the future you can contact us at *(telephone number)* or contact the study investigator, *(name)* at *(e-mail address)* or *(mailing address)*.

The measurements of your child will take a total of about 30 minutes to complete. In appreciation for the time this will take away from your other responsibilities we would like to remunerate you with 30 Pula (60 Pula if your child is over the age of 5). May I begin the measurements on your child now?

**Consent:** The caregiver agrees that the following has been explained to him/her: (completed by the research assistant)

- The study has been explained to me. Yes □ No □
- All my questions were answered. Yes □ No □
- I understand that I have the right not to participate and the right to stop at any time. Yes □ No □
- I understand that I may refuse to participate without consequence. Yes □ No □
- I am free now, and in the future, to ask any questions about the study. Yes □ No □
- I have been told that my child's personal information will be kept confidential. Yes □ No □

Caregiver's relation to child:
Mother ____ Father ____ First degree relative most responsible for child's care _____

The caregiver has provided verbal consent to participate in this study: Yes □ No □

Name of Research Assistant obtaining verbal consent:

_____

I hereby confirm that I have read this consent form to the caregiver, answered any questions, obtained verbal agreement for each of the above statements and have been given verbal consent for their child to participate in this study. Signed and dated:

_____ _____

Signature of Research Assistant Date

Signature of Co-Principal Investigator:

_____ _____

Signature Date

## Appendix B. Survey Question

| Module 1: CHILD AND CAREGIVER INFORMATION | |
|---|---|
| 1. What is (NAME'S) birthdate? | _____ (DD/MM/YYYY) |
| 2. What is the (NAME's) gender? | 0 = Male<br>1 = Female |
| 3. What is the HIV status of (NAME)? | 0 = Negative for HIV (does not have HIV)<br>1 = Positive for HIV<br>2 = Unknown |
| 4. Is (NAME) currently taking ARVs? | 0 = No<br>1 = Yes |
| 5. What is your age? | _____ years |
| 6. How many people in total live in your household? | _____ Adults<br>_____ Children<br>_____ Total (Adults + Children) |
| 7. What is the *main* reason for bringing (NAME) to the clinic today?<br><br>ONLY CIRCLE THE MAIN REASON | 1 = Scheduled appointment/check-up<br>2 = Diarrhea<br>3 = Vomiting<br>4 = Cough<br>5 = Difficulty breathing<br>6 = Fever<br>7 = No appetite<br>8 = Other (Specify: _____) |

## Appendix C. MUAC-Ulna Weight-Estimation Chart

| MUAC (cm) \ Ulna Length (cm) | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **10** | -2.4 | -0.9 | 0.6 | 2.1 | 3.6 | 5.1 | 6.6 | 8.1 | 9.6 | 11.2 | 12.7 |
| **10.5** | -1.7 | -0.2 | 1.3 | 2.8 | 4.3 | 5.9 | 7.4 | 8.9 | 10.4 | 11.9 | 13.4 |
| **11** | -1.0 | 0.6 | 2.1 | 3.6 | 5.1 | 6.6 | 8.1 | 9.6 | 11.1 | 12.6 | 14.2 |
| **11.5** | -0.2 | 1.3 | 2.8 | 4.3 | 5.8 | 7.3 | 8.9 | 10.4 | 11.9 | 13.4 | 14.9 |
| **12** | 0.5 | 2.1 | 3.6 | 5.1 | 6.6 | 8.1 | 9.6 | 11.1 | 12.6 | 14.1 | 15.7 |
| **12.5** | 1.3 | 2.8 | 4.3 | 5.8 | 7.3 | 8.8 | 10.4 | 11.9 | 13.4 | 14.9 | 16.4 |
| **13** | 2.0 | 3.5 | 5.1 | 6.6 | 8.1 | 9.6 | 11.1 | 12.6 | 14.1 | 15.6 | 17.1 |
| **13.5** | 2.8 | 4.3 | 5.8 | 7.3 | 8.8 | 10.3 | 11.9 | 13.4 | 14.9 | 16.4 | 17.9 |
| **14** | 3.5 | 5.0 | 6.6 | 8.1 | 9.6 | 11.1 | 12.6 | 14.1 | 15.6 | 17.1 | 18.6 |
| **14.5** | 4.3 | 5.8 | 7.3 | 8.8 | 10.3 | 11.8 | 13.3 | 14.9 | 16.4 | 17.9 | 19.4 |
| **15** | 5.0 | 6.5 | 8.0 | 9.6 | 11.1 | 12.6 | 14.1 | 15.6 | 17.1 | 18.6 | 20.1 |
| **15.5** | 5.8 | 7.3 | 8.8 | 10.3 | 11.8 | 13.3 | 14.8 | 16.4 | 17.9 | 19.4 | 20.9 |
| **16** | 6.5 | 8.0 | 9.5 | 11.1 | 12.6 | 14.1 | 15.6 | 17.1 | 18.6 | 20.1 | 21.6 |
| **16.5** | 7.3 | 8.8 | 10.3 | 11.8 | 13.3 | 14.8 | 16.3 | 17.8 | 19.4 | 20.9 | 22.4 |
| **17** | 8.0 | 9.5 | 11.0 | 12.6 | 14.1 | 15.6 | 17.1 | 18.6 | 20.1 | 21.6 | 23.1 |
| **17.5** | 8.8 | 10.3 | 11.8 | 13.3 | 14.8 | 16.3 | 17.8 | 19.3 | 20.9 | 22.4 | 23.9 |
| **18** | 9.5 | 11.0 | 12.5 | 14.0 | 15.6 | 17.1 | 18.6 | 20.1 | 21.6 | 23.1 | 24.6 |
| **18.5** | 10.3 | 11.8 | 13.3 | 14.8 | 16.3 | 17.8 | 19.3 | 20.8 | 22.3 | 23.9 | 25.4 |
| **19** | 11.0 | 12.5 | 14.0 | 15.5 | 17.1 | 18.6 | 20.1 | 21.6 | 23.1 | 24.6 | 26.1 |
| **19.5** | 11.8 | 13.3 | 14.8 | 16.3 | 17.8 | 19.3 | 20.8 | 22.3 | 23.8 | 25.4 | 26.9 |
| **20** | 12.5 | 14.0 | 15.5 | 17.0 | 18.5 | 20.1 | 21.6 | 23.1 | 24.6 | 26.1 | 27.6 |
| **20.5** | 13.2 | 14.8 | 16.3 | 17.8 | 19.3 | 20.8 | 22.3 | 23.8 | 25.3 | 26.8 | 28.4 |
| **21** | 14.0 | 15.5 | 17.0 | 18.5 | 20.0 | 21.6 | 23.1 | 24.6 | 26.1 | 27.6 | 29.1 |
| **21.5** | 14.7 | 16.3 | 17.8 | 19.3 | 20.8 | 22.3 | 23.8 | 25.3 | 26.8 | 28.3 | 29.9 |
| **22** | 15.5 | 17.0 | 18.5 | 20.0 | 21.5 | 23.0 | 24.6 | 26.1 | 27.6 | 29.1 | 30.6 |
| **22.5** | 16.2 | 17.8 | 19.3 | 20.8 | 22.3 | 23.8 | 25.3 | 26.8 | 28.3 | 29.8 | 31.3 |
| **23** | 17.0 | 18.5 | 20.0 | 21.5 | 23.0 | 24.5 | 26.1 | 27.6 | 29.1 | 30.6 | 32.1 |
| **23.5** | 17.7 | 19.2 | 20.8 | 22.3 | 23.8 | 25.3 | 26.8 | 28.3 | 29.8 | 31.3 | 32.8 |
| **24** | 18.5 | 20.0 | 21.5 | 23.0 | 24.5 | 26.0 | 27.5 | 29.1 | 30.6 | 32.1 | 33.6 |
| **24.5** | 19.2 | 20.7 | 22.3 | 23.8 | 25.3 | 26.8 | 28.3 | 29.8 | 31.3 | 32.8 | 34.3 |
| **25** | 20.0 | 21.5 | 23.0 | 24.5 | 26.0 | 27.5 | 29.0 | 30.6 | 32.1 | 33.6 | 35.1 |
| **25.5** | 20.7 | 22.2 | 23.7 | 25.3 | 26.8 | 28.3 | 29.8 | 31.3 | 32.8 | 34.3 | 35.8 |
| **26** | 21.5 | 23.0 | 24.5 | 26.0 | 27.5 | 29.0 | 30.5 | 32.0 | 33.6 | 35.1 | 36.6 |
| **26.5** | 22.2 | 23.7 | 25.2 | 26.8 | 28.3 | 29.8 | 31.3 | 32.8 | 34.3 | 35.8 | 37.3 |
| **27** | 23.0 | 24.5 | 26.0 | 27.5 | 29.0 | 30.5 | 32.0 | 33.5 | 35.1 | 36.6 | 38.1 |
| **27.5** | 23.7 | 25.2 | 26.7 | 28.2 | 29.8 | 31.3 | 32.8 | 34.3 | 35.8 | 37.3 | 38.8 |
| **28** | 24.5 | 26.0 | 27.5 | 29.0 | 30.5 | 32.0 | 33.5 | 35.0 | 36.6 | 38.1 | 39.6 |
| **28.5** | 25.2 | 26.7 | 28.2 | 29.7 | 31.3 | 32.8 | 34.3 | 35.8 | 37.3 | 38.8 | 40.3 |
| **29** | 26.0 | 27.5 | 29.0 | 30.5 | 32.0 | 33.5 | 35.0 | 36.5 | 38.0 | 39.6 | 41.1 |
| **29.5** | 26.7 | 28.2 | 29.7 | 31.2 | 32.7 | 34.3 | 35.8 | 37.3 | 38.8 | 40.3 | 41.8 |
| **30** | 27.5 | 29.0 | 30.5 | 32.0 | 33.5 | 35.0 | 36.5 | 38.0 | 39.5 | 41.1 | 42.6 |

| MUAC (cm) | Ulna Length (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 10 | 14.2 | 15.7 | 17.2 | 18.7 | 20.2 | 21.7 | 23.2 | 24.8 | 26.3 | 27.8 |
| 10.5 | 14.9 | 16.4 | 17.9 | 19.5 | 21.0 | 22.5 | 24.0 | 25.5 | 27.0 | 28.5 |
| 11 | 15.7 | 17.2 | 18.7 | 20.2 | 21.7 | 23.2 | 24.7 | 26.2 | 27.8 | 29.3 |
| 11.5 | 16.4 | 17.9 | 19.4 | 20.9 | 22.5 | 24.0 | 25.5 | 27.0 | 28.5 | 30.0 |
| 12 | 17.2 | 18.7 | 20.2 | 21.7 | 23.2 | 24.7 | 26.2 | 27.7 | 29.3 | 30.8 |
| 12.5 | 17.9 | 19.4 | 20.9 | 22.4 | 24.0 | 25.5 | 27.0 | 28.5 | 30.0 | 31.5 |
| 13 | 18.7 | 20.2 | 21.7 | 23.2 | 24.7 | 26.2 | 27.7 | 29.2 | 30.7 | 32.3 |
| 13.5 | 19.4 | 20.9 | 22.4 | 23.9 | 25.4 | 27.0 | 28.5 | 30.0 | 31.5 | 33.0 |
| 14 | 20.2 | 21.7 | 23.2 | 24.7 | 26.2 | 27.7 | 29.2 | 30.7 | 32.2 | 33.8 |
| 14.5 | 20.9 | 22.4 | 23.9 | 25.4 | 26.9 | 28.5 | 30.0 | 31.5 | 33.0 | 34.5 |
| 15 | 21.6 | 23.2 | 24.7 | 26.2 | 27.7 | 29.2 | 30.7 | 32.2 | 33.7 | 35.2 |
| 15.5 | 22.4 | 23.9 | 25.4 | 26.9 | 28.4 | 30.0 | 31.5 | 33.0 | 34.5 | 36.0 |
| 16 | 23.1 | 24.7 | 26.2 | 27.7 | 29.2 | 30.7 | 32.2 | 33.7 | 35.2 | 36.7 |
| 16.5 | 23.9 | 25.4 | 26.9 | 28.4 | 29.9 | 31.4 | 33.0 | 34.5 | 36.0 | 37.5 |
| 17 | 24.6 | 26.1 | 27.7 | 29.2 | 30.7 | 32.2 | 33.7 | 35.2 | 36.7 | 38.2 |
| 17.5 | 25.4 | 26.9 | 28.4 | 29.9 | 31.4 | 32.9 | 34.5 | 36.0 | 37.5 | 39.0 |
| 18 | 26.1 | 27.6 | 29.2 | 30.7 | 32.2 | 33.7 | 35.2 | 36.7 | 38.2 | 39.7 |
| 18.5 | 26.9 | 28.4 | 29.9 | 31.4 | 32.9 | 34.4 | 35.9 | 37.5 | 39.0 | 40.5 |
| 19 | 27.6 | 29.1 | 30.7 | 32.2 | 33.7 | 35.2 | 36.7 | 38.2 | 39.7 | 41.2 |
| 19.5 | 28.4 | 29.9 | 31.4 | 32.9 | 34.4 | 35.9 | 37.4 | 39.0 | 40.5 | 42.0 |
| 20 | 29.1 | 30.6 | 32.1 | 33.7 | 35.2 | 36.7 | 38.2 | 39.7 | 41.2 | 42.7 |
| 20.5 | 29.9 | 31.4 | 32.9 | 34.4 | 35.9 | 37.4 | 38.9 | 40.4 | 42.0 | 43.5 |
| 21 | 30.6 | 32.1 | 33.6 | 35.2 | 36.7 | 38.2 | 39.7 | 41.2 | 42.7 | 44.2 |
| 21.5 | 31.4 | 32.9 | 34.4 | 35.9 | 37.4 | 38.9 | 40.4 | 41.9 | 43.5 | 45.0 |
| 22 | 32.1 | 33.6 | 35.1 | 36.6 | 38.2 | 39.7 | 41.2 | 42.7 | 44.2 | 45.7 |
| 22.5 | 32.9 | 34.4 | 35.9 | 37.4 | 38.9 | 40.4 | 41.9 | 43.4 | 44.9 | 46.5 |
| 23 | 33.6 | 35.1 | 36.6 | 38.1 | 39.7 | 41.2 | 42.7 | 44.2 | 45.7 | 47.2 |
| 23.5 | 34.4 | 35.9 | 37.4 | 38.9 | 40.4 | 41.9 | 43.4 | 44.9 | 46.4 | 48.0 |
| 24 | 35.1 | 36.6 | 38.1 | 39.6 | 41.1 | 42.7 | 44.2 | 45.7 | 47.2 | 48.7 |
| 24.5 | 35.9 | 37.4 | 38.9 | 40.4 | 41.9 | 43.4 | 44.9 | 46.4 | 47.9 | 49.4 |
| 25 | 36.6 | 38.1 | 39.6 | 41.1 | 42.6 | 44.2 | 45.7 | 47.2 | 48.7 | 50.2 |
| 25.5 | 37.3 | 38.9 | 40.4 | 41.9 | 43.4 | 44.9 | 46.4 | 47.9 | 49.4 | 50.9 |
| 26 | 38.1 | 39.6 | 41.1 | 42.6 | 44.1 | 45.6 | 47.2 | 48.7 | 50.2 | 51.7 |
| 26.5 | 38.8 | 40.4 | 41.9 | 43.4 | 44.9 | 46.4 | 47.9 | 49.4 | 50.9 | 52.4 |
| 27 | 39.6 | 41.1 | 42.6 | 44.1 | 45.6 | 47.1 | 48.7 | 50.2 | 51.7 | 53.2 |
| 27.5 | 40.3 | 41.8 | 43.4 | 44.9 | 46.4 | 47.9 | 49.4 | 50.9 | 52.4 | 53.9 |
| 28 | 41.1 | 42.6 | 44.1 | 45.6 | 47.1 | 48.6 | 50.1 | 51.7 | 53.2 | 54.7 |
| 28.5 | 41.8 | 43.3 | 44.9 | 46.4 | 47.9 | 49.4 | 50.9 | 52.4 | 53.9 | 55.4 |
| 29 | 42.6 | 44.1 | 45.6 | 47.1 | 48.6 | 50.1 | 51.6 | 53.2 | 54.7 | 56.2 |
| 29.5 | 43.3 | 44.8 | 46.3 | 47.9 | 49.4 | 50.9 | 52.4 | 53.9 | 55.4 | 56.9 |
| 30 | 44.1 | 45.6 | 47.1 | 48.6 | 50.1 | 51.6 | 53.1 | 54.7 | 56.2 | 57.7 |

## Appendix D. MUAC-Tibia Weight-Estimation Chart

| MUAC (cm) \ Tibia Length (cm) | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | -2.0 | -1.1 | -0.2 | 0.7 | 1.6 | 2.5 | 3.4 | 4.3 | 5.2 | 6.1 | 7.0 | 7.9 | 8.8 | 9.6 |
| 10.5 | -1.1 | -0.2 | 0.7 | 1.5 | 2.4 | 3.3 | 4.2 | 5.1 | 6.0 | 6.9 | 7.8 | 8.7 | 9.6 | 10.5 |
| 11 | -0.3 | 0.6 | 1.5 | 2.4 | 3.3 | 4.1 | 5.0 | 5.9 | 6.8 | 7.7 | 8.6 | 9.5 | 10.4 | 11.3 |
| 11.5 | 0.5 | 1.4 | 2.3 | 3.2 | 4.1 | 5.0 | 5.9 | 6.7 | 7.6 | 8.5 | 9.4 | 10.3 | 11.2 | 12.1 |
| 12 | 1.3 | 2.2 | 3.1 | 4.0 | 4.9 | 5.8 | 6.7 | 7.6 | 8.5 | 9.4 | 10.2 | 11.1 | 12.0 | 12.9 |
| 12.5 | 2.1 | 3.0 | 3.9 | 4.8 | 5.7 | 6.6 | 7.5 | 8.4 | 9.3 | 10.2 | 11.1 | 12.0 | 12.8 | 13.7 |
| 13 | 3.0 | 3.9 | 4.7 | 5.6 | 6.5 | 7.4 | 8.3 | 9.2 | 10.1 | 11.0 | 11.9 | 12.8 | 13.7 | 14.6 |
| 13.5 | 3.8 | 4.7 | 5.6 | 6.5 | 7.3 | 8.2 | 9.1 | 10.0 | 10.9 | 11.8 | 12.7 | 13.6 | 14.5 | 15.4 |
| 14 | 4.6 | 5.5 | 6.4 | 7.3 | 8.2 | 9.1 | 9.9 | 10.8 | 11.7 | 12.6 | 13.5 | 14.4 | 15.3 | 16.2 |
| 14.5 | 5.4 | 6.3 | 7.2 | 8.1 | 9.0 | 9.9 | 10.8 | 11.7 | 12.6 | 13.4 | 14.3 | 15.2 | 16.1 | 17.0 |
| 15 | 6.2 | 7.1 | 8.0 | 8.9 | 9.8 | 10.7 | 11.6 | 12.5 | 13.4 | 14.3 | 15.2 | 16.0 | 16.9 | 17.8 |
| 15.5 | 7.1 | 7.9 | 8.8 | 9.7 | 10.6 | 11.5 | 12.4 | 13.3 | 14.2 | 15.1 | 16.0 | 16.9 | 17.8 | 18.6 |
| 16 | 7.9 | 8.8 | 9.7 | 10.5 | 11.4 | 12.3 | 13.2 | 14.1 | 15.0 | 15.9 | 16.8 | 17.7 | 18.6 | 19.5 |
| 16.5 | 8.7 | 9.6 | 10.5 | 11.4 | 12.3 | 13.1 | 14.0 | 14.9 | 15.8 | 16.7 | 17.6 | 18.5 | 19.4 | 20.3 |
| 17 | 9.5 | 10.4 | 11.3 | 12.2 | 13.1 | 14.0 | 14.9 | 15.8 | 16.6 | 17.5 | 18.4 | 19.3 | 20.2 | 21.1 |
| 17.5 | 10.3 | 11.2 | 12.1 | 13.0 | 13.9 | 14.8 | 15.7 | 16.6 | 17.5 | 18.4 | 19.2 | 20.1 | 21.0 | 21.9 |
| 18 | 11.1 | 12.0 | 12.9 | 13.8 | 14.7 | 15.6 | 16.5 | 17.4 | 18.3 | 19.2 | 20.1 | 21.0 | 21.8 | 22.7 |
| 18.5 | 12.0 | 12.9 | 13.7 | 14.6 | 15.5 | 16.4 | 17.3 | 18.2 | 19.1 | 20.0 | 20.9 | 21.8 | 22.7 | 23.6 |
| 19 | 12.8 | 13.7 | 14.6 | 15.5 | 16.3 | 17.2 | 18.1 | 19.0 | 19.9 | 20.8 | 21.7 | 22.6 | 23.5 | 24.4 |
| 19.5 | 13.6 | 14.5 | 15.4 | 16.3 | 17.2 | 18.1 | 19.0 | 19.8 | 20.7 | 21.6 | 22.5 | 23.4 | 24.3 | 25.2 |
| 20 | 14.4 | 15.3 | 16.2 | 17.1 | 18.0 | 18.9 | 19.8 | 20.7 | 21.6 | 22.4 | 23.3 | 24.2 | 25.1 | 26.0 |
| 20.5 | 15.2 | 16.1 | 17.0 | 17.9 | 18.8 | 19.7 | 20.6 | 21.5 | 22.4 | 23.3 | 24.2 | 25.0 | 25.9 | 26.8 |
| 21 | 16.1 | 16.9 | 17.8 | 18.7 | 19.6 | 20.5 | 21.4 | 22.3 | 23.2 | 24.1 | 25.0 | 25.9 | 26.8 | 27.7 |
| 21.5 | 16.9 | 17.8 | 18.7 | 19.5 | 20.4 | 21.3 | 22.2 | 23.1 | 24.0 | 24.9 | 25.8 | 26.7 | 27.6 | 28.5 |
| 22 | 17.7 | 18.6 | 19.5 | 20.4 | 21.3 | 22.2 | 23.0 | 23.9 | 24.8 | 25.7 | 26.6 | 27.5 | 28.4 | 29.3 |
| 22.5 | 18.5 | 19.4 | 20.3 | 21.2 | 22.1 | 23.0 | 23.9 | 24.8 | 25.6 | 26.5 | 27.4 | 28.3 | 29.2 | 30.1 |
| 23 | 19.3 | 20.2 | 21.1 | 22.0 | 22.9 | 23.8 | 24.7 | 25.6 | 26.5 | 27.4 | 28.2 | 29.1 | 30.0 | 30.9 |
| 23.5 | 20.1 | 21.0 | 21.9 | 22.8 | 23.7 | 24.6 | 25.5 | 26.4 | 27.3 | 28.2 | 29.1 | 30.0 | 30.9 | 31.7 |
| 24 | 21.0 | 21.9 | 22.8 | 23.6 | 24.5 | 25.4 | 26.3 | 27.2 | 28.1 | 29.0 | 29.9 | 30.8 | 31.7 | 32.6 |
| 24.5 | 21.8 | 22.7 | 23.6 | 24.5 | 25.4 | 26.2 | 27.1 | 28.0 | 28.9 | 29.8 | 30.7 | 31.6 | 32.5 | 33.4 |
| 25 | 22.6 | 23.5 | 24.4 | 25.3 | 26.2 | 27.1 | 28.0 | 28.8 | 29.7 | 30.6 | 31.5 | 32.4 | 33.3 | 34.2 |
| 25.5 | 23.4 | 24.3 | 25.2 | 26.1 | 27.0 | 27.9 | 28.8 | 29.7 | 30.6 | 31.4 | 32.3 | 33.2 | 34.1 | 35.0 |
| 26 | 24.2 | 25.1 | 26.0 | 26.9 | 27.8 | 28.7 | 29.6 | 30.5 | 31.4 | 32.3 | 33.2 | 34.1 | 34.9 | 35.8 |
| 26.5 | 25.1 | 26.0 | 26.8 | 27.7 | 28.6 | 29.5 | 30.4 | 31.3 | 32.2 | 33.1 | 34.0 | 34.9 | 35.8 | 36.7 |
| 27 | 25.9 | 26.8 | 27.7 | 28.6 | 29.4 | 30.3 | 31.2 | 32.1 | 33.0 | 33.9 | 34.8 | 35.7 | 36.6 | 37.5 |
| 27.5 | 26.7 | 27.6 | 28.5 | 29.4 | 30.3 | 31.2 | 32.0 | 32.9 | 33.8 | 34.7 | 35.6 | 36.5 | 37.4 | 38.3 |
| 28 | 27.5 | 28.4 | 29.3 | 30.2 | 31.1 | 32.0 | 32.9 | 33.8 | 34.7 | 35.5 | 36.4 | 37.3 | 38.2 | 39.1 |
| 28.5 | 28.3 | 29.2 | 30.1 | 31.0 | 31.9 | 32.8 | 33.7 | 34.6 | 35.5 | 36.4 | 37.3 | 38.1 | 39.0 | 39.9 |
| 29 | 29.2 | 30.0 | 30.9 | 31.8 | 32.7 | 33.6 | 34.5 | 35.4 | 36.3 | 37.2 | 38.1 | 39.0 | 39.9 | 40.7 |
| 29.5 | 30.0 | 30.9 | 31.8 | 32.6 | 33.5 | 34.4 | 35.3 | 36.2 | 37.1 | 38.0 | 38.9 | 39.8 | 40.7 | 41.6 |
| 30 | 30.8 | 31.7 | 32.6 | 33.5 | 34.4 | 35.2 | 36.1 | 37.0 | 37.9 | 38.8 | 39.7 | 40.6 | 41.5 | 42.4 |

| MUAC (cm) \ Tibia Length (cm) | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10** | 10.5 | 11.4 | 12.3 | 13.2 | 14.1 | 15.0 | 15.9 | 16.8 | 17.7 | 18.6 | 19.5 | 20.3 | 21.2 | 22.1 |
| **10.5** | 11.4 | 12.2 | 13.1 | 14.0 | 14.9 | 15.8 | 16.7 | 17.6 | 18.5 | 19.4 | 20.3 | 21.2 | 22.1 | 23.0 |
| **11** | 12.2 | 13.1 | 14.0 | 14.8 | 15.7 | 16.6 | 17.5 | 18.4 | 19.3 | 20.2 | 21.1 | 22.0 | 22.9 | 23.8 |
| **11.5** | 13.0 | 13.9 | 14.8 | 15.7 | 16.6 | 17.5 | 18.3 | 19.2 | 20.1 | 21.0 | 21.9 | 22.8 | 23.7 | 24.6 |
| **12** | 13.8 | 14.7 | 15.6 | 16.5 | 17.4 | 18.3 | 19.2 | 20.1 | 20.9 | 21.8 | 22.7 | 23.6 | 24.5 | 25.4 |
| **12.5** | 14.6 | 15.5 | 16.4 | 17.3 | 18.2 | 19.1 | 20.0 | 20.9 | 21.8 | 22.7 | 23.5 | 24.4 | 25.3 | 26.2 |
| **13** | 15.4 | 16.3 | 17.2 | 18.1 | 19.0 | 19.9 | 20.8 | 21.7 | 22.6 | 23.5 | 24.4 | 25.3 | 26.2 | 27.0 |
| **13.5** | 16.3 | 17.2 | 18.0 | 18.9 | 19.8 | 20.7 | 21.6 | 22.5 | 23.4 | 24.3 | 25.2 | 26.1 | 27.0 | 27.9 |
| **14** | 17.1 | 18.0 | 18.9 | 19.8 | 20.7 | 21.5 | 22.4 | 23.3 | 24.2 | 25.1 | 26.0 | 26.9 | 27.8 | 28.7 |
| **14.5** | 17.9 | 18.8 | 19.7 | 20.6 | 21.5 | 22.4 | 23.3 | 24.1 | 25.0 | 25.9 | 26.8 | 27.7 | 28.6 | 29.5 |
| **15** | 18.7 | 19.6 | 20.5 | 21.4 | 22.3 | 23.2 | 24.1 | 25.0 | 25.9 | 26.7 | 27.6 | 28.5 | 29.4 | 30.3 |
| **15.5** | 19.5 | 20.4 | 21.3 | 22.2 | 23.1 | 24.0 | 24.9 | 25.8 | 26.7 | 27.6 | 28.5 | 29.4 | 30.2 | 31.1 |
| **16** | 20.4 | 21.3 | 22.1 | 23.0 | 23.9 | 24.8 | 25.7 | 26.6 | 27.5 | 28.4 | 29.3 | 30.2 | 31.1 | 32.0 |
| **16.5** | 21.2 | 22.1 | 23.0 | 23.9 | 24.7 | 25.6 | 26.5 | 27.4 | 28.3 | 29.2 | 30.1 | 31.0 | 31.9 | 32.8 |
| **17** | 22.0 | 22.9 | 23.8 | 24.7 | 25.6 | 26.5 | 27.3 | 28.2 | 29.1 | 30.0 | 30.9 | 31.8 | 32.7 | 33.6 |
| **17.5** | 22.8 | 23.7 | 24.6 | 25.5 | 26.4 | 27.3 | 28.2 | 29.1 | 29.9 | 30.8 | 31.7 | 32.6 | 33.5 | 34.4 |
| **18** | 23.6 | 24.5 | 25.4 | 26.3 | 27.2 | 28.1 | 29.0 | 29.9 | 30.8 | 31.7 | 32.6 | 33.4 | 34.3 | 35.2 |
| **18.5** | 24.5 | 25.3 | 26.2 | 27.1 | 28.0 | 28.9 | 29.8 | 30.7 | 31.6 | 32.5 | 33.4 | 34.3 | 35.2 | 36.0 |
| **19** | 25.3 | 26.2 | 27.1 | 27.9 | 28.8 | 29.7 | 30.6 | 31.5 | 32.4 | 33.3 | 34.2 | 35.1 | 36.0 | 36.9 |
| **19.5** | 26.1 | 27.0 | 27.9 | 28.8 | 29.7 | 30.5 | 31.4 | 32.3 | 33.2 | 34.1 | 35.0 | 35.9 | 36.8 | 37.7 |
| **20** | 26.9 | 27.8 | 28.7 | 29.6 | 30.5 | 31.4 | 32.3 | 33.2 | 34.0 | 34.9 | 35.8 | 36.7 | 37.6 | 38.5 |
| **20.5** | 27.7 | 28.6 | 29.5 | 30.4 | 31.3 | 32.2 | 33.1 | 34.0 | 34.9 | 35.8 | 36.6 | 37.5 | 38.4 | 39.3 |
| **21** | 28.5 | 29.4 | 30.3 | 31.2 | 32.1 | 33.0 | 33.9 | 34.8 | 35.7 | 36.6 | 37.5 | 38.4 | 39.2 | 40.1 |
| **21.5** | 29.4 | 30.3 | 31.1 | 32.0 | 32.9 | 33.8 | 34.7 | 35.6 | 36.5 | 37.4 | 38.3 | 39.2 | 40.1 | 41.0 |
| **22** | 30.2 | 31.1 | 32.0 | 32.9 | 33.7 | 34.6 | 35.5 | 36.4 | 37.3 | 38.2 | 39.1 | 40.0 | 40.9 | 41.8 |
| **22.5** | 31.0 | 31.9 | 32.8 | 33.7 | 34.6 | 35.5 | 36.4 | 37.2 | 38.1 | 39.0 | 39.9 | 40.8 | 41.7 | 42.6 |
| **23** | 31.8 | 32.7 | 33.6 | 34.5 | 35.4 | 36.3 | 37.2 | 38.1 | 39.0 | 39.8 | 40.7 | 41.6 | 42.5 | 43.4 |
| **23.5** | 32.6 | 33.5 | 34.4 | 35.3 | 36.2 | 37.1 | 38.0 | 38.9 | 39.8 | 40.7 | 41.6 | 42.4 | 43.3 | 44.2 |
| **24** | 33.5 | 34.3 | 35.2 | 36.1 | 37.0 | 37.9 | 38.8 | 39.7 | 40.6 | 41.5 | 42.4 | 43.3 | 44.2 | 45.1 |
| **24.5** | 34.3 | 35.2 | 36.1 | 36.9 | 37.8 | 38.7 | 39.6 | 40.5 | 41.4 | 42.3 | 43.2 | 44.1 | 45.0 | 45.9 |
| **25** | 35.1 | 36.0 | 36.9 | 37.8 | 38.7 | 39.6 | 40.4 | 41.3 | 42.2 | 43.1 | 44.0 | 44.9 | 45.8 | 46.7 |
| **25.5** | 35.9 | 36.8 | 37.7 | 38.6 | 39.5 | 40.4 | 41.3 | 42.2 | 43.0 | 43.9 | 44.8 | 45.7 | 46.6 | 47.5 |
| **26** | 36.7 | 37.6 | 38.5 | 39.4 | 40.3 | 41.2 | 42.1 | 43.0 | 43.9 | 44.8 | 45.6 | 46.5 | 47.4 | 48.3 |
| **26.5** | 37.5 | 38.4 | 39.3 | 40.2 | 41.1 | 42.0 | 42.9 | 43.8 | 44.7 | 45.6 | 46.5 | 47.4 | 48.3 | 49.1 |
| **27** | 38.4 | 39.3 | 40.1 | 41.0 | 41.9 | 42.8 | 43.7 | 44.6 | 45.5 | 46.4 | 47.3 | 48.2 | 49.1 | 50.0 |
| **27.5** | 39.2 | 40.1 | 41.0 | 41.9 | 42.8 | 43.6 | 44.5 | 45.4 | 46.3 | 47.2 | 48.1 | 49.0 | 49.9 | 50.8 |
| **28** | 40.0 | 40.9 | 41.8 | 42.7 | 43.6 | 44.5 | 45.4 | 46.2 | 47.1 | 48.0 | 48.9 | 49.8 | 50.7 | 51.6 |
| **28.5** | 40.8 | 41.7 | 42.6 | 43.5 | 44.4 | 45.3 | 46.2 | 47.1 | 48.0 | 48.8 | 49.7 | 50.6 | 51.5 | 52.4 |
| **29** | 41.6 | 42.5 | 43.4 | 44.3 | 45.2 | 46.1 | 47.0 | 47.9 | 48.8 | 49.7 | 50.6 | 51.5 | 52.3 | 53.2 |
| **29.5** | 42.5 | 43.3 | 44.2 | 45.1 | 46.0 | 46.9 | 47.8 | 48.7 | 49.6 | 50.5 | 51.4 | 52.3 | 53.2 | 54.1 |
| **30** | 43.3 | 44.2 | 45.1 | 46.0 | 46.8 | 47.7 | 48.6 | 49.5 | 50.4 | 51.3 | 52.2 | 53.1 | 54.0 | 54.9 |