Tracking the development of lean and fat areas of the arm from childhood to adulthood in a cohort of the Ellisras Longitudinal Study

by

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DISSERTATION

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DEDICATION

I dedicate this dissertation to my late mother (Evelyn Tebogo Mabogoana), who was my best friend, and my support system, and who always encouraged me to never stop studying. I would like to express special gratitude to my daughter (Queen Makhubedu), and father (Selatole Mothabong Mabogoana), who continuously encouraged and supported me through my studies. My sisters (Bafedile Huandi Lerato, Mafoloane Pheladi Mokete Sello and Saphaku Hlapogadi Mogau Mabogoana) for being supportive.

DECLARATION

I declare that the dissertation hereby submitted to the University of Limpopo, for the degree of Masters in Science (Physiology) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Mabogoana MMK (Ms) **07 November 2023**

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ABSTRACT

Undernutrition is a major public health problem in Africa. The risk of underweight is associated with a negative impact on children's health, growth and development in later life. Upper arm composition is used to determine the prevalence of undernutrition. The use of upper arm composition reflects body protein and calorie reserves. However, there is a paucity of data on the upper arm composition of children from African countries. This study aimed to investigate the development of fat and lean areas of the arms and seasonal variation of upper arm fat and lean areas from childhood into young adulthood. Mid-upper arm circumference (MUAC), triceps and biceps skinfold measurements were measured according to the recommended anthropometric standard procedures. The measurements were collected during the autumn (April – May) and spring (October – November) seasons from 1997 to 2003. The total upper-arm area (TUA), arm fat area (AFA) and arm muscle area (AMA) were calculated. A total of 911 boys and 852 girls, aged 4 to 17 years participated in the survey in 1997 were included in this study. This was a retrospective data analysis study. Data was analysed using the Mann-Whitney U test to examine sex and age differences in anthropometric characteristics in autumn and spring. Ellisras boys and girls had a low mean value in AMA development when compared with the NHANES (National Health and Nutrition Examination Survey III) reference population. Moreover, the Ellisras girls had higher AMA when compared to boys of the same age. Furthermore, there was no clear pattern in the development of MUAC among Ellisras children when compared to the reference population. Contrary to other findings Ellisras children had a higher AFA when compared to the NHANES III reference population. The generalised estimate equation (GEE) was used to test the relationship between autumn and spring according to AFA, AMA and MUAC. The prevalence of undernutrition was low by AFA at 3.9% in boys when compared to girls at 13.2%, high when using AMA at 95.1% and 82.1% in boys and girls respectively. In addition, the prevalence of undernutrition by MUAC was 58.0% and 49.5% for boys and girls respectively. Boys aged between 8 – 11 years had a significant (p-value = 0.020) positive association in AFA with β = 0.47, (95% CL: 0.07; 0.82) and girls of the same age also had a positive significant association (p-value = 0.001), in AFA with β = 1.30, (95% CL: 0.58; 2.03) in spring as compared to autumn. Furthermore, there was a significant median difference between arm fat area (AFA) and arm muscle area (AMA), in autumn and spring. There was seasonal variation observed between the seasons over time, from mid-childhood to the adolescent stage. There was a positive significant ($p < 0.001$) association between the first AFA, AMA and MUAC and the subsequent measurements for both boys and girls, throughout the period. AFA of $\beta = 0.01$, (95% CL: 0.00; 0.01) and $\beta = 0.03$, (95% CL: 0.03; 0.04) for boys and girls respectively. Moreover, girls had an elevated beta range when compared to boys. A similar trend was observed with AMA $\beta = -0.01$, (95% CL: -0.01; 0.01) and $\beta = 0.04$, (95% CL: 0.03; 0.04) for boys and girls respectively. However, MUAC for boys was elevated $\beta = 0.03$, (95% CL: 0.02; 0.04) when compared to girls $\beta = 0.01$, (95% CL: 0.00; 0.01). The tracking coefficient between the initial measurements and the subsequent measurements was higher for AMA and AFA when compared to MUAC. This could be supported by slightly higher tracking coefficients in Ellisras girls compared to boys over time. The six-year duration of the study with measurements carried out twice yearly not only provides accurate tracking measurements of the arm anthropometry. In conclusion, the findings of this study suggest that there high prevalence of undernutrition found in this study. Furthermore, there was a substantial seasonal variation in the growth and development of fat and lean arm areas among the Ellisras children. Arm anthropometry may be a valuable way to evaluate the nutritional status of children. On the other hand, there are a limited number of studies available, and there are limited longitudinal studies that have investigated the development of MUAC, arm muscle and fat area over more or less the same length where the current study was carried out.

KEY CONCEPTS

Lean mass; Fat mass; Mid upper arm circumference; Arm anthropometry; Undernutrition; Rural South African children, Seasonal variation, Arm fat area, Arm muscle area

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LIST OF ABBREVIATIONS

AUC – Area under curve

AMA – Arm Muscle Area

AFA – Arm Fat Area

FM – Fat Mass

FFM – Fat-Free Mass

ELS – Ellisras Longitudinal Study

ISAK – International Society for the Advancement of Kinanthropometry

MUAC – Mid-upper arm circumference

NHANES – National Health and Nutrition Examination Survey III

SAT – Subcutaneous Adipose Tissue

VAT - Visceral Adipose Tissue

ROC – Receiver operating characteristics

BMI – Body Mass Index

CHAPTER 1

PROBLEMS AND AIMS OF THE STUDY

1.1. Problem statement

1.2. Rationale

1.3. Aim and objectives of the study

1.4. Scientific contribution

1.5. Structure of the dissertation

1.6. References

1.1. PROBLEM STATEMENT

Undernutrition is a major public health concern in the world (Mphahlele *et al*., 2020). Stunting, wasting and underweight are all common conditions in a developing country like South Africa (Nyati *et al*., 2021) and their prevalence is increasing with increasing transition in socio-economic, political, and epidemiological changes (Misra & Khurana, 2008). These are common phenomena that affect children and adolescents' growth and development (Olivieri *et al*., 2008). Furthermore, undernutrition is associated with a negative impact on children in later life as it increases the risk of developing non-communicable diseases such as hypertension (Mphahlele *et al*., 2020). The use of arm anthropometry to assess body composition has been extensively studied (Gasser *et al*., 1994; Chomtho *et al*., 2006) and assessing the shape of the upper arm is important in both clinical and field settings (Oyhenart *et al*., 2020). However, most of the studies focus only on a limited number of aspects, including the arm anthropometry of athletes such as swimmers (Mazić *et al*., 2014), malnutrition or the relationship between body composition and obesity (Moeng-Mahlangu *et al*., 2021). Little information is available on arm anthropometric growth and development of children from childhood into adulthood, especially in rural areas in the Limpopo province. Therefore, the current study will investigate the use of upper arm anthropometry to track the development of lean and fat areas in children into adulthood over time.

1.2. RATIONALE

Worldwide, most developing countries are affected by food security and natural disasters (Mphahlele *et al*., 2020). These are some common phenomena that affect children's growth and development (Olivieri *et al*., 2008). These are dominating in low-income countries where the prevalence of undernutrition is very high (Mramba *et al*., 2017). South Africa, like most developing countries, has been going through an economic transition (Misra & Khurana, 2008). The economic burden associated with increased undernutrition puts more pressure on the limited health budgets of these countries (Sen *et al*., 2018). Furthermore, there is little information available about the prevalence and tracking of undernutrition from childhood into adulthood.

Undernutrition refer to an insufficient intake of nutrients for a specific age or state (Maleta, 2006; WHO, n.d.). Stunting is being underweight for one's age, and wasted which refers to the state of being too thin (Mphahlele *et al*., 2020). The prevalence of stunting and wasting are increasing in the rural areas (Motadi *et al*., 2015). Furthermore, being underweight is directly associated with a weak immune system, causing different diseases that will eventually lead to death (Black *et al*., 2003). It is therefore important to monitor the level of adiposity in children using body composition, to control and minimise the health risks associated with excess or low body fatness.

According to Debnath *et al*., (2017), in a given population, body composition differs based on geographical setting, genetics, and environmental and socio-economic factors. Moreover, the relationship between body composition and health has been well established (Mazić *et al*., 2014; Oyhenart *et al*., 2020). Anthropometric measurements are useful tools for quantifying body composition in children (Lipsberga & Kažoka, 2016). Salazar-Preciado *et al*., (2021) highlight that the most well-documented and widely used anthropometric measurements include weight, height, waist, and hip circumferences. However, these methods are not without limitations, as they cannot differentiate between the fat and lean mass, and are therefore unable to give the fat to lean body mass proportions (Gasser *et al*., 1994; Lipsberga & Kažoka, 2016).

Arm anthropometry can be used to quantify the distribution of fat and lean mass, by using the skinfold measurements (Gasser *et al*., 1994; Chomtho *et al*., 2006). Consequently, Mramba *et al*., (2017) showed that a decrease of skinfolds is associated with a real loss of fat tissue during early childhood development, however, Gasser *et al*., (1994) stated that the reason may be due to its association with the increase of limb circumference stretching the ring of fat. According to Chomtho *et al*., (2006), the arm muscle area and arm fat area are better predictors of the nutritional assessment status in a cross-sectional study of children than the arm circumference and skinfold thickness. Therefore, it is important to monitor the growth of children into adulthood.

Growth monitoring assists in the early detection of growth disorders, giving a better understanding of the influence of different childhood growth stages, especially when the measurements are repeated severally (Dalskov *et al*., 2016). However, there is a current shortage of information on the effects of undernutrition development from childhood to adulthood over time, especially in the rural areas of Limpopo province.

Furthermore, the development and tracking of body composition of children into adulthood has received little attention in the rural, South African population. Therefore, there is a need to investigate the development of fat and lean arm areas of the arm as a predictor of future health.

1.3. AIM, OBJECTIVES AND HYPOTHESIS

The aim of the study is to investigate the development and tracking of fat and lean arm area of Ellisras children aged 4 to 17 years who are part of the Ellisras Longitudinal Study over time (from 1997 to 2003).

The objectives of the study were to:

i. Measure fat and lean arm area from childhood into adulthood in subjects who are part of the Ellisras Longitudinal Study (ELS) over time (1997 to 2003).
ii. Compare the fat and lean arm area of Ellisras rural children with the National Health and Nutrition Examination Survey (NHANES) III reference population (Frisancho, 1990).
iii. Determine the prevalence of undernutrition using fat and lean arm area measurements of Ellisras rural children into adults over time (1997 to 2003).
iv. Investigate seasonal variation (autumn and spring) in the development of fat and lean arm area from childhood into late adolescent over time (1997 to 2003).
v. Determine the sensitivity and specificity of AFA, AMA and MUAC cut-off points among Ellisras rural children.
vi. Track the trend of fat and lean arm area of the Ellisras rural population over time.
vii. Assess if fat and lean arm mass in childhood can be used to predict fat and lean mass in adulthood.

Hypothesis:

i. The measurement of the fat and lean arm area will be similar to those studied in the world.

ii. The fat and lean arm area among Ellisras children and adolescents will be low when compared to the reference population.
iii. The prevalence of low fat and lean arm area will be similar to those studied in the world.
iv. The development of fat and lean areas over the season will be those studied in the world.
v. The sensitivity and specificity cut-off points for AFA, AMA and MUAC will be established amongst Ellisras rural children aged 4 – 17 years.
vi. The association between trends in the development of fat and lean areas between autumn and spring is similar to those studied in the world.
vii. In the ELS population the fat and lean area of children can be predicted in the adult population.

1.4. SCIENTIFIC CONTRIBUTION

The study aimed to provide information about the health status and healthcare needs among children and their growth into adulthood, using anthropometric arm measurements on participants residing in Ellisras rural areas of Limpopo province. The information obtained from the study may assist in improving the health status of children and adults. Furthermore, it will assist in developing intervention programmes that can be used by healthcare professionals and policy makers in Limpopo province of South Africa and other developing countries. There is need to establish one growth standard to assess undernutrition in children aged 4 – 17 years old; agree on the sampling methodology for national surveys and generate representative data at provincial levels to improve the national sampling framework. In addition, the findings of the study will be compared with the findings of current literature to ascertain whether there have been any changes since 20 years ago.

1.5. STRUCTURE OF THE DISSERTATION

I. Chapter 1 - Problem and aim of the study
II. Chapter 2 - Literature Review
III. Chapter 3 - Materials and Methods
IV. Chapter 4 – Results and Discussion
V. Chapter 5 – Introduction, Summary, Conclusion and Recommendations
VI. Articles published and submitted to the International peer-review journal will be compiled as an appendix

1.6. REFERENCES

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CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

2.2. Body composition

2.3. Arm anthropometry

2.4. Relationship of different anthropometric indicators with undernutrition

2.5. Seasonal variation

2.6. Summary

2.7. References

2.1. INTRODUCTION

Growth may be defined as a quantitative increase in size, mass, physique and body composition (Tanner, 1981). Growth is also marked by progressive development that leads to physical and biological maturity (Malina *et al*., 1999; Leppik, 2005; Tanner, 1981), but also in the timing of progress (Tanner, 1962; Rodríguez *et al*., 2005). There are different phases of growth: prenatal, postnatal infancy, childhood, puberty, adolescence, adulthood and senescence, which are marked by several body changes (Dietz, 1994; Monyeki *et al*., 2009; Kang, 2018). The infancy stage is marked by postnatal month to age three years of life total dependency on the mother (Monyeki *et al*., 2009), and the most rapidly changing rate of growth. The childhood stage is after infancy and ends just before the adolescent stage (Kang, 2018a; Balasundaram & Avulakunta, 2023).

Childhood growth is a state that is associated with the change in body size, shape and composition, (Rodríguez *et al*., 2005; Ashby-Thompson *et al*., 2023), characterised by a brief slowing down in growth due to the growth hormone synthesis of protein, which prevents the formation of fat and carbohydrate, and is necessary for the proliferation of cartilage cells at the epiphyseal plate permitting linear growth (Leppik, 2005; Sherwood, 2015). During childhood, the child no longer depends on their mother for survival and this stage is followed by the adolescent stage. Kang (2018) describes the adolescent stage as beginning with pubescence, with age ranges from 10 to 19 years old. The earliest signs of the adolescent stage are emergence of secondary sexual characters and continuing up to the morphological and physiological maturation to the adult status (de Onis *et al*., 2019; Balasundaram & Avulakunta, 2023). Annual gain in height, weight and fat-free mass continuously increases during childhood and adolescence (Das *et al*., 2017). Moreover, it can be measured in terms of height, weight and metabolic balance retention of hydrogen and calcium in the body.

The normality of the child is gauged by referring toage and sex-specific standards of the distribution of the particular dimension or maturity indicator in a reference population (Frisancho & Tracer, 1987). Growth is a critical indicator of a child's health and the WHO identifies growth assessment as the best single measure to define the nutritional status and health of children (de Onis *et al*., 2019; WHO, n.d.). Therefore, failure to grow at an appropriate rate may be associated with a primary growth disorder, infections, or poor nutrition such as undernutrition (Mokone *et al*., 2022; Kubeka & Modjadji, 2023). There are different anthropometric assessment methods carried out in children as indicators of growth and maturity.

2.2. BODY COMPOSITION

Sherwood (2015), described the human body composition as the level of organisation that is from the chemical level to the organism level. The human body is structured at the atomic level (such as oxygen, carbon, nitrogen and hydrogen, etc.); a molecular level (that is water, lipid, protein, minerals, and glycogen), a cellular level (such as cells, intracellular and extracellular fluid, etc.), or a tissue level; (that is adipose tissue, skeletal muscle, bone, etc.); organ (skeletal muscle, bones, skin etc.); body system (skeletal system, muscular system etc.) and human organism. However, in epidemiology studies that focus on undernutrition and obesity, the human body composition is mainly defined in terms of molecular level (Goran, 1998; Rodríguez *et al*., 2005).

Malina *et al*., (1999) suggest that regional body composition refers to variation in the anatomical distribution of the major components of the body mass such as adipose, skeletal muscle and skeletal tissues. Moreover, the human body weight is composed of 60% of water and 40% of the body is composed of protein, fat and minerals (Fogelholm *et al*., 1996; De, 2017). Human body composition can be best defined in terms of fat mass (FM) and fat-free mass (FFM) which is the lean mass. FM is the absolute amount of body fat; it includes all extractable lipids from adipose and other tissues. The FFM consists of all residual chemicals and tissues including water, muscle, bone, connective tissues, and internal organs (Sen & Mondal, 2013; De, 2017).

In addition muscle and adiposity develop in size with advancing age and newborns have high fat and reach the adiposity peak during infancy, then decline in the period of childhood (Tanner, 1981; Apibantaweesakul *et al*., 2021). In contrast, skeletal muscles continually grow from infancy to adulthood. In early childhood, segmental growth, muscularity, and adiposity might change to a greater degree than that of the whole body dimensions and may even result in greater changes in strength development (Kyle *et al.*, 2003; Apibantaweesakul *et al*., 2021).

The evaluation of body composition plays a vital role in growth monitoring and it also serves as an integral part of childhood development, especially in developing countries wherein environmental factors such as climatic conditions and natural disasters (Fentahun *et al*., 2018) affect the food, water and nutrition security (Mphahlele *et al*., 2020; Marshak *et al*., 2021). Adipose tissues, skeletal muscle and skeletal tissues differ in terms of age, sex, and ethnicity (Malina *et al*., 1999; Mandal *et al*., 2021).

2.2.1. Adiposity

Adipose tissue is a loose connective tissue composed of adipocytes and originally derived from lipoblasts (Shuster *et al*., 2012; Sherwood, 2015; Mittal, 2019) and it serves as a storage of energy, cushion for protection of vital organs and insulation of the body against cold environment (Sherwood, 2015; Ronquillo *et al*., 2019). Adipose tissue is anatomically distributed in different proportions throughout the human body, and the pattern of distribution is dependent upon many factors including sex, age, race, ethnicity, genotype (Sen & Mondal, 2013), diet, physical activity, hormone levels and medication. Furthermore, the percentage of adipose tissue is higher in females, the elderly and overweight individuals (Mandal *et al*., 2021).

Body fat tissue is traditionally distributed into two main compartments with different metabolic characteristics: subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) (Sherwood, 2015). Subcutaneous adipose tissue refers to the adipose tissue underneath the skin whereas VAT is the adipose tissue lining internal organs (Mittal, 2019). On the other hand, both tissue types are important, particular attention has been directed to visceral adiposity owing to its association with various medical pathologies. However, recent studies have also shown that SAT plays an important role in the diagnosis or screening of malnutrition and its direct associations with disease, bio-chemical changes, clinical symptoms and nutritional status among children (Hadjibabaie *et al*., 2011; Sen *et al*., 2016; Mittal, 2019). The SAT is also known as FM and exhibits high fats and liquid content from adipose tissue.

During childhood development there is an increase in SAT and VAT however, it differs between females and males (Leppik, 2005). Females naturally have larger SAT than VAT (Bloor & Symonds, 2014). In addition, sexual maturity is associated with the accumulation of body fats (Mittal, 2019). The degree of overall fatness that is the distribution of fat and adipose tissue is an important predictor of disease risk (Peeters *et al*., 2007). SAT is comprised of well-organised, tightly packed spherical adipocytes, whereas VAT is highly vascularised with disorganised, irregularly shaped lobules (Mittal, 2019). Females possess larger subcutaneous than visceral adipocytes, suggesting a lower storage capacity in visceral depots for triglycerides, creating higher lipid saturation, increased lipolysis and greater susceptibility for dysfunction (Wells, 2007; Bloor & Symonds, 2014).

Although fat and adipose tissue are differentiated by distinct biochemical and metabolic features, these terms will be used interchangeably for this thesis. Furthermore, the discussion in this thesis will focus on subcutaneous adipose tissue and muscle tissues.

2.2.2. Muscle

Muscle tissue consists of cells specialised for contracting, which generates tension and produces movement (McCuller *et al*., 2023). The three types of muscle tissue include skeletal, cardiac, and smooth muscle. The cardiac muscle pumps blood out of the heart and the smooth muscle, which involves selective movement of internal structures to generate tension in the muscle cells. In addition, the skeletal muscle moves the skeleton (Sherwood, 2015). Skeletal muscle comprises approximately 40% of total body weight in men and 32% in women, while smooth and cardiac muscles make up 10% of total weight (Sherwood, 2015). However, for this thesis, the skeletal muscle will be discussed in greater length.

Skeletal muscle is found throughout the body and functions to contract in response to a stimulus. Skeletal muscle serves many purposes, including producing movement, sustaining body posture and position, maintaining body temperature, storing nutrients, and stabilising joints. In contrast to smooth and cardiac muscle contraction, most skeletal muscle contraction is under voluntary control, receiving neural inputs allowing conscious control of muscles (McCuller *et al*., 2023). Moreover, the skeletal muscle contains 50 to 75% of all body proteins. The skeletal muscles are associated with the FFM and are also known as lean mass as its main constituents are protein and less to no fats.

Muscle is mainly composed of water (75%), protein (20%), and other substances including inorganic salts, minerals, fat, and carbohydrates (5%) (Frontera & Ochala, 2015; McCuller *et al*., 2023). In general, muscle mass depends on the balance between protein synthesis and degradation and both processes are sensitive to factors such as nutritional status, hormonal balance, physical activity and injury or disease, among others (Sherwood, 2015; McCuller *et al*., 2023). The various protein compartments (structural, contractile, and regulatory) have received significant scientific attention because of their important contribution to mobility, exercise capacity, functioning, and health. However, there is a need to explore the regional distribution of protein and fat using upper-arm anthropometry.

2.3. ARM ANTHROPOMETRY

Arm anthropometry is the measurement used to assess regional body composition such as muscles and adiposities see Figure 1, focusing on the shape of the upper arm, in a resource-limited setting (DAPA, n.d.; Jaswant & Nitish, 2014). The main measurements are the Mid Upper Arm Circumference (MUAC) and triceps skinfold, which are used to derive equations that estimate the Arm Muscle Area (AMA) and Arm Fat Area (AFA) (Frisancho, 1981; Mphahlele *et al*., 2020). The AMA that is the FFM can measure the degree of muscularity, thus reflecting the body's protein reserve (Sen & Mondal, 2013). The AFA that is the FM measures the body adiposity, thus reflecting the body calorie reserve stored in the form of body fat (Sen & Mondal, 2013; Senbanjo *et al*., 2014).

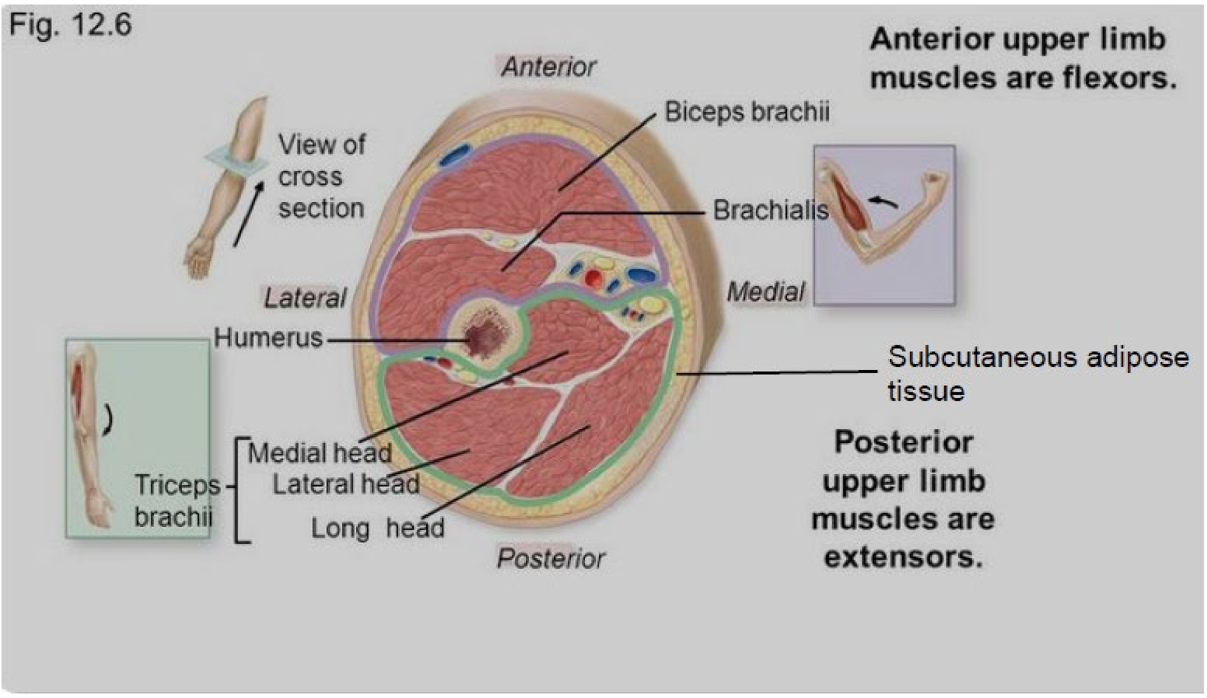

Figure 1: Cross-sectional view of the upper arm (McGraw – Hill, Human anatomy n.d)

2.3.1. USE OF MID-UPPER ARM CIRCUMFERENCE

MUAC is measured using a flexible and inexpensive tape to estimate the sum of the muscles, bones and fats of the upper arm (DAPA, n.d.; Eaton-Evans, 2013). MUAC can be used not only as a tool for the diagnosis of undernutrition but also as a predictor of the level of adiposity in children and adolescents (Żegleń *et al.*, 2021). Moreover, in each population there are different cut-off points according to age and sex for children. Brazil and Turkey have introduced age and gender-specific MUAC cut-offs for children (Çiçek *et al.*, 2014). However, no study was reported among South African children using AFA, AMA and MUAC at these international cut-off points.

2.3.2. USE OF TRICEPS SKINFOLD

Skinfolds or fat folds can be defined as the double thickness of skin, plus the adipose tissue between the parallel layers of the skin. It is another anthropometrics indicator that measures the distribution pattern of subcutaneous adipose fat (Tanner, 1981). It has been reported that subcutaneous tissues are associated with total body fat. Skinfold thickness values can be used to estimate percentages of total body fat (Davidson *et al*., 2011).

On the other hand triceps skinfold thickness (TSF) is a useful method to assess SAT in various regions or the whole body (Debnath *et al*., 2018), using a skinfold calliper. Both triceps skinfold and MUAC are important tools for predicting undernutrition in children and adolescents moreover, BMI correlates with skinfold (Olutekunbi *et al*., 2018; Shaikh *et al*., 2020). In addition, skinfold and MUAC are used to derive mathematical areas and indices such as AFA and AMA that can be used to predict undernutrition in children and adolescents (Frisancho, 1981; Mphahlele *et al*., 2020). The AFA and AMA are calculated using the formula below:

$$\text{TUA (cm)} = \text{MUAC}^2/(4 \text{ x } \pi) \ldots\ldots\ldots\ldots\ldots\ldots\text{(1)}$$

$$\text{AMA (cm}^2\text{)} = [\text{MUAC} - (\text{TSF} \times \pi)]^2/(4 \times \pi)\ldots\ldots\ldots\ldots\text{(2)}$$

$$\text{AFA (cm}^2\text{)} = \text{TUA} - \text{AMA}\ldots\ldots\ldots\ldots\ldots\ldots\text{(3)}$$

where: TUA – total upper-arm area in cm, MUAC – mid-upper arm circumference in cm, TSF – triceps skinfold thickness in cm, AMA – upper arm muscle area in cm^2, AFA – upper arm fat area in cm^2.

2.3.3. BODY MASS INDEX AS METHOD TO ASSESS FAT AND LEAN MASS

Body mass index (BMI) has been the most used measure of adiposity in epidemiological research (Thorup *et al*., 2020). Numerous studies have found that obesity, defined by BMI, is a significant risk factor for many diseases (Lee *et al*., 2017). However, BMI, which is calculated by weight in kilograms divided by height in metres squared, reflects both lean body mass and fat mass (Gasser *et al*., 1994; Lipsberga & Kažoka, 2016). Lean body mass accounts for most of the human body and is known to play an important role in many physiological processes (e.g. physical, social, and metabolic functions) (Sherwood, 2015; De, 2017). Reduction in lean body mass may have negative effects on many health outcomes. On the other hand, excess body fat is linked to adverse metabolic disease risks (Chomtho *et al*., 2006; Sizoo *et al*., 2021).

However, BMI does not differentiate between individuals whose excessive weight is a result of excessive fat or excessive muscular development (Senbanjo *et al*., 2014). Hence the use of arm anthropometry is preferable when compared to BMI.

2.3.4. USE OF LABORATORY TECHNIQUES TO ASSESS FAT AND LEAN MASS

Laboratory techniques like ultrasound, computer tomography and Magnetic Resonance Imaging are accurate enough to be used to assess fat and lean mass and are regarded as golden standards (Sizoo *et al*., 2021; López-Gómez *et al*., 2023).

- Ultrasound - measures visceral and subcutaneous fat by scanning through the body.
- Computer Tomography (CT) - high resolution images that can be processed to differentiate and measure volumes of fat and lean tissue.
- Magnetic Resonance Imaging (MRI) - measure the contrast among muscle tissue and fat tissue. In addition, MRI has been replaced with CT scan as gold standard.

However, they are expensive, time consuming, could not be used in populations' studies and require sensitive instruments which can only be operated by highly trained technician (Sizoo *et al*., 2021; Barazzoni *et al*., 2022).

2.3.5. COMPARISON OF FAT AND LEAN ARM AREA OF CHILDREN

Several studies compared the development of fat and lean areas worldwide with the reference population in the National Health and Nutrition Examination Survey III (NHANES III) (Frisancho, 1990). Senbanjo *et al*., (2014) conducted a study among 570 Nigerian, school children aged 5 – 19 years, the findings showed that girls had a significantly higher AFA than boys of the same age. MUAC and AMA were significantly higher in girls aged 10 – 14 years, whereas AMA was significantly higher in boys aged 15 – 19 years. AMA and AFA of the children were lower than those of Americans as the reference population in the NHANES III but similar to those of Zimbabweans (Olivieri *et al*., 2008), and higher than those of Indians (Sen & Mondal, 2013).

Chowdhury & Ghosh, (2009) conducted a study in Santal, India among 890 children aged 5 – 12 years and compared it with the reference population in the NHANES III. The growth curve of AMA-for-age for boys at earlier ages 5 – 8 years was above the 25th percentile values but with the advancement of ages, the curve is placed close to the 10th percentile of reference values (Frisancho, 1981). While the AMA-for-age curve for girls is always placed between the 25th and 10th percentile of reference values (Frisancho, 1981).

Ozturk *et al*., (2009) compared the Turkish children, aged 6 – 17 years with the reference population and found that the MUAC for both boys and girls was lower than that of the reference population NHANES I, II (Frisancho, 1981; Frisancho & Tracer, 1987). However, the study did not compare AMA and AFA.

Al-Sendi *et al*., (2003) reported a high mean AFA among Bahraini adolescents compared with the NHANES I, of the boys at most age groups were above the 50th percentile of the reference population whereas girls' values exceeded the 85th percentile of the same reference. However, the result did not report on MUAC, AMA and low AFA.

2.3.6. FINDINGS OF FAT AND LEAN MASS ACROSS THE WORLD

Gasser *et al*., (1994), in a Zürich growth study a longitudinal reported AMA develops slowly until the onset of puberty, with girls showing a slightly smaller value than boys. A similar finding was observed by (Tanner, 1962, 1981) based on radiographically determined muscle width, and was comparable with Forbes (1972) based on estimates of whole-body lean mass. The pubertal spurt is remarkable in boys and moderate in girls, timed to the age of peak height velocity in both sexes. While AFA changes only minimally in boys older than 16 months and increases steadily in girls until age 16 (Gasser *et al*., 1994). However, the study did not report any information on MUAC.

In Turkish, Ozturk *et al*., (2009) reported that MUAC and AFA across ages 6 – 17 years were significantly higher in school girls than in boys, in rural and urban areas of Kayseri, Central Anatolia, Turkey. However, the study did not report on AMA.

In addition, Yavuz & Özer (2020), found a higher correlation between BMI, AMA and AFA in a cross-sectional study among 1484 children and adolescents of Turkey, aged between 6 – 17 years. The results indicate that BMI is associated with both fat tissue and muscle tissue. For this reason, only BMI values are not sufficient to determine the nutritional status of the children. Particularly triceps skinfold thickness values increased until 11 years of age. After this age, triceps skinfold thickness decreased in boys and AFA values decreased from 12 years of age. Triceps skinfold and AFA values were decreased in girls aged 11 – 12. In boys, subcutaneous fat increases from 7 years to 12 – 13 years and then declines again, that is the increase in subcutaneous fat before male adolescence is defined as the male preadolescent fat wave (Malina and Bouchard 1991; Tanner and Whitehouse 1962).

The findings from a cross-sectional study of 3305, school children, aged 4 – 12 years in Argentina, reported the prevalence of low AMA was higher in boys (28.2%) when compared with girls (24.4%). In addition, there was no significant difference between sexes and stunned children. Furthermore, the prevalence of low AFA was higher in boys (0.5%), compared to girls (0.4%). However, high AFA and AMA were obtained in boys when compared to girls (Oyhenart *et al*., 2020).

Żegleń *et al*., (2021) recent findings of the two cohorts of Bengali, Indian boys aged 7 – 16 from middle-class families, in 1982 – 1983 and 2005 – 2011, found that AMA differed between the age groups and cohorts, in all age groups, boys examined in 2005 – 2011 had a higher AMA than those from the 1982 – 1983 cohort. These differences were significant in almost all age groups, and were largest, among 14 – 16-year-olds. A positive secular trend was also observed for the fat tissue area of the arm, as indicated by AFA. The study conducted above did not report information on all parameters of interest, as a result, there is a need to investigate the development of all the parameters, particularly in Africa, in resource-limited settings.

2.3.7. FINDINGS OF FAT AND LEAN MASS IN AFRICA

There are studies on growth that have been carried out in Africa on widespread undernutrition and delayed growth. However, few studies looked at the development of fat and lean mass in Africa, particularly, in rural areas. In rural Zimbabwean children aged between 6 – 17 years of age, boys had a decrease in AFA as they age, while girls had an increase in AFA, as they age (Olivieri *et al*., 2008). However, this study did not report any information on MUAC and AMA.

In a rural South African study, Mphahlele *et al*., (2020), conducted a cross-sectional study among 1701 rural Ellisras children aged between the ages of 9 – 17 years old. There was a positive significant association between MUAC, AFA, AMA, and undernutrition. BMI, MUAC and AMA were significantly higher in girls compared to boys in the 12 – 14 years age group. On the other hand, fewer studies have investigated this before in Africa. There are no longitudinal studies available that are well-designed to highlight the use of AMA, AFA and MUAC as an indicator of undernutrition in Africa.

2.3.8. CUT-OFF POINTS USED FOR LEAN AND FAT MASS

The receiver operating curve (ROC) is a common statistical technique which was first used in the 1950s and became evident later in the 1970s when it was considered a relevant technique for the evaluation of medical tests. Many studies in clinical epidemiology have used the ROC to test the ability of the instrument or biomarkers and imaging test in the classification of the diseased from the healthy person. Engwa *et al*., (2021) used the ROC to the relative abilities of the anthropometric measures to correctly identify children with obesity. Therefore, the ROC curve will be used to investigate the ability of anthropometric indicators to identify rural children with undernutrition. The upper arm areas measurements are the Mid Upper Arm Circumference (MUAC) and triceps skinfold, which are used to derive equations that estimate the Arm Muscle Area (AMA) and Arm Fat Area (AFA) (Frisancho, 1981, 1990; Gasser *et al*., 1994; Mphahlele *et al*., 2020). There are no cut-off points in Africa that have been established, hence the use of the American, black cut-off point by (Frisancho, 1990a). The National Health and Nutrition Examination Survey III (NHANES III) reference population is mainly used to compare Africans or where there is a lack of cut-off points in a given population (Frisancho, 1981, 1990; Addo *et al*., 2017). Previous studies used the NHANES III as a reference population (Olivieri *et al*., 2008; Senbanjo *et al*., 2014; Mphahlele *et al*., 2020).

Addo *et al*., (2017) recently established the cut-off points for AFA, AMA and MUAC based on five 5 United States cross-sectional national surveys from 1963 through 1994: the National Health Examination Surveys (cycles II and III) and NHANES I – III. However, there is a lack of standard reference cut-off points for AMA, AFA and MUAC in Africa and South Africa. Hence there is a need to establish the cut-off point in African children. In addition, cut-off should also reflect the genetic, ethnic and growth pattern differences existing in different populations (Engwa *et al*., 2021).

2.4. UNDERNUTRITION

Undernutrition is a major public health concern in Africa that affects children from early life. The condition occurs due to insufficient diet and protein energy that manifests in the form of stunting, wasting, or being underweight which leads to growth failure (Madzorera *et al*., 2023). Stunting is having low height for age when compared to the reference population and it is regarded as a chronic form of undernutrition (WHO, 2021). While underweight refers to the state of being low weight for age and wasting refers to the state of being too thin when compared to the reference population (Sambu, 2019; Popkin *et al*., 2020; Mphahlele *et al*., 2020). It can also be caused by factors such as genetics, lack of food, metabolism, and Illness (Martins *et al*., 2004; Blössner and de Onis, 2005).

Undernutrition is more predominant in less developed countries that are undergoing rapid economic changes, nutritional and lifestyle changes (Mramba *et al*., 2017; Fentahun *et al*., 2018). The prevalence of undernutrition was estimated at 21.3% (144 million) of all children under five years were stunted, 47 million of them living in South Africa (WHO, 2021; Quamme & Iversen, 2022). The number of children with stunting is declining in all regions except Africa, from 2012 to 2019, the prevalence of stunting in SA has decreased slightly from 34.5% to 31.1%, however not at a sufficient rate to meet the global target (WHO, 2021).

Undernutrition affects the nutritional, health status and growth of children, moreover, childhood is marked by rapid body changes associated with growth (Misra & Khurana, 2008; Olivieri *et al*., 2008; Mramba *et al*., 2017). The physical growth in muscle and bone size and menstruation in girls are observed during puberty (Tanner, 1981; Shaikh *et al*., 2020). The adolescent stage is linked with creating a greater demand for protein and energy (Das *et al*., 2017) and a continued need for micronutrients.

Furthermore, the long-term effects of undernutrition are associated with limited cognitive development and lower education level (Black *et al*., 2013; Quamme & Iversen, 2022), physical impairment, and increased chance of cardiovascular metabolic diseases that may be inherited by the next generation (Modjadji & Modiba, 2019). Therefore, failure to grow at an appropriate rate may be associated with a primary growth disorder, infections, or poor nutrition such as undernutrition (Mokone *et al*., 2022; Kubeka & Modjadji, 2023).

Many studies on growth have been carried out in Africa on malnutrition and delayed growth. In particular, rural environments of sub-Saharan Africa influence growth and development, especially in preschool children who are particularly exposed to undernutrition (Olivieri *et al*., 2008; Modjadji & Madiba, 2019; Mokone *et al*., 2022). Consequently, it is important to quantify, screen and determine the prevalence of undernutrition from early childhood particularly over the different seasons. However, little is known about the development of low-fat and lean areas during the spring and autumn seasons in Africa and South Africa.

2.5. SEASONAL VARIATION

Seasonal variation can be described as the difference in a time series within one year (Branca & D’Acapito, 2013), and for decades’ seasonal variation has been commonly used to determine the linear growth of children (Palmer, 1933; Xu *et al*., 2001), particularly in developed countries (Xu *et al*., 2001). Growth monitoring plays a crucial role in childhood development and it is important to monitor the growth of children, particularly when growth measurements are repeated (Palmer, 1933; Dalskov *et al*., 2016). This helps with the understanding of variation in childhood growth at different phases (Mantsena *et al*., 2004) and it will help in the early detection of growth disorders such as undernutrition.

In addition, the season when the measurement is conducted is also important. However, according to (Fentahun *et al*., 2018; Baye & Hirvonen, 2020), the concepts of seasonal variation are not taken into consideration when assessing child growth studies and Demographic and Health Surveys in recent studies. This negatively affects the assessment of the nutritional status of children, particularly in the least developed countries.

Several studies looked at the seasonal variation in height and weight rather than the upper arm anthropometry (Kondo *et al*., 1978; Ikeda & Watanabe, 1985). As a result, it is difficult to outline seasonal variation in later years, because of the inconsistencies in the studies conducted (Dalskov *et al*., 2016). Conversely, growth variation exists and differs in population based on ethnicity (Kobayashi & Kobayashi, 2006), geographical location, environment and socio-economic factors (Nyati *et al*., 2021). On the other hand, according to my knowledge, no other studies have investigated this previously therefore there are no comparable studies available.

In addition, there are fewer longitudinal studies available that are well-designed to highlight seasonal variation and as such it affects the direct comparison of the outcome of these studies (Madan *et al*., 2018). Most literature is available in India and Bangladesh region (Shaikh *et al*., 2020). Nevertheless, there is a lot of inconsistency when defining seasonality factors. Seasonal variation is sometimes defined in terms of agroecological conditions (Baye & Hirvonen, 2020) and by annual weather cycles (Dalskov *et al*., 2016; Dwivedi *et al*., 2023). In addition, there are a lot of inconsistences in the season of exposure, which makes it difficult to make a comparison between seasons. Moreover, there is evidence from developed countries indicating that weather cycles do not seem to translate into the same seasonal variation in factors, such as food availability, as they do in developing countries (Madan *et al*., 2018). Ultimately, there is a need to assess the dry and wet seasons in rural areas because of the differences that exist between these seasons, particularly in developing countries. For this study, autumn and spring were compared, of which the surveys were carried out during the May and November months, which represent the cooler, drier and warmer, wetter periods, respectively.

2.6. SUMMARY

Undernutrition is a life-threatening condition among children and adolescents in Africa. Furthermore, undernutrition starts in early life from the prenatal to the adolescent stage and it is associated with numerous body changes due to growth and development. Undernutrition occurs due to insufficient diet and protein energy that manifests in the form of stunting, wasting, or underweight leading to growth failure. Moreover, regional body composition assessment represents a relative estimation of lean and fat arm area changes due to environment, early disease, and nutritional status during childhood. There is a need to diagnose the risk of undernutrition at an early life, to enable intervention and management programmes.

The use of upper arm anthropometry to diagnose undernutrition in a large population, in a rural setting with inadequate resources, is easy, inexpensive, and reliable. There were no age-sex-specific changes in studies in body composition and standard growth reference for South Africa children and adolescents related to upper-arm anthropometry. In addition, there is a need for more recent longitudinal studies on seasonal variation that focus on the conventional method for measuring undernutrition. Therefore, it is essential to investigate the development of lean and fat areas of the arm from childhood to adulthood as an indicator of undernutrition.

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CHAPTER 3

MATERIALS AND METHODS

3.1. GEOGRAPHICAL AREA

Lephalale, previously known as Ellisras, is a rural settlement under Waterberg Municipality situated in the north-western part of the Limpopo province, South Africa. Lephalale has about 42 rural villages with an estimated total population size of 125 198 (Statistics South Africa, 2022). The villages are located on the outskirts of Ellisras town, which lies at latitude 23° 40S and longitude 27° 45W, and part of the Lephalale area is near the Botswana border (Sidiropoulos *et al*., 1996).

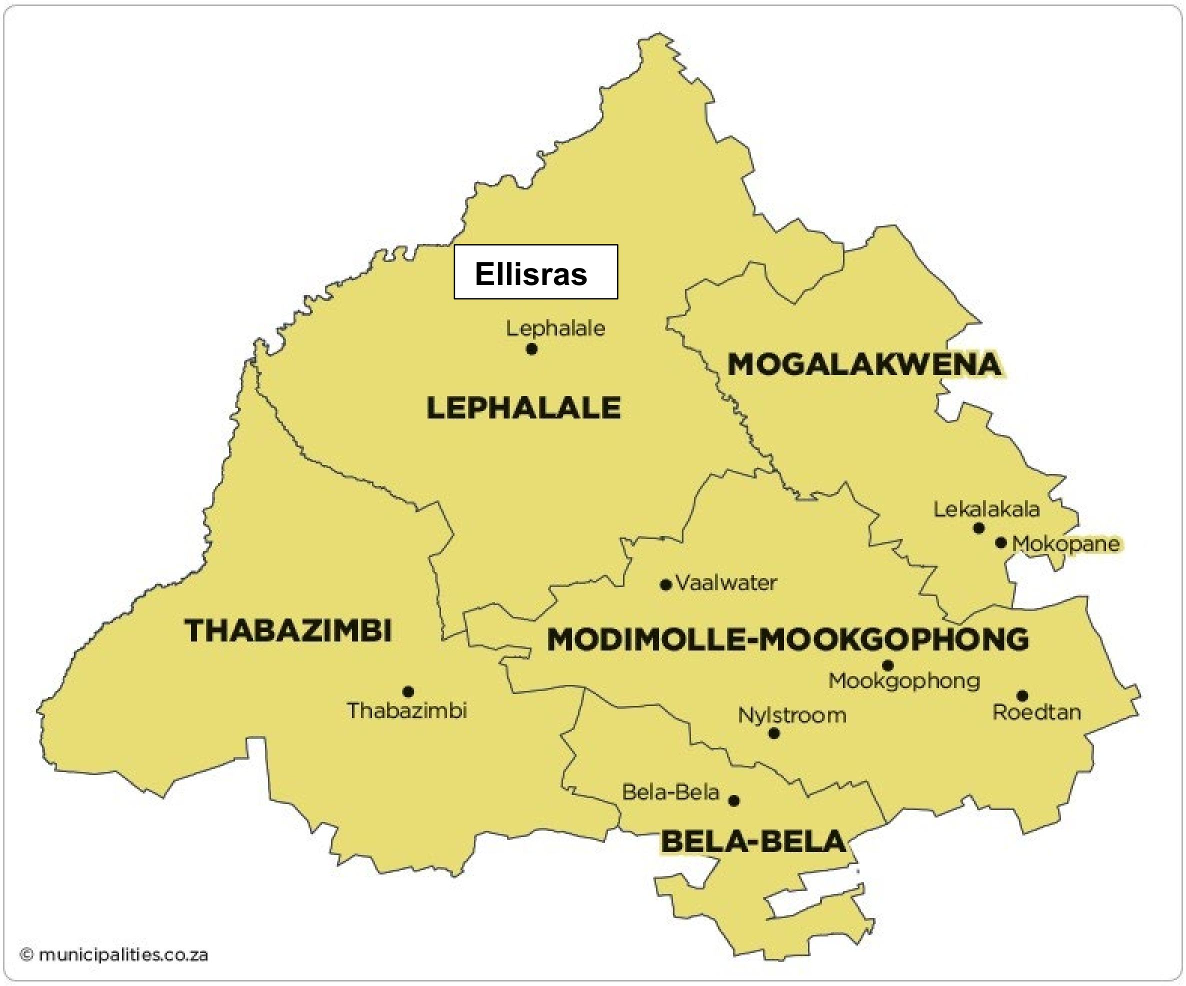

Figure 2: Map showing Lephalale (*Lephalale Local Municipality - Map*, n.d.)

3.2. SAMPLE

The Ellisras Longitudinal Study (ELS) sampling procedure is documented elsewhere (Monyeki *et al*., 2000). The ELS is an ongoing commenced in 1996 autumn (October and November) (Monyeki *et al.*, 2000). Briefly, the study commenced with a total of 22 schools (10 preschools and 12 primary schools) that were randomly selected from 68 schools in the Ellisras area. A total of 2225 children (550 preschool learners and 1675 primary school learners aged 3 to 10) enrolled in the ELS at baseline in 1996 (Monyeki *et al.*, 2000). The same population that enrolled in the ELS at baseline formed part of this study. From 1997 to 2003 measurements were collected twice per year in autumn and spring seasons. As a result, this enables longitudinal tracking of the participants from 1997 – 2003 and between seasons. In addition, participants will have two measurements per year, which were used for the study to track the changes from earlier years of the study's commencement to recent years. Therefore, only participants who have a full data set for the investigated years were included in the study and pregnant women were excluded from this study.

Anthropometric measurements of the ELS participants were performed on 911 boys and 825 girls (n = 1736), aged 4 – 17 years. The Ethics Committee of the University of Limpopo granted ethical approval before the study (TREC/89/2022: PG). Permission was sought from the ELS Principal research to use the ELS data from 1997 to 2003. This was a retrospective data analysis study. The ELS is part of the ongoing study that started in 1996 November with the first registration done by the University of the North Senate registration number 1404/5010. The subsequent ethical clearance was granted by the Turfloop Research Ethics Committee (TREC) of the University of Limpopo (MREC/P/204/2013:IR) dated 5 March 2013 after a year.

3.3. SAMPLING AND DATA COLLECTION

The sample size required for this study within the ELS sample was calculated using STATA and this was based on the power of 80%, with a two-tailed significance level of 5% and the prevalence of lean and fat area at the arm at 30%. The data for this study was extracted from a total of 1736 children and adolescents (911 boys and 825 girls), aged between 4 – 17 years, who were part of the ELS participants in 1996. Only ELS participants with 95% of measurement records were included in the study, as other measurements were estimated based on interpolation and extrapolation (Twisk *et al*., 1994). The seasonal measurements were collected in autumn (April – May); 1999, 2000, 2001 and 2003 and spring (October – November) each year during the periods 1999, 2000, 2001 and 2003 were included in the survey. The data for the participants who were part of the 1996 baseline and only those participants who were eligible for the ELS were recruited was included in the study. The procedures for the training of field workers for anthropometric measurements were carried out under the supervision of the ELS principal investigator and reported elsewhere (Monyeki *et al*., 2000). The data form for the relevant variable in the current study is attached (Appendix A).

3.4. ANTHROPOMETRY

Anthropometric measurements for the participants were done according to the International Society for the Advancement of Kinanthropometry (ISAK) (Norton & Olds, 1996). The following anthropometric measurements were taken: circumferences of relaxed arms and triceps skinfolds. The triceps and biceps skinfolds were measured using a plastic Slim Guide skinfold calliper. Correct anatomical landmarks were carefully located at the skinfold site and marked on the participant's skin using a surgical marking pen. At the landmark's site, the skinfolds were picked up and grabbed in such a way that a double fold of skin plus the underlying subcutaneous adipose tissue was held between the thumb and index finger. Measurements were recorded after two seconds of full pressure of the calliper. The dial of the calliper was read to the nearest 0.1 mm. Average values of 2 − 3 measurements were taken at each site for any further calculations. The arm circumference was measured with a flexible steel tape to the nearest 0.1 cm (Monyeki *et al*., 2002).

Figure 3: The picture shows triceps skinfold measurement.

Upper arm muscle and fat areas were expressed based on mid-upper arm circumference and triceps skinfold thickness using the established equations (Frisancho 1981). The AFA and AMA were calculated using the formula below:

$$\text{TUA (cm)} = \text{MUAC}^2/(4 \text{ x } \pi) \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{AMA (cm}^2) = [\text{MUAC} - (\text{TSF} \times \pi)]^2/(4 \times \pi)\ldots\ldots\ldots\ldots(2)$$

$$\text{AFA (cm}^2) = \text{TUA} - \text{AMA}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where: TUA – total upper-arm area in cm, MUAC – mid-upper arm circumference in cm, TSF – triceps skinfold thickness in cm, AMA – upper arm muscle area in cm^2, AFA – upper arm fat area in cm^2.

3.5. QUALITY CONTROL

All training of anthropometric measurements was done following the standard procedures of the ISAK (Norton & Olds, 1996). Reliability and validity of anthropometric measurements were reported elsewhere (Monyeki *et al*., 2002). In brief, the absolute and relative values for intra- and inter-tester technical error of measurements (% TEM) for stature, ranged from 0.04 – 4.16 cm (0.2 – 5.01%) and circumference measurements ranged from 0.0 – 3.4 cm (0 – 4%) (Monyeki *et al*., 2002, 2008).

3.6. STATISTICAL ANALYSIS

3.6.1. DESCRIPTIVE STATISTICS

3.6.1.1. SEASONAL VARIATION

The descriptive statistics for AFA, AMA and MUAC in the Ellisras rural children and adolescents aged 4 – 17 years were reported as frequencies (expressed as percentages) and median. The data was not normally distributed, as such the non-parametric was applied to test the significance level ($P < 0.05$) between sexes. Linear regression was used to determine the association between anthropometric indices with seasonal variation among Ellisras rural children and adolescents.

3.6.1.2. LONGITUDINAL TRACKING

The descriptive statistics for AFA, AMA and MUAC in the Ellisras rural children and adolescents aged 4 – 17 years were reported as frequencies and mean. T-tests was applied to test the significance level ($P < 0.05$) between sexes.

3.6.2. PREVALENCE OF LOW FAT AND LEAN ARM AREA

The prevalence (%) of low fat and lean arm area was determined as the AFA, AMA and MUAC below the 5th percentile cut-off points for children and adolescents (Addo *et al*., 2017).

3.6.3. COMPARISON BETWEEN ELS CHILDREN AND NHANES III

The AFA, AMA and MUAC of Ellisras children were compared with the NHANES III reference population (Frisancho, 1990).

3.6.4. SEASONAL VARIATION

Mann-Whitney U test was used for comparison of between autumn and spring seasons and data was expressed as a median and interquartile range.

3.6.5. RECEIVER OPERATING CURVE (ROC) ANALYSIS

We assessed the ability of AFA, AMA and MUAC to discriminate between children with low fat and lean areas. For this purpose, we produced sex-specific receiver operating characteristics (ROC) curves and used the corresponding area under curves (AUC) to determine the ability of each anthropometric indicator to identify children with low lean and fat areas. The ROC curve is a plot of the true-positive rate (sensitivity) against the false-positive rate (1-specificity). A good test has ROC skewed to the upper left corner with an AUC of 1, whereas an AUC of 0.5 means that the test performs no better than chance (Schisterman *et al*., 2001; Zhou *et al*., 2002). The sensitivity and specificity of AFA, AMA and MUAC have been calculated at all possible cut-off points to find the optimal cut-off value. The optimal sensitivity and specificity were the values yielding maximum sums from the ROC curves (clinical significance of cut-off was checked with the Youden index). The data for all age groups were classified into percentiles for males and females, and percentile values were identified. Cut-off values and the corresponding AUCs of AFA, AMA and MUAC for undernutrition were computed along age and sex.

3.6.6. GENERALISED ESTIMATING EQUATION (GEE)

3.6.6.1. SEASONAL VARIATION

The GEE was used to assess the relationship between anthropometric indicators (AFA, AMA and MUAC) and the seasons (spring when compared to autumn) by age and sex.

3.6.6.2. LONGITUDINAL TRACKING

A longitudinal tracking GEE was used to measure the association between an indicator at the first period of measurement and the same indicator at all other periods of measurement. Tracking was assessed by calculating odds ratios and 95% confidence interval for subjects “at risk of having undernutrition” at the initial measurements to maintain ‘at risk of their position’ at the follow-up measurements using the GEE.

3.6.7. STATISTICAL PACKAGE AND SIGNIFICANT LEVEL

All the statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 27.

3.7. REFERENCES

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CHAPTER 4

RESULTS AND DISCUSSION

4.1. Results and discussion

4.2. References

4.1. RESULTS AND DISCUSSION

4.1.1. LONGITUDINAL DESCRIPTIVE STATISTICS OF FAT AND LEAN AREA AMONGST ELLISRAS RURAL CHILDREN

Tables 1–3 show the mean and standard deviation of the anthropometric measurement AMA, AFA and MUAC for Ellisras boys and girls by age for data collected in the autumn of 1997, 1998, 1999, 2000, 2001 and 2003, and spring of 1997, 1998, 1999, 2000, 2001 and 2003. Tables 1a, 2a and 3a show the first anthropometric measurements in 1997 autumn and subsequent measurements throughout the period. Tables 1b, 2b and 3b show the subsequent anthropometric measurements in spring of 1997, 1998, 1999, 2000, 2001 and 2003. Boys and girls had a significant difference ($p \leq 0.05$) at age 7 at the first MUAC measurement in 1997 autumn with mean values of 15.97 and 15.86 respectively.

The Ellisras children showed a significant mean difference ($p < 0.01$ to 0.05) in the development of AFA and AMA throughout the period. However, there were no statistical significant difference observed in the first MUAC measurement in early age and later for MUAC. Furthermore, there was a significant difference ($p \leq 0.05$) at age 9 at the first AMA measurement in 1997 autumn with mean values of 1.88 and 3.22 in boys and girls respectively. However, there was no significant mean difference in AMA across all the ages for both boys and girls at the first measurement in 1997 autumn.

Table 1a: Descriptive statistics for Arm Fat Area among Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Autumn.

age	1997				1998				1999				2000				2001				2003			
	Boys		***Girls***		***Boys***		***Girls***		***boys***		***girls***		***boys***		***girls***		***Boys***		***girls***		***boys***		***Girls***	
	N	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**
4	32	11.62(5.01)	32	9.55(9.58)	12	7.04(13.04)	4	12.79(0.68)																
5	74	11.62(6.66)	71	9.97(8.17)	39	11.33(6.55)	34	7.13(14.20)	10	13.60(5.64)	4	11.03(8.25)												
6	107	14.15(5.21)	84	13.40(4.70)	73	12.92(7.93)	63	11.50(8.67)	37	15.92(4.06)	27	10.56(9.53)	10	15.04(6.29)	6	14.61(4.64)								
7	110	16.34(3.77)	104	13.90(5.31)	98	15.98(4.49)	75	14.69(4.81)	62	16.68(5.08)	63	14.34(5.63)	37	16.94(3.40)	30	11.07(10.92)	11	21.64(4.81)	4	26.16(5.44)				
8	178	17.67(4.44)	167	15.36(6.32)	109	17.80(4.05)	109	15.13(6.22)	97	18.65(4.04)	69	15.56(6.39)	72	16.59(6.46)	68	12.77(8.76)	39	18.79(10.21)	30	20.88(12.50)				
9	196	17.97(6.73)	192	14.74(9.42)	154	18.94(5.92)	150	16.17(8.22)	115	19.96(6.05)	118	14.35(13.44)	99	18.30(5.40)	84	13.46(8.35)	69	21.20(7.44)	68	20.77(9.89)	13	17.01(7.53)	5	13.72(6.99)
10	149	20.68(4.19)	147	11.92(20.86)	168	20.51(5.23)	169	15.75(10.85)	181	20.87(7.80)	177	14.71(15.27)	117	19.32(15.31)	113	12.36(19.29)	92	20.57(9.54)	77	20.09(16.89)	41	12.58(12.07)	34	4.35(24.29)
11	59	19.82(3.99)	52	12.44(24.53)	140	21.06(5.89)	110	14.00(26.08)	224	21.88(7.28)	223	14.24(20.16)	167	20.30(8.80)	175	10.34(19.26)	114	20.23(14.28)	104	20.25(12.72)	74	14.72(8.17)	75	10.02(17.42)
12	6	20.55(1.66)	3	16.54(7.06)	56	21.41(4.80)	43	17.63(14.03)	182	21.50(12.88)	170	10.89(37.31)	207	20.07(13.02)	198	5.78(36.95)	171	18.67(21.62)	171	19.12(16.03)	97	16.96(10.26)	79	8.35(26.94)
13					4	22.29(2.96)	3	22.91(7.42)	83	22.49(13.64)	66	9.82(26.71)	160	23.23(11.28)	153	7.05(32.69)	200	19.29(16.64)	198	12.86(40.68)	120	18.65(13.16)	116	10.52(20.36)
14									7	25.45(3.91)	3	22.13(15.90)	62	22.18(18.97)	48	2.99(46.54)	142	19.28(17.87)	151	19.63(20.53)	169	19.66(12.06)	164	-0.44(49.54)
15													5	28.75(4.94)	2	15.40(31.59)	68	20.59(7.05)	49	21.07(9.97)	190	20.58(18.23)	183	-2.57(52.06)
16																	7	16.82(6.62)	1	21.73	152	23.24(24.59)	152	-6.71(52.10)
17																					52	23.77(25.10)	47	-20.62(72.89)
total *N*	911		852		853		760		998		920		936		877		913		853		903		855	

AFA –Arm Fat Area, *N* = number of participants, M = mean value [cm^2], SD = standard deviation

Table 1b: Descriptive statistics AFA –Arm Fat Area among Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Spring.

age	1997				1998				1999				2000				2001				2003			
	Boys		*Girls*		*Boys*		*Girls*		*boys*		*girls*		*boys*		*girls*		*Boys*		*girls*		*boys*		*girls*	
	N	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)	*N*	M (SD)
4	20	12.07(9.23)	15	9.56(6.17)	12	13.26(6.58)	11	5.48(12.29)	2	11.20(3.98)	1	-5.12												
5	72	15.15(5.14)	57	10.94(9.64)	55	11.33(6.55)	49	9.68(8.48)	15	13.73(6.38) *	10	7.24(6.96) *	2	15.73(2.83)	2	17.80(6.97)								
6	92	16.65(4.29)	78	14.44(4.76)	89	13.13(6.14)	74	12.68(6.16)	32	13.31(3.64)	26	11.16(8.05)	19	16.46(4.34)	14	9.83(11.46)	2	20.55(7.33)	2	27.05(9.45)				
7	126	17.49(3.26)	126	15.57(5.22)	105	15.62(3.98)	89	13.72(4.51)	54	16.23(4.33)	39	12.86(5.98)	59	15.75(4.04) *	41	14.93(4.76) *	22	21.01(6.35)	13	15.99(16.95)				
8	165	18.51(5.48)	151	17.53(5.62)	120	17.09(3.71)	131	14.05(7.54)	72	17.96(4.33)	52	15.99(6.67)	86	17.44(4.67) *	75	13.05(7.27) *	56	19.56(8.98) *	47	21.55(8.66) *	2	11.32(14.73)	2	18.22(3.95)
9	86	19.84(3.58)	70	17.76(4.55)	162	17.95(5.81)	161	15.31(8.37)	109	18.28(5.58)	110	14.86(7.88)	108	19.83(4.61)	90	15.96(7.35)	85	20.05(9.91) *	79	21.20(14.69) *	25	20.24(5.10)	15	18.60(4.16)
10	34	20.68(4.19)	20	16.27(9.32)	171	19.59(4.20)	144	14.07(15.93)	152	19.38(5.52)	138	14.35(13.44)	139	20.45(7.36) **	156	11.73(20.10) **	108	21.49(7.34) **	90	20.31(11.53) **	60	19.42(7.36) **	51	19.43(5.44) **
11	15	20.41(3.38)	14	20.44(4.68)	108	20.25(3.85) **	85	14.83(22.03) **	179	21.97(4.01**)	170	15.35(15.06) **	203	20.96(10.63**)	196	11.74(21.26) **	132	20.42(14.10) **	156	19.22(16.25) **	91	19.61(6.45)	86	17.01(17.70)
12					13	20.29(3.18)	12	19.88(6.92)	124	6.00(178)	97	14.73(25.25)	214	23.62(8.50)	205	9.24(30.86)	209	18.23(19.17)	187	15.75(35.79)	110	21.74(12.04)	90	20.13(13.75)
13									13	23.53(3.00) **	7	18.78(12.34) **	158	23.30(16.83) **	122	10.30(29.21) **	196	18.32(22.16)	200	17.00(25.93)	134	21.74(16.89)	153	18.62(26.78)
14													18	22.21(14.86)	17	20.67(11.33)	135	19.68(13.64)	115	19.11(22.68)	200	22.93(21.69) *	176	16.54(31.71) *
15																	15	15.30(20.23)	14	21.01(9.27)	191	26.23(14.72)	186	12.58(45.02)
16																					120	14.42(77.24)	105	12.61(43.99)
17																					9	22.49(10.57)	13	18.37(30.29)
total *N*	610		531		835		756		752		650		1006		918		960		903		942		877	

*-P≤0.05, **-P≤0.01, AFA –Arm Fat Area, *N* = number of participants, M = mean value [cm^2], SD = standard deviation

Table 2a: Descriptive statistics for Arm Muscle Area Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Autumn.

age	**1997**				**1998**				**1999**				**2000**				**2001**				**2003**			
	Boys		***Girls***		***Boys***		***Girls***		***boys***		***girls***		***boys***		***girls***		***Boys***		***girls***		***boys***		***girls***	
	N	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**
4	32	5.00(4.56)	32	7.35(9.73)	12	11.25(13.40)	4	2.51(1.89)																
5	74	5.36(6.88)	71	7.24(8.23)	39	5.46(5.80)	34	11.08(15.41)	10	5.87(5.11)	4	6.45(5.70)												
6	107	3.52(4.99)	84	4.49(4.65)	73	5.61(7.96)	63	7.66(8.32)	37	2.80(3.16)	27	8.31(9.39)	10	6.43(6.93)	6	3.02(4.49)								
7	110	2.31(2.97)	104	4.45(5.78)	98	3.12(3.97)	75	4.41(4.31)	62	3.19(4.58)	63	6.08(6.03)	37	2.56(3.31)	30	8.97(12.06)	11	2.86(3.00)	4	3.58(3.73)				
8	178	1.99(4.09)	167	3.38(5.75)	109	3.32(3.68)	109	5.18(6.76)	97	2.37(3.01)	69	5.49(6.32)	72	4.78(6.25)	68	8.33(9.07)	39	7.02(13.32)	30	8.46(17.21)				
9	196	2.82(6.13)	192	6.04(10.71)	154	2.65(6.66)	150	5.85(8.92)	115	2.61(6.73)	118	7.09(9.34)	99	4.00(5.68)	84	8.75(8.73)	69	4.59(6.98)	68	9.93(12.14)	13	6.90(6.36)	5	5.99(5.23)
10	149	2.40(7.75)	147	10.52(22.68)	168	2.12(4.91)	169	7.55(12.66)	181	3.14(8.78)	177	10.03(17.20)	117	4.53(16.19)	113	12.17(21.57)	92	5.60(10.69)	77	8.42(20.62)	41	8.64(12.08)	34	18.89(27.14)
11	59	1.87(2.95)	52	10.83(26.46)	140	2.56(6.71)	110	11.21(29.33)	224	3.47(7.85)	223	12.21(23.28)	167	5.44(10.38)	175	15.99(22.33)	114	5.58(18.17)	104	7.80(14.91)	74	8.04(8.53)	75	14.74(16.98)
12	6	1.55(1.51)	3	5.49(7.71)	56	1.68(3.40)	43	7.97(15.77)	182	4.97(14.97)	170	18.70(41.11)	207	7.18(14.82)	198	22.78(41.05)	171	9.86(25.28)	171	9.37(19.37)	97	7.92(11.76)	79	18.27(27.82)
13					4	0.96(1.36)	3	6.43(6.29)	83	4.33(14.83)	66	20.77(29.90)	160	5.35(13.28)	153	24.56(36.32)	200	9.10(20.73)	198	15.31(46.16)	120	7.36(14.81)	116	18.99(23.78)
14									7		3	11.88(16.96)	62	6.30(20.86)	48	29.82(51.55)	142	8.32(21.04)	151	8.81(22.41)	169	8.37(12.37)	164	31.69(53.09)
15													5	2.50(4.41)	2	21.41(29.17)	68	4.29(8.21)	49	6.11(1.07)	190	10.04(20.15)	183	37.22(59.13)
16																	7	7.09(7.81)	1	4.05	152	9.65(26.29)	152	43.40(55.83)
17		.																			52	8.76(29.87)	47	59.23(79.03)
total *N*	911		852		853		760		998		920		936		877		913		853		903		855	

AMA – Arm Muscle Area, *N* = number of participants, M = mean value [cm^2], SD = standard deviation

Table 2b: Descriptive statistics Arm Muscle Area among Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Spring.

age	1997				1998				1999				2000				2001				2003			
	Boys		*Girls*		*Boys*		*Girls*		*Boys*		*girls*		*boys*		*girls*		*Boys*		*girls*		*boys*		*girls*	
	N	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**
4	20	5.93(9.01)	15	8.53(6.73)	12	4.49(4.66)	11	11.32(14.44)	2	7.49(5.73)	1	18.57												
5	72	3.04(4.57)	57	7.37(9.32)	55	5.66(6.01)	49	7.30(8.91)	15	4.88(5.76) *	10	11.03(9.34) *	2	5.95(0.97)	2	0.43(0.22)								
6	92	2.54(3.54)	78	4.40(4.44)	89	3.93(5.41)	74	5.41(5.58)	32	4.43(3.65)	26	7.69(8.84)	19	3.47(4.51)	14	9.59(13.08)	2	1.61(1.95)	2	0.68(0.96)				
7	126	1.80(2.48)	126	4.09(5.59)	105	2.61(3.60)	89	4.28(4.25)	54	3.13(3.64) *	39	6.28(5.48) *	59	3.77(4.23) *	41	4.70(4.72) *	22	4.00(4.96)	13	13.95(24.73)				
8	165	2.22(4.95)	151	3.38(5.75)	120	1.92(2.60)	131	5.13(8.19)	72	2.64(3.93)	52	4.48(6.19)	86	3.12(3.84) *	75	8.18(7.44) *	56	6.26(10.78) *	47	7.41(11.61) *	2	15.94(16.81)	2	1.07(1.29)
9	86	1.88(2.84) *	70	3.22(4.04) *	162	2.57(5.70)	161	5.49(9.21)	109	2.92(6.01)	110	6.66(8.87)	108	2.66(4.22)	90	6.29(7.23)	85	6.11(10.82) *	79	9.08(18.12) *	25	1.84(4.40)	15	2.68(5.12)
10	34	0.75(1.05)	20	5.79(10.48)	171	1.75(3.85)	144	7.62(17.69)	152	3.42(6.28)	138	9.18(16.42)	139	3.37(8.13) **	156	12.68(23.02) **	108	4.82(8.02) *	90	7.35(14.03) *	60	3.66(8.20) **	51	4.32(6.93) **
11	15	1.24(1.24)	14	2.97(4.46)	108	1.57(2.56) **	85	8.87(24.60) **	179	1.90(2.93) *	170	9.33(17.26) *	203	4.88(11.91) **	196	15.18(24.57) **	132	6.50(18.30) *	156	8.42(20.62) *	91	4.20(7.49)	86	9.03(19.12)
12					13	1.77(2.08)	12	4.12(7.89)	124	19.47(178.03)	97	12.09(27.92)	214	3.99(9.61)	205	19.00(34.46)	209	9.96(23.62)	187	12.21(39.19)	110	4.91(14.46)	90	7.75(14.75)
13									13	2.11(2.31)	7	10.31(14.50)	158	5.25(18.71)	122	21.12(32.31)	196	10.50(26.75)	200	11.06(30.56)	134	5.62(18.84)	153	13.20(31.79)
14													18	6.64(15.97) **	17	11.18(15.30) **	135	5.58(15.07)	115	9.27(24.70)	200	8.04(23.36) *	176	18.81(35.71) *
15																	15	8.89(23.93)	14	5.74(9.73)	191	6.78(16.13)	186	24.38(52.04)
16																					120	20.46(83.99)	105	26.72(48.53)
17																					9	12.05(13.58)	13	20.82(31.40)
total *N*	610		531		835		756		752		650		1006		918		960		903		942		877	

*-P≤0.05, **-P≤0.01, AMA – Arm Muscle Area, *N* = number of participants, M = mean value [cm^2], SD = standard deviation

Table 3a: Descriptive statistics for Mid Upper Arm Circumference among Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Autumn.

age	**1997**				**1998**				**1999**				**2000**				**2001**				**2003**			
	Boys		***Girls***		***Boys***		***Girls***		***boys***		***girls***		***Boys***		***girls***		***Boys***		***girls***		***boys***		***girls***	
	N	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**
4	32	16.09(1.61)	32	15.93(1.71)	12	16.88(1.33)	4	18.20(2.78)																
5	74	16. 14(1.28)	71	15.80(1.49)	39	16.15(1.53)	34	15.87(1.15)	10	15.49(0.95)	4	14.83(1.41)												
6	107	16.01(1.20)	84	15.67(1.14)	73	16.03(1.43)	63	15.67(1.43)	37	15.22(1.05)	27	15.21(1.34)	10	16.32(0.97)	6	14.62(1.27)								
7	110	15.82(1.47)	104	15.60(1.46)	98	15.99(1.31)	75	15.85(1.35)	62	15.69(1.14)	63	15.86(1.24)	37	15.56(1.03)	30	15.72(1.44)	11	17.52(1.75)	4	19.00(2.12)				
8	178	16.10(1.61)	167	16.24(1.43)	109	15.84(1.22)	109	15.76(1.55)	97	16.14(1.07)	69	16.21(1.01)	72	16.31(0.99)	68	16.16(1.26)	39	17.83(2.34)	30	19.03(2.19)				
9	196	16.7(1.62)	192	16.03(1.48)	154	16.12(1.44)	150	16.31(1.43)	115	16.67(1.13)	118	16.78(1.22)	99	16.59(1.19)	84	16.58(1.23)	69	17.90(1.74)	68	19.45(2.45)	13	17.11(1.59)	5	15.32(2.18)
10	149	15.98(1.30)	147	16.09(1.57)	168	16.04(1.43)	169	15.90(1.56)	181	17.17(1.32)	177	17.46(1.64)	117	17.19(1.22)	113	17.31(1.92)	92	17.98(1.81)	77	18.75(2.05)	41	16.22(1.09)	34	16.92(1.74)
11	59	16.38(1.63)	52	15.79(1.65)	140	16.02(1.44)	110	15.94(1.55)	224	17.68(1.38)	223	18.05(1.63)	167	18.49(1.55)	175	18.0(1.74)	114	17.85(2.12)	104	18.62(2.06)	74	16.83(1.06)	75	17.38(1.78)
12	6	15.35(0.72)	3	16.10(1.01)	56	16.14(1.41)	43	15.54(1.46)	182	18.07(1.58)	170	19.8(2.07)	207	18.78(1.75)	198	18.75(1.85)	171	8.71(2.38)	171	18.71(2.22)	97	17.53(1.33)	79	18.05(1.73)
13					4	16.20(0.91)	3	14.33(1.22)	83	18.20(1.69)	66	19.43(1.99)	160	18.82(1.15)	153	19.69(2.14)	200	18.68(2.23)	198	18.61(2.53)	120	17.91(1.61)	116	19.01(2.13)
14									7	18.63(1.32)	3	20.43(0.60)	62	18.77(1.75)	48	20.03(2.24)	142	18.43(2.24)	151	18.65(2.16)	169	18.67(1.42)	164	19.60(2.10)
15											5	19.78(1.09)	5	19.78(1.09)	2	21.40(0.85)	68	17.51(1.80)	49	18.26(18.5)	190	19.46(2.00)	183	20.66(2.41)
16																	7	17.09(1.25)	1	18.00	152	20.14(2.22)	152	21.21(1.34)
17																					52	20.07(2.21)	47	21.79(2.24)
total *N*	911		852		853		760		998		920		936		877		913		853		903		855	

MUAC – Mid Upper Arm Circumference, *N* = number of participants, M = mean value [cm], SD = standard deviation

Table 3b: Descriptive statistics for Mid Upper Arm Circumference among Ellisras Longitudinal Study children from 1997,1998,1999,2000, 2001 and 2003 Spring.

age	**1997**				**1998**				**1999**				**2000**				**2001**				**2003**			
	Boys		***Girls***		***boys***		***Girls***		***boys***		***girls***		***boys***		***girls***		***boys***		***girls***		***boys***		***girls***	
	N	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**	***N***	**M (SD)**
4	20	16.37(11.41)	15	15.67(2.08)	12	16.88(1.36) *	11	16.69(1.53) *	2	15.5(0.42) *	1	12.50*												
5	72	16.17(1.39)	57	15.85(1.33)	55	15.78(1.63)	49	15.90(1.73)	15	15.09(0.83)	10	14.89(1.36)	2	16.70(0.71)	2	14.95(3.04)								
6	92	16.10(1.53)	78	15.80(1.48)	89	16.09(1.49)	74	15.72(1.50)	32	14.84(0.80)	26	15.13(1.09)	19	15.66(1.16)	14	15.44(1.35)	2	16.70(3.39)	2	18.60(3.25)				
7	126	15.97(1.36) *	126	15.86(1.34) *	105	16.01(1.26)	89	16.03(1.63)	54	15.42(1.03) *	39	15.42(1.21) *	59	15.65(0.96)	41	15.51(1.25)	22	17.57(1.73)	13	18.95(3.05)				
8	165	16.10(1.61)	151	16.04(1.51)	120	16..11(1.58)	131	16.05(1.55)	72	15.93(1.11)	52	15.88(1.07)	86	15.99(1.23)	75	16.20(1.13)	56	17.89(2.04)	47	18.92(2.28)	2	18.50(0.71)	2	15.50(2.12)
9	86	16.19(1.33)	70	16.01(1.69)	162	16.07(1.53)	161	16.04(1.53)	109	16.21(1.11)	110	16.29(1.27)	108	16.72(1.14)	90	16.58(1.25)	85	18.00(1.76) **	79	19.33(2.36) **	25	16.60(1.38) *	15	16.27(1.75) *
10	34	15.99(1.22)	20	15.81(1.36)	171	16.11(1.32)	144	16.02(1.50)	152	16.77(1.33)	138	17.01(1.68)	139	17.22(1.23)	156	17.31(1.64)	108	18.06(1.77)	90	18.47(1.88)	60	16.98(1.30) *	51	17.20(1.67) *
11	15	15.91(1.63)	14	15.74(1.25)	108	16.20(1.45)	85	15.98(1.62)	179	17.16(1.29) *	170	17.44(1.64) *	203	17.89(1.37)	196	18.16(1.82)	132	18.18(2.32) **	156	18.85(2.18) **	91	17.24(1.39)	86	18.00(1.80)
12					13	15.96(1.05)	12	15.62(1.03)	124	17.72(1.66)	97	18.18(1.83)	214	18.49(1.55)	205	18.61(1.99)	209	18.60(2.39)	187	18.58(2.13)	110	18.22(1.75)	90	18.64(1.66)
13									13	17.97(1.05)	7	18.87(2.24)	158	18.78(1.75)	122	19.65(2.01)	196	18.81(2.40)	200	18.55(2.36)	134	18.47(1.64)	153	19.84(2.47)
14													18	18.99(1.15) *	17	19.76(2.30) *	135	17.64(2.03)	115	18.76(2.25)	200	19.64(1.92)	176	20.96(2.21)
15																	15	17.25(1.81)	14	18.19(1.37)	191	20.26(2.12)	186	21.39(2.64)
16																					120	20.78(2.58)	105	22.10(2.36)
17																					9	20.78(1.64)	13	22.15(1.34)
total *N*	610		531		835		756		752		650		1006		918		960		903		942		877	

*-P≤0.05, **-P≤0.01, MUAC – Mid Upper Arm Circumference, *N* = number of participants, M = mean value [cm], SD = standard deviation

4.1.2. DESCRIPTIVE STATISTICS OF FAT AND LEAN AREA AMONGST ELLISRAS RURAL CHILDREN DURING AUTUMN AND SPRING

Tables 4 – 5 show the median and interquartile ranges of the anthropometric measurements: AFA, AMA and MUAC for boys and girls of the ELS participants for data collected from 1999, 2000, 2001, and 2003 in the autumn and spring seasons. The results of the current study showed that there was a significant median difference ($p < 0.01$ to 0.05) between AFA and AMA, in autumn and spring among Ellisras boys and girls. In addition, seasonal variation is observed from the mid-childhood (8 – 11 years) to the adolescent stage. There was a significant median difference ($P \leq 0.01$) in AFA among boys aged 8 − 11 years in autumn (median=20.4 cm^2) and spring (median=21.4 cm^2) of 1999. Girls of the same age group in the same year also showed a significant median difference ($P \leq 0.05$ cm^2) in autumn (median=17.5 cm^2) and spring (median=17.3 cm^2).

There was a significant median difference in MUAC for the year 1999 across all the age categories. The boys aged 8 − 11 years had a significant difference in MUAC ($p \leq 0.01$) in autumn (median=16.5 cm) and spring (median=17.0 cm) of 1999. Girls of the same age group in the same year also showed a significant median difference ($p \leq 0.01$ cm) in autumn (median=16.7 cm) and spring (median=17.3 cm). In 1999, both boys and girls aged 8 – 11 years and above 12 years had a significant median seasonal variation in AFA and MUAC.

There was a seasonal median variation ($p < 0.01$ to 0.05) in the autumn and spring of 2000, for boys and girls aged 8 – 11 years in AFA and AMA. While boys and girls of the same age had no significant variation in MUAC. There was no seasonal difference in AFA, AMA and MUAC in 2001 in the cohort across all the age categories, because of the literature there are no comparable studies available. There was a significant difference ($p < 0.01$) between AFA, AMA and MUAC for boys and girls (aged 8 – 11 years and above 12 years) across all the age categories in 2003, between the autumn and spring seasons. Seasonality refers to any regular pattern or variation that is correlated with the seasons (Madan *et al.*, 2018; Baye & Hirvonen, 2020) and influences childhood growth (Rudolf *et al.*, 1991). Several growth studies reported that seasonal changes have an effect (Xu *et al.*, 2001), however, the seasonal variation associated with upper arm anthropometry has not been studied extensively.

Table 4: Descriptive statistics of the AFA, AMA and MUAC of boys in autumn (May 1999 - 2003) and spring (November 1999 - 2003)

Age (years)	Autumn	N	Spring	N	Autumn	N	Spring	N	Autumn	N	Spring	N
	Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)	
1999 AFA					**1999 AMA**				**1999 MUAC**			
4 – 7	14.0 (13.7: 17.5) *	103	16.7 (13.7: 19.7) *	109	2.0 (0.9: 6.4)	103	1.6 (0.6: 4.5)	109	15.2 (14.5: 15.9) *	103	15.6 (14.7: 16.3) *	109
8 – 11	20.4 (17.5: 22.7) **	512	21.4 (17.9:24.5) **	617	0.7 (0.3: 2.9)	512	0.9 (0.1: 2.9)	617	16.5 (15.8: 17.5) **	512	17.0 (16.2: 17.9) **	617
above 12	22.7 (20.4: 25.7) *	137	22.9 (21.4: 25.7) *	272	1.2 (0.2: 4.0)	137	0.9 (0.2: 3.0)	272	17.5 (16.8: 18.7) *	137	18.0 (17.0: 19.0) *	272
2000 AFA					**2000 AMA**				**2000 MUAC**			
4 – 7	16.7 (13.7: 17.9)	80	17.4 (14.0: 19.7)	47	2.0 (0.6: 6.3)	80	1.2 (0.3: 3.9)	47	15.7 (14.9: 16.4)	80	15.7 (15.0: 16.6)	47
8-11	21.0 (17.5: 24.5) *	536	20.4 (17.4: 22.9) *	455	1.3 (0.3: 3.9) *	536	2.0 (2.0: 5.3) *	455	17.1 (16.2: 17.9)	536	17.1 (16.2: 17.9)	455
above 12	25.4 (21.7: 27.9)	390	24.5 (20.9: 27.9)	434	0.9 (0.3: 4.0)	390	1.4 (0.4: 5.3)	434	18.5 (17.5: 19.6)	390	18.4 (17.4: 19.6)	434
2001 AFA					**2001 AMA**				**2001 MUAC**			
4 – 7	21.2 (17.6: 24.5)	24	22.7 (17.5: 25.7)	11	2.1 (0.8: 5.0)	24	2.9 (0.3: 3.9)	11	17.6 (16.3: 18.9)	24	17.5 (16.1: 19.1)	11
8 – 11	21.7 (17.5: 25.7)	381	21.7 (17.5: 25.7)	314	2.0 (0.6: 6.6)	381	2.0 (0.4: 5.3)	314	17.9 (16.7: 19.2)	381	17.8 (16.5: 19.0)	314
above 12	21.7 (17.5: 25.7)	555	21.7 (17.5: 25.7)	588	2.1 (0.6: 6.8)	555	2.1 (0.6: 7.1)	588	18.0 (16.9: 19.6)	555	18.2 (17.0: 19.7)	588
2003 AFA					**2003 AMA**				**2003 MUAC**			
8 – 11	17.7 (20.4: 22.7) **	178	17.5 (9.9: 20.4) **	128	1.2 (0.2: 4.0) **	178	5.2 (1.3 10.1) **	128	17.0 (16.0: 18.0) **	178	16.5 (15.8: 17.5) **	128
above 12	25.7 (21.7: 30.4) **	764	22.7 (17.4: 28.0) **	780	1.3 (0.3: 5.3) **	764	3.2 (0.7: 8.4) **	780	19.0 (18.0: 21.0) **	764	18.7 (17.6: 20.1) **	780

*-P≤0.05, **-P≤0.01, AFA –Arm Fat Area, AMA – Arm Muscle Area, MUAC – Mid Upper Arm Circumference

Table 5: Descriptive statistics of the AFA, AMA and MUAC of girls in autumn (May 1999 - 2003) and spring (November 1999 - 2003)

Age (years)	Autumn	N	Spring	N	Autumn	N	Spring	N	Autumn	N	Spring	N
	Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)		Median (25 and 75 interquartile)	
	1999 AFA				**1999 AMA**				**1999 MUAC**			
4 – 7	13.7 (8.4: 15.4)	87	15.7 (14.7: 16.5)	83	5.3 (1.9: 11.7)	87	4.0 (1.2: 10.1)	83	15.3 (14.4: 16.2) *	87	15.7 (14.7: 16.5) *	83
8 – 11	17.5 (12.9: 21.0) *	470	17.3 (16.3: 18.3) *	587	3.9 (1.2: 8.4)	470	4.0 (1.3: 10.4)	587	16.7 (15.9: 17.7) **	470	17.3 (16.3: 18.3) **	587
above 12	17.7(13.7:22.5) *	104	21.0(11.5: 24.9) *	239	5.3 (2.0:12.3)	104	7.1 (2.0: 16.9)	239	18.1 (17.1:19.3) **	104	18.9 (17.8: 20.0) **	239
	2000 AFA				**2000 AMA**				**2000 MUAC**			
4 – 7	14.0 (12.9: 17.7)	57	13.7 (9.7: 17.0)	36	2.9 (0.9: 7.4)	57	3.9 (1.4: 10.1)	36	15.8 (14.2: 16.8)	57	15.5 (14.5: 16.4)	36
8 – 11	17.5 (11.5: 21.0) **	517	16.5 (9.6: 16.0) **	440	5.3 (2.0: 12.4) *	517	6.7 (2.9: 16.5) *	440	17.0 (16.0: 18.2)	517	16.0 (17.0: 18.0)	440
above 12	17.4 (7.1: 21.9) *	344	16.5 (6.5: 21.7) *	401	10.4 (3.0: 22.1) **	344	12.3 (5.4: 24.9) **	401	18.8 (17.8: 20.0)	344	19.0 (17.9: 20.2)	401
	2001 AFA				**2001 AMA**				**2001 MUAC**			
4 – 7	20.5 (17.5: 22.7)	15	24.6 (22.0: 31.9)	4	4.0 (1.4: 10.4)	15	2.7 (0.5: 7.5)	4	18.2 (16.3: 20.8)	15	19.3 (16.9: 20.8)	4
8 – 11 s	21.9 (17.7: 21.9)	372	21.7 (17.7: 25.7)	279	3.0 (0.7: 10.1)	372	3.0 (0.8: 10.4)	279	18.4 (17.3: 20.1)	372	18.5 (17.3: 20.2)	279
above 12	21.7 (17.4: 25.7)	516	21.7 (17.5: 25.7)	570	2.5 (0.6: 8.6)	516	2.1 (0.6: 8.6)	570	18.3 (17.0: 19.9)	516	18.2 (17.0: 19.9)	570
	2003 AFA				**2003 AMA**				**2003 MUAC**			
8 – 11	20.4 (16.7: 22.7) **	154	13.7 (4.0: 19.7) **	114	2.0 (0.4: 6.8) **	154	8.2 (3.0: 21.8) **	114	17.0 (16.0: 19.0) *	154	17.0 (16.0: 18.2) *	114
above 12	25.4 (17.4: 29.7) **	723	13.7 (-6.9: 22.7) **	741	5.4 (0.9: 17.2) **	723	16.9 (5.6: 41.8) **	741	20.0 (19.0: 22.0) **	723	20.0 (18.5: 21.5) **	741

*-P≤0.05, **-P≤0.01, AFA –Arm Fat Area, AMA – Arm Muscle Area, MUAC – Mid Upper Arm Circumference

4.1.3. THE PREVALENCE OF LOW FAT AND LEAN AREA AMONGST ELLISRAS RURAL CHILDREN OVER THE TIMESPAN

Table 6 shows the prevalence of undernutrition defined as low AFA, AMA and MUAC in children between the ages of 4 – 17 years based on the 5th percentile for boys and girls. The prevalence of undernutrition in the population was high in the current study. The overall population prevalence was highest when determining undernutrition by AMA was 88.9% when compared to the overall prevalence of undernutrition by MUAC (53.9%) when using AFA (8.3%) for the cohort. Previous studies have reported a similar trend among South African children (Reddy *et al*., 2009; Sambu, 2019; Kubeka & Modjadji, 2023). Moreover, the prevalence of undernutrition by AMA was higher in boys (95.1%) when compared to girls (82.1%). On the other hand, the prevalence of undernutrition by AFA was the lowest at 3.9% in boys when compared to 13.2% in girls. A similar finding was reported among, school children, aged 4 – 12 years in Argentina (Oyhenart *et al*., 2020). Contrary to the findings among Zimbabweans (Olivieri *et al*., 2008) and Nigerian children (Senbanjo *et al*., 2014). The prevalence of undernutrition by MUAC in boys (58.0%) was high when compared to girls (49.5%).

Table 6: The prevalence of low anthropometric indices in predicting undernutrition in boys and girls at the 5th percentile

Cohort			**Female**		**Males**	
	Undernutrition **(%)**	**Non-** undernutrition **(%)**	Undernutrition **(%)**	**Non-** undernutrition **(%)**	Undernutrition **(%)**	**Non-** undernutrition **(%)**
AFA	1701 (8.3%)	18676 (91.7%)	1283 (13.2%)	8470 (86.8%)	418 (3.9%)	10206 (96.1%)
AMA	18111 (88.9%)	2266 (11.1%)	8007 (82.1%)	1746 (17.9%)	10104 (95.1%)	520 (4.9%)
MUAC	10992(53.9%)	9385 (46.1%)	4826 (49.5%)	4927 (50.5%)	6166 (58.0%)	4458 (42.0%)

4.1.4. COMPARISON BETWEEN FAT AND LEAN AREA AMONGST ELLISRAS AND NHANES III CHILDREN AGED 4 – 17 YEARS

Figure 2 showed that the Ellisras children had an elevated mean value in the development of AFA when compared to the reference population (Frisancho, 1981). Moreover, Ellisras boys exhibited high AFA when compared to Ellisras girls. On the contrary, boys tend to have low AFA when compared to girls (Olivieri *et al*., 2008; Mphahlele *et al*., 2020; Mandal *et al*., 2021). A study by Żegleń *et al*., (2021), suggested that the AFA is the most suitable index to monitor obesity in prepubertal, and pubertal children and adolescents rather than undernutrition. This may be due to the ethnic differences, genetics and environmental factors that affect children's growth patterns (Engwa *et al*., 2021; Mandal *et al*., 2021). Figure 2 shows a drop in AFA of that the Ellisras girls from age 14. This may indicate that girls had energy rather than protein is the nutritional problem (Singh *et al*., 2005). In addition, at ages 14 to 17, girls tend to gain more fat than muscle, depending on their lifestyle, environmental factors, and availability of food (Mphekgwana *et al*., 2019).

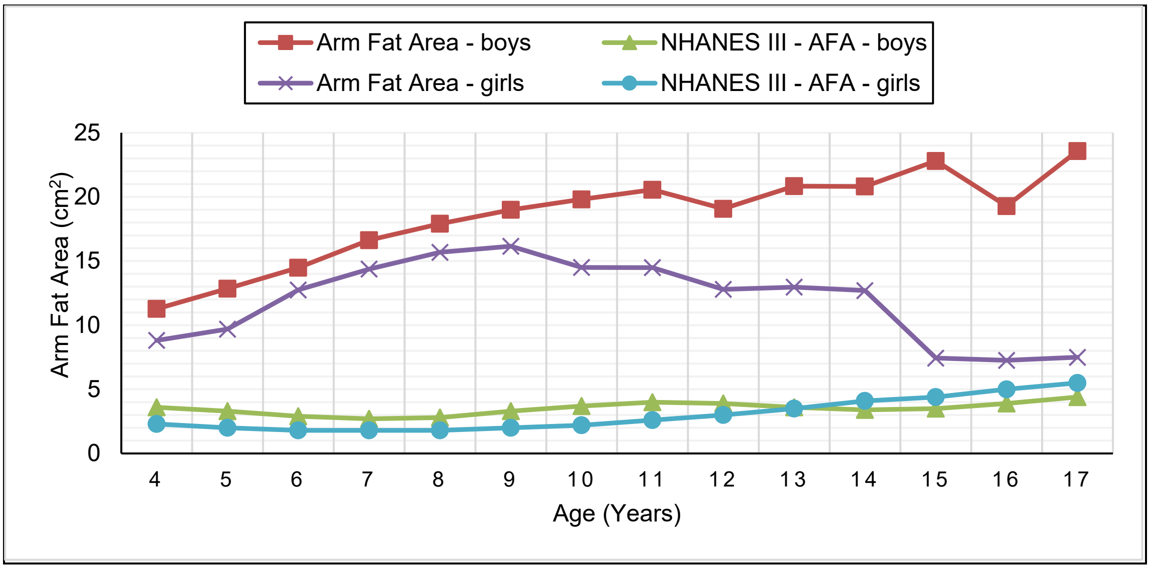

Figure 2: Development of mean AFA of Ellisras rural children and NHANES III reference population.

Figure 3 shows there was low development of mean AMA of Ellisras children when compared to the NHANES III reference population aged 4 – 17 years. Ellisras boys were below the 5th percentile of the NHANES III reference population throughout the period. While Ellisras girls were below the 5th percentile of the NHANES III reference population until age 15, the mean peaked above the reference population at 16 and 17. Furthermore, there was a significant mean difference ($p < 0.001$ to 0.05) in AMA for Ellisras boys aged 5 – 6 years compared to girls of the same age. While girls had a significant mean difference ($p < 0.001$ to 0.05) in AMA at age 9 – 17 years when compared to Ellisras boys. Similar, finding has been reported (Chomtho *et al*., 2006; Piperata, 2007; Chowdhury & Ghosh, 2009; Mphahlele *et al*., 2020; Ellemunter *et al*., 2022). Figure 3 shows a drop in AMA of that the Ellisras children from age 5 – 9 year. This may indicate that muscle in the upper arm grows less rapidly and this may also be an indication that protein is the nutritional problem (Singh *et al*., 2005; Sen *et al*., 2016). Moreover, high prevalence of early age undernutrition among Ellisras children and poor living make children more vulnerable (Mphekgwana *et al*., 2019). Furthermore, early life experiences involving adverse environmental condition, intrauterine growth retardation, poor physical growth in early childhood and subsequent catch-up growth can also have an impact on growth attainment, poor body composition, and health related outcomes later in adulthood. Ellisras boys showed a decrease AMA at age 16 – 17, this was contrary to the finding observed among Punjab, Indian boys who had a decrease at age 18 (Singh *et al*., 2005; Senbanjo *et al*., 2014).

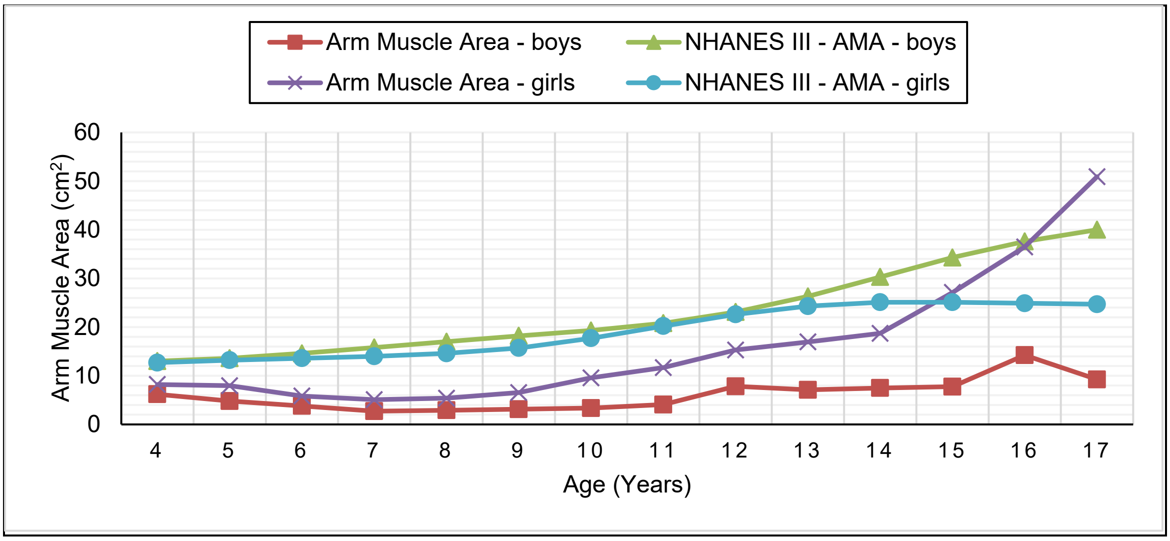

Figure 3: Development of mean AMA of Ellisras rural NHANES III reference population

Figure 4 shows the development of MUAC of Ellisras children when compared to the NHANES III reference population. There was a significant mean difference ($p < 0.001$ to 0.05) in MUAC for Ellisras boys aged 5 – 6 years compared to girls of the same age. While girls had a significant mean difference ($p < 0.001$ to 0.05) in MUAC at age 14 – 16 years when compared to Ellisras boys. There was a significant mean difference ($p < 0.001$ to 0.05) in the development of MUAC, however, there was no clear pattern in the development of MUAC when compared to the reference population of children aged 4 – 17 years (Frisancho, 1981). Contrary to Olivieri *et al*., (2008), findings amongst Zimbabwean boys had MUAC below the reference population.

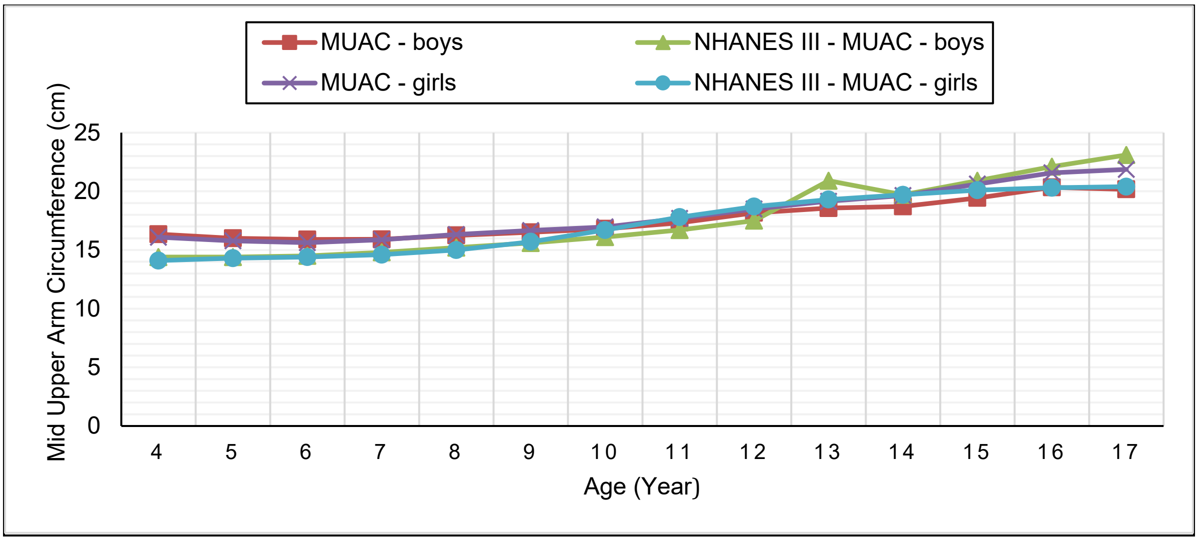

Figure 4: Development of mean MUAC of Ellisras rural children and NHANES III reference population

On the other hand, girls had an elevated AMA when compared to boys over time. However, both boys and girls were below the 5th percentile of the reference population. Similar, finding has been reported (Chomtho *et al*., 2006; Piperata, 2007; Mphahlele *et al*., 2020). This may also highlight the differences that exist between developing and developed countries. More so, South Africa is also faced with poor living conditions, and food insecurity and ultimately it leads to long-term effects such as delayed growth and mental development, and increased risk of cardiovascular diseases (Mphahlele *et al*., 2020; Mokone *et al*., 2022; Kubeka & Modjadji, 2023). In addition, a decline in the level of AMA serves as an early indicator of undernutrition (Nkwana *et al*., 2017;

Ellemunter *et al*., 2022). Contrary to Çiçek *et al*., (2014), the Turkish children had a linear elevation in AFA, AMA and MUAC values in boys and girls with increasing age.

4.1.5. THE TRENDS OF FAT AND LEAN AREA AMONGST ELLISRAS RURAL CHILDREN DURING AUTUMN AND SPRING

Figure 5 shows the trends of AFA in autumn and spring for both boys and girls. There was no seasonal variation observed in AFA for boys over time. However, the trends for AFA in girls decreased in the year 2000 spring and increased in the year 2001 autumn. In addition, there was a further decrease in AFA in 2003 spring. There was no seasonal variation was observed in trends of AMA overtime for boys. However, there was a variation observed in girls, there was a steady increase over time from the 1999 autumn to 2000 spring. Later, there was a decrease observed in 2001 the autumn and the trends changed with a steady increase from 2001 spring to 2003 spring. Boys and girls showed seasonal variation in the trends of MUAC over time. As children grow over the seasons, MUAC increases too. However, there was a decline observed in MUAC in both boys and girls in the spring of the year 2003. However, there are a limited number of local studies that have been done on seasonal variation of upper arm anthropometry, as such it is difficult to make comparison.

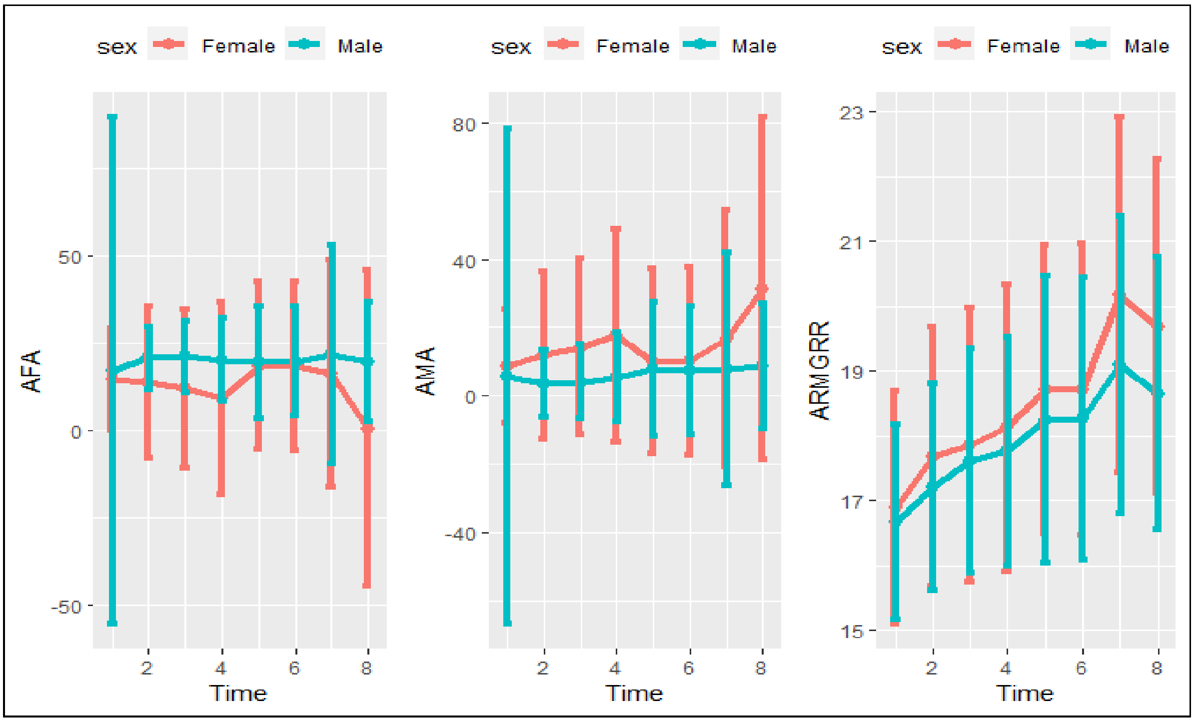

Figure 5. Seasonal changes over time of Arm Fat Area (AFA), Arm Muscle Area (AMA), Mid Upper Arm Circumference (MUAC); Time indication of the seasonal changes over the years for the boys and girls.

4.1.6. THE RELATIONSHIP BETWEEN ANTHROPOMETRIC INDICATORS (AFA, AMA AND MUAC) IN SPRING WHEN COMPARED TO AUTUMN AMONG ELLISRAS CHILDREN

Table 7 indicates the GEE analysis of AFA, AMA and MUAC AFA in autumn and spring for both boys and girls. A significant (p-value = 0.020) positive association in AFA for boys aged between 8 – 11 years β = 0.47, (95% CL: 0.07; 0.82). Furthermore, AFA increased by 0.43 cm^2 in spring as compared to autumn. The girls aged between 8 – 11 years had a significant (p-value = 0.001) positive association with AFA. In addition, AFA increased by 1.30 cm^2 in spring when compared to autumn β = 1.30, (95% CL: 0.58; 2.03). There was seasonal variation observed (p-value = 0.004), in AMA for boys aged between 8 – 11 years in spring compared to autumn. Furthermore, AMA was negatively associated with spring when compared to autumn β = -0.58, (95% CL: -0.98; -0.18). The girls, of the same age, also had a negative association with AMA β = -1.42, (95% CL: -2.22; -0.61). However, there was no significant association of

MUAC between spring and autumn for both boys and girls aged between 8 – 11 years. A positive significant association in MUAC was observed in both boys and girls aged above 12 years, β = 0.24, (95% CL: 0.17;0.32), p-value = 0.001 and β = 0.20, (95% CL: 0.11;0.29), p-value = 0.001, respectively.

Table 7: General estimated equation regression coefficients (β), p-value, and 95% confidence intervals for the association of seasonal variation with AFA, AMA and MUAC for the boys and girls

	AFA		**AMA**		**MUAC**	
	***β* (95% CL)**	**p-Value**	***β* (95% CL)**	**p-Value**	***β* (95% CL)**	**p-Value**
Boys						
4 – 7	-0.64 (-1.35;0.08)	0.080	0.53 (-0.07;1.12)	0.09	-0.06 (-0.21; 0.10)	0.48
8 – 11	0.45 (0.07;0.82)	0.020*	-0.58 (-0.98; -0.18)	0.004*	-0.03 (-0.09;0.03)	0.262
above 12	-0.30 (-2.56;1.97)	0.795	0.99 (-1.33;3.31)	0.401	0.24 (0.17;0.32)	0.001*
Girls						
4 – 7	-0.28 (-1.66;1.09)	0.685	0.41 (-1.23;1.94)	0.604	-0.02 (-0.30;0.25)	0.866
8 – 11	1.30 (0.58;2.03)	0.001*	-1.42 (-2.22;-0.61)	0.001*	-0.05 (-0.12;0.03)	0.223
above 12	7.79 (6.34;9.24)	0.001 *	-7.24(-8.83;-5.66)	0.001 *	0.20 (0.11;0.29)	0.001*

¥ Reference: Autumn; *p-value <0.05; AFA –Arm Fat Area, AMA – Arm Muscle Area, MUAC – Mid Upper Arm Circumference, ***β***—beta coefficient and confidence intervals (CI)

The results of the current study showed that there was a significant median difference between AFA and AMA, in autumn and spring among Ellisras boys and girls. In addition, seasonal variation is observed from the mid-childhood to the adolescent stage. Moreover, there was no seasonal median variation observed in MUAC for the current study. There was a positive correlation in AFA for boys and girls in spring compared to autumn, during the mid-childhood stage at the age range of 8 – 11 years. Kang (2018) highlighted that mid-adolescence is associated with high adiposity rebound after 7 years. On the other hand, both boys and girls aged 8 – 11 years had a negative correlation with AMA, indicating that the boys had a decrease in AMA for spring compared to autumn.

Dietz, (1994), reported that during the mid-adolescent stage, there is more fat gain than muscle mass. The study conducted by Yavuz & Özer (2020) reported that Turkish children and adolescents aged 6 – 17 years correlated with BMI, AMA and AFA. Moreover, the increase in the upper arm muscle area occurred with increasing age. In addition, sex hormones affect the upper arm muscles and fat areas during adolescence. The increase in age also indicates significant sexual dimorphism in upper arm muscle and fat area values. Moreover, environmental conditions play an important role in the development of AFA, AMA and MUAC.

Environmental factors such as climatic conditions such as drought and floods over several decades or longer influence the availability of food and water security and seasons (Rudolf *et al.*, 1991; Baye & Hirvonen, 2020). Seasonal variation is mainly linked to climatic conditions such as rainfall (wet) and dry season (Fentahun *et al.*, 2018). The wet seasons are associated with the increase in the availability of food which is associated with high food consumption, weight gain, obesity and being overweight (Han *et al.*, 2021). The dry season is associated with less /low availability of food which may lead to malnutrition. However, this study did not look at the specific climatic conditions associated with the seasons.

In addition, there are fewer longitudinal studies available that are well-designed to highlight seasonal variation and as such it affects the direct comparison of the outcome of these studies (Madan *et al.*, 2018). Most literature is available in India and Bangladesh region (Shaikh *et al.*, 2020). Nevertheless, there is a lot of inconsistency when defining seasonality factors.

4.1.7. THE RELATIONSHIP BETWEEN FIRST ANTHROPOMETRIC INDICATORS (AFA, AMA AND MUAC) AND SUBSEQUENT MEASUREMENTS OVER TIME AMONG ELLISRAS CHILDREN

Table 8 shows the longitudinal tracking coefficient for the association between the first and the subsequent measurements of Ellisras children aged 4 – 17 years for the cohort. There was a positive significant ($p < 0.001$) association between the first AFA, AMA and MUAC and the subsequent measurements for both boys and girls, throughout the period. AFA of $\beta = 0.01$, (95% CL: 0.00; 0.01) and $\beta = 0.03$, (95% CL: 0.03; 0.04) for boys and girls respectively. Moreover, girls had an elevated beta range when compared to boys. A similar trend was observed with AMA $\beta = -0.01$, (95% CL: -0.01; 0.01) and $\beta = 0.04$, (95% CL: 0.03; 0.04) for boys and girls respectively. However, MUAC for boys was elevated $\beta = 0.03$, (95% CL: 0.02; 0.04) when compared to girls $\beta = 0.01$, (95% CL: 0.00; 0.01).

The tracking coefficient between the initial measurements and the subsequent measurements was higher for AMA and AFA when compared to MUAC. This could be supported by slightly higher tracking coefficients in Ellisras girls compared to boys over time. The six-year duration of the study with measurements carried out twice yearly not only provides accurate tracking measurements of the arm anthropometry. On the other hand, according to my knowledge, there are no longitudinal studies that have investigated the development of MUAC, arm muscle and fat area over the same length where the current study was carried out.

Table 8: Specific tracking coefficient between the first and the subsequent measurements

Sex	**AFA**		**AMA**		**MUAC**	
Age (years)	***β* (95% CL)**	**p-Value**	***β* (95% CL)**	**p-Value**	***β* (95% CL)**	**p-Value**
Boys						
4	2.07 (-1.46; 0.08)	0.251	-1.61 (-4,61;2,29)	0.510	0.09 (-0.56; 0.74)	0.779
5	1.52 (0.55; 2,49)	0.020*	-1.60 (-2,07;-0,25)	0.013*	-0.17 (-0.42;0.74)	0.172
6	0.79 (0.03; 1.56)	0.043*	-0.81 (-1,49;-0,13)	0.020*	-0.01 (-0.02;0.19)	0.935
7	0.15 (-0.32; 0.63)	0.527	-0.10 (-0,47;0,27)	0.598	-0.07 (-0.08; 0.22)	0.366
8	0.17 (- 0.34; 0.69)	0.508	-0.07 (-0.62; -0.48)	0.800	0.054 (-0.06;0.19)	0.460
9	0.13 (-0.34;0.63)	0.618	-0.14 (-0.64;0.36)	0.571	0.06(0.17;0.32)	0.300
10	0.49 (-0.09;1.09)	0.102	-0.49 (-1.08; -0.11)	0.106	0.15 (0.04;0.27)	0.008*
11	-0.51 (-0,11; - 1,13)	0.104	-0.56 (-1.25;0,13)	0.111	0.13 (0.01;0.24)	0.038*
12	-1.48 (-7.29;4.33)	0.618	1.94 (-3.89; -7.77)	0.514	0.23 (0.09;0.36)	0.001*
13	0.19 (-1.46;1.83)	0.825	0.41 (-1.49;2.30)	0.675	022 (0.06:0.39)	0.008*
14	1.62 (-0.66;3.90)	0.165	-0.88 (-3.36; 1.60)	0.489	0.25 (0.01;0.49)	0.042*
15	4.69 (2.13;7.26)	0.001*	-1.48 (-4.32;1.35)	0.305	1.07 (0.73;1.42)	0.001*
16	-8.54 (-22.71;5.63)	0.237	10.92 (-4.49;26.33)	0.165	0.77 (0.23;1.30)	0.005*
17	-1.28 (-10.38;7.83)	0.783	3.29 (-8.09;14.68)	0.571	0.71 (-0.43;.85)	0.220
Girls						
4	-2.55 (-6,95;1,85)	0.256	0.53 (-0.07;1.12)	0.177	-0.21 (-1.02; 0.60)	0.615
5	1,09 (-0,61; 2,79)	0.209	-0.58 (-0.98; -0.18)	0.295	-0.01 (-0.28;26)	0.933
6	0.77 (-0,12;1,66)	0.088	0.99 (-1.33;3.31)	0.182	0.24 (0.17;0.32)	0.309
7	0.52 (-0,30;1,34)	0.214	0.53 (-0.07;1.12)	0.381	-0.12 (-0.11; 0.34)	0.101
8	0.73 (0,11;1,36)	0.022*	-0.41 (-1,14;0,32)	0.270	0.05 (-0.12;0.22)	0.569
9	0.89 (0,11;1,66)	0.025*	-0.96 (-1.82;-0.01)	0.027*	0.04 (-0.11;0.12)	0.584
10	0,89 (-0,20;1,99)	0.110	-0.22 (-2,38;-0,05)	0.040*	0.14 (-0.05;0.28)	0.058
11	1,87 (0,57;3,17)	0.005*	-1.70 (-3,11;-0,28)	0.019*	0.23 (0.09;0.37)	0.001*
12	2,42 (-0,04;4,88)	0.054	-3.00 (-5,64;-0,37)	0.025*	-0.04 (-0.20;0.11)	0,563
13	5.47 (2,57; 8,37)	0.001*	-5.09 (-8,28;-1,91)	0.002*	0.16 (-0.03;0.38)	0.106
14	9.25 (5,24;13,26)	0.001*	-6.85 (-11,22;-2,47)	0.002*	0.79 (0.51;1.09)	0.001*

15	10.63 (4,91;16,35)	0.001*	-7.50 (-14,01;-0,99)	0.024*	1.00 (0.60;1.40)	0.001*
16	19.13 (10,02;28,24)	0.001*	-16.43(10,02;28,24)	0.001*	0.89 (0.38;1.40)	0.001*
17	38.99 (13,89;64,08)	0.002*	-38.41 (-64,92;11.89)	0.005*	0.36(-0.48;0.71)	0.398
Longitudinal tracking coefficient derived from GEE						
	β **(95% CL)**	**p-Value**	***β*** **(95% CL)**	**p-Value**	***β*** **(95% CL)**	**p-Value**
Boys	0.01 (0.00;0.01)	0.001 *	-0.01 (-0,01;0.01)	0.001 *	0.03 (0.02;0.04)	0.001 *
Girls	0.03 (0.03;0.04)	0.001 *	0.04 (0.03;0.04)	0.001 *	0.01 (0.00;0.01)	0.001 *

¥ Reference: Autumn; *p-value <0.05; AFA –Arm Fat Area, AMA – Arm Muscle Area, MUAC – Mid Upper Arm Circumference, ***β***—beta coefficient and confidence intervals (CI)

4.1.8. AFA, AMA AND MUAC PROPOSED CUT-OFF POINTS FOR UNDERNUTRITION

Table 9 – 10 shows the result of the proposed optical cut-off points for AMA, AFA and MUAC in Ellisras children by age and sex. Therefore, this was the first study to introduce the cut-off points for low-fat and lean arm areas to determine undernutrition in children from South Africa.

Table 9: Optimal cut-off, sensitivity, specificity, SE and area under the ROC curves for anthropometric indices in predicting undernutrition in boys

Age (Years)	Variables	Cut off	Sensitivity (%)	Specificity (%)	AUC	P value	SE	95%CI
Boys								
4	AFA	4.302	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	13.048	100	91.0	1.000	0.001	0.001	1.000 – 1.000
	MUAC	15.150	100	100	1.000	0.001	0.001	1.000 – 1.000
5	AFA	4.535	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	12.843	100	99.2	1.000	0.001	0.001	0.999 – 1.000
	MUAC	15.450	99.5	97.1	0.997	0.001	0.002	0.994 – 1.001
6	AFA	3.925	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	11.659	96.5	93.7	0.982	0.001	0.015	0.954 – 1.011
	MUAC	15.450	99.1	97.9	0.996	0.001	0.002	0.992 – 1.000
7	AFA	3.990	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	11.795	99.8	98.1	0.999	0.001	0.001	0.997 – 1.001
	MUAC	15.650	96.9	92.2	0.985	0.001	0.005	0.975 – 0.994
8	AFA	3.698	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	15.202	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	16.050	97.5	89.4	0.987	0.001	0.003	0.982 – 0.993
9	AFA	4.235	100	99.8	1.000	0.001	0.001	1.000 – 1.000
	AMA	15.860	100	99.7	1.000	0.001	0.001	1.000 – 1.000
	MUAC	16.550	98.1	93.1	0.991	0.001	0.003	0.985 – 0.996
10	AFA	5.214	100	99.9	1.000	0.001	0.001	1.090 – 1.000
	AMA	17.449	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	16.750	96.1	86.0	0.981	0.001	0.003	0.974 – 0.987
11	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	18.062	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	17.350	98.1	91.0	0.991	0.001	0.002	0.987 – 0.994

12	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	19.437	100	99.8	1.000	0.001	0.001	1.000 – 1.000
	MUAC	18.250	97.3	90.7	0.986	0.001	0.003	0.980 – 0.993
13	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	20.892	99.9	99.1	1.000	0.001	0.001	0.999 – 1.000
	MUAC	18.850	96.8	88.1	0.984	0.001	0.004	0.977 – 0.991
14	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	26.377	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	20.050	94.3	85.7	0.972	0.001	0.009	0.955 – 0.988
15	AFA	5.435	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	29.787	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	21.350	98.8	97.0	0.994	0.001	0.003	0.989 – 0.999
16	AFA	4.851	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	32.945	99.8	99.2	0.999	0.001	0.001	0.997 – 1.000
	MUAC	22.850	98.8	98.0	0.994	0.001	0.004	0.987 – 1.001
17	AFA	3.967	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	35.140	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	23.900	100	100	1.000	0.001	0.001	1.000 – 1.000

AUC: Area Under Curve; ROC: Receiver Operative Characteristics; SE: Standard Error; AFA: Arm Fat Area; AMA: Arm Muscle Area; MUAC: Mid Upper Arm Circumference

Table 10: Optimal cut-off, sensitivity, specificity, SE and area under the ROC curves for anthropometric indices in predicting undernutrition in girls

Age (Years)	Variables	Cut off	Sensitivity (%)	Specificity (%)	AUC	P value	SE	95%CI
				Girls				
4	AFA	3.946	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	11.602	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	14.900	100	100	1.000	0.001	0.001	1.000 – 1.000
5	AFA	4.459	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	11.920	100	98.9	1.000	0.001	0.001	0.999 – 1.000
	MUAC	15.050	98.8	93.4	0.994	0.001	0.003	0.988 – 1.000
6	AFA	4.436	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	11.413	99.8	97.9	0.999	0.001	0.001	0.998 – 1.001
	MUAC	15.250	98.3	95.6	0.991	0.001	0.005	0.982 – 1.001
7	AFA	4.346	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	13.164	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	15.350	98.9	96.6	0.995	0.001	0.002	0.991 – 0.998
8	AFA	4.211	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	13.336	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	15.850	97.5	91.8	0.988	0.001	0.003	0.981 – 0.994
9	AFA	4.999	100	99.8	1.000	0.001	0.001	1.000 – 1.000
	AMA	12.031	99.5	95.9	0.998	0.001	0.001	0.996 – 0.999
	MUAC	16.250	98.1	93.6	0.990	0.001	0.003	0.985 – 0.996
10	AFA	5.418	100	99.9	1.000	0.001	0.001	1.000 – 1.000
	AMA	15.269	99.5	94.8	0.998	0.001	0.001	0.996 – 0.999

	MUAC	16.850	99.4	93.8	0.997	0.001	0.001	0.995 – 0.998
11	AFA	4.780	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	15.856	99.6	96.5	0.998	0.001	0.001	0.997 – 1.000
	MUAC	17.650	98.8	91.1	0.994	0.001	0.001	0.992 – 0.996
12	AFA	4.851	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	18.227	99.4	97.1	0.997	0.001	0.001	0.995 – 0.999
	MUAC	18.450	98.7	90.4	0.994	0.001	0.001	0.991 – 0.996
13	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	21.631	100	99.7	1.000	0.001	0.001	1.000 – 1.000
	MUAC	19.250	99.3	94.5	0.997	0.001	0.001	0.995 – 0.999
14	AFA	5.214	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	22.759	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	20.350	100	99.4	1.000	0.001	0.001	0.999 – 1.000
15	AFA	8.264	100	99.3	1.000	0.001	0.001	1.000 – 1.000
	AMA	23.550	99.9	99.7	0.999	0.001	0.001	0.998 – 1.001
	MUAC	20.650	98.4	90.8	0.992	0.001	0.002	0.987 – 0.997
16	AFA	7.722	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	24.730	99.9	98.2	1.000	0.001	0.001	0.999 – 1.000
	MUAC	21.400	100	98.5	1.000	0.001	0.001	1.000 – 1.000
17	AFA	8.264	100	100	1.000	0.001	0.001	1.000 – 1.000
	AMA	25.129	100	100	1.000	0.001	0.001	1.000 – 1.000
	MUAC	21.750	100	100	1.000	0.001	0.001	1.000 – 1.000

AUC: Area Under Curve; ROC: Receiver Operative Characteristics; SE: Standard Error; AFA: Arm Fat Area; AMA: Arm Muscle Area; MUAC: Mid Upper Arm Circumference

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CHAPTER 5

INTRODUCTION, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. INTRODUCTION

Undernutrition is a major public health concern in Africa that affects children from early life into adulthood. Undernutrition occurs due to insufficient diet and protein energy that manifests in the form of stunting, wasting, or underweight which leads to growth failure (Popkin *et al*., 2020; Madzorera *et al*., 2023). As a result, failure to grow at an appropriate rate may be associated with growth disorders, infections, poor nutrition, reduced lean body mass, diminished intellectual functioning, and reduced earnings later in life (Mokone *et al*., 2022; Kubeka & Modjadji, 2023). Furthermore, a deficit in growth status in early life predisposes children to slow linear growth during childhood (Madan *et al*., 2018).

Growth monitoring is an integral part of childhood development, especially in developing countries wherein environmental factors such as climatic conditions and natural disasters (Fentahun *et al*., 2018) affect food, water and nutrition security (Mphahlele *et al*., 2020; Marshak *et al*., 2021). Determination of arm fat area and arm muscle area allows the evaluation of the nutritional status and growth in children. Upper AMA determines the organic protein pool that is based on the linear correlation between the body muscle mass and the organic protein. It is widely used to evaluate the depletion of lean tissue in protein energy malnutrition (Sen & Mondal, 2013; De, 2017). While, upper AFA reflects calorie reserves stored in the form of fat (Addo *et al*., 2017). Furthermore, cross-sectional arm area estimations are preferable because they describe the relative contributions of muscle and adipose tissue to the total arm area (Gültekin *et al*., 2006; Żegleń *et al*., 2021). However, the use of upper arm anthropometry to assess undernutrition in South Africa has received little attention in the literature.

5.2. SUMMARY

Chapter 1 addressed the need to investigate the development of fat and lean arm area and undernutrition risk factors in children in the Ellisras rural area in Limpopo Province, South Africa. The need for finding the best indicator of undernutrition in Ellisras rural children was shown. The need for establishing the cut-off points for undernutrition in Ellisras rural children was indicated. To answer the above-mentioned statements successfully, the following objectives of the study were outlined in the first chapter:

i. Measure fat and lean arm area from childhood into adulthood in subjects who are part of the Ellisras Longitudinal Study (ELS) over time (1997 to 2003).
ii. Compare the fat and lean arm area of Ellisras rural children with the National Health and Nutrition Examination Survey (NHANES) III reference population (Frisancho, 1990).
iii. Determine the prevalence of low fat and lean arm area of Ellisras rural children into adults over time (1997 to 2003).
iv. Investigate seasonal variation (autumn and spring) in the development of fat and lean arm area from childhood into late adolescent over time (1997 to 2003).
v. Determine the sensitivity and specificity of AFA, AMA and MUAC cut-off points among Ellisras rural children.
vi. Track the trend of fat and lean arm area of the Ellisras rural population over time.
vii. Assess if fat and lean arm mass in childhood can be used to predict fat and lean mass in adulthood.

Chapter 2, literature on the topic was reviewed. We reviewed the literature of some important international researchers who argued that anthropometric indicators of fat and lean arm area are associated with undernutrition in children and adolescents (De, 2017; Żegleń *et al*., 2021; Madzorera *et al*., 2023). We reviewed the development of anthropometric indices on childhood growth overtime (Gasser *et al*., 1994; Zvonar *et al*., 2022) and across the various seasons (Kobayashi & Kobayashi, 2006; Dalskov *et al*., 2016; Madan *et al*., 2018).

Chapter 3, indicated the methodology and the statistical analysis of the data collected. Linear regression was used to determine the association between anthropometric indices with seasonal variation among Ellisras rural children and adolescents. A longitudinal tracking GEE was used to measure the association between an indicator at the first period of measurement and the same indicator at all other periods of measurement.

Chapter 4, results and discussion of the study were described. There was a significant ($P<0.05$) association between anthropometrics indicators with undernutrition among Ellisras rural children aged 4 – 17 years. Therefore, the present study concurs with the previous studies on the association of anthropometric indicators with undernutrition in children and adolescents (Mphahlele *et al*., 2020; Mandal *et al*., 2021; Ellemunter *et al*., 2022).

In chapter 5, a summary overview of the dissertation was presented together with recommendations of the study which will help to uproot the dynamics of undernutrition among a paediatric population in rural South Africa.

5.3. CONCLUSIONS

The conclusions of the study are provided regarding the objectives and hypothesis set out in Chapter 1.

Objective 1: To measure fat and lean arm area from childhood into adulthood in subjects who are part of the Ellisras Longitudinal Study (ELS) over time (1997 to 2003).

Hypothesis 1: The measurement of the fat and lean arm area will be similar to those studied in the world.

Boys and girls had a significant difference ($p \leq 0.05$) at age 7 at the first MUAC measurement in 1997 autumn with mean values of 15.97 cm and 15.86 cm respectively, when compared to spring measurements. However, there were no statistical significant differences observed in the first MUAC measurement in early age and later for MUAC. Furthermore, there was a significant difference ($p \leq 0.05$) at age 9 at the first AMA measurement in 1997 autumn with mean values of 1.88 cm^2 and 3.22 cm^2 in boys and girls respectively, compared to spring measurements. However, there was no significant mean difference in AMA across all the ages for both boys and girls at the first measurement in 1997 autumn.

In line with the findings above, hypothesis 1 was therefore accepted.

Objective 2: To compare the fat and lean arm area of Ellisras rural children with the National Health and Nutrition Examination Survey (NHNES) III reference population (Frisancho, 1990).

Hypothesis 2: The fat and lean arm area among Ellisras children and adolescents will be low when compared to the reference population.

The findings of the study were that the Ellisras children showed a significant mean difference in the development of AFA and AMA from 1997 – 2003. Ellisras children showed an elevated mean value in the development of AFA when compared to the National Health and Nutrition Examination Survey (NHNES) III reference population (Frisancho, 1990). Moreover, the Ellisras boys exhibited high AFA when compared to Ellisras girls. On the contrary, Ellisras boys tend to have low AFA when compared to Ellisras girls (Mphahlele *et al*., 2020; Mandal *et al*., 2021). A study by (Żegleń *et al*., 2021), suggested that the AFA is the most suitable index to monitor obesity in prepubertal, and pubertal children and adolescents rather than undernutrition. There was a significant median difference ($p < 0.001$ to 0.05) in the development of MUAC, however, there was no clear pattern in the development of MUAC when compared to the reference population of children aged 4 – 17 years (Frisancho, 1981). This may be due to the ethical differences, genetics and environmental factors that affect children's growth patterns (Engwa *et al*., 2021; Mandal *et al*., 2021). On the other hand, girls had an elevated AMA when compared to boys over time. However, both Ellisras boys and girls were below the 5th percentile of the reference population. Similar, finding has been reported (Chomtho *et al*., 2006; Piperata, 2007; Mphahlele *et al*., 2020). This may also highlight the differences that exist between developing and developed countries.

In line with the findings above, hypothesis 2 was therefore partially accepted.

Objective 3: To determine the prevalence of low fat and lean arm area of Ellisras rural children into adults over time (1997 to 2003).

Hypothesis 3: The prevalence of low fat and lean arm area will be similar to those studied in the world.

The overall prevalence for this study was highest when determining undernutrition by AMA was 88.9% when compared to the overall prevalence of undernutrition by MUAC (53.9%) when using AFA (8.3%) for the cohort. The prevalence of undernutrition by AFA was the lowest at 3.9% in Ellisras boys when compared to 13.2% in Ellisras girls. A similar finding was reported among, school children, aged 4 – 12 years in Argentina (Oyhenart *et al*., 2020). Contrary to the findings among Zimbabwean (Olivieri *et al*., 2008) and Nigerian children (Senbanjo *et al*., 2014). The prevalence of undernutrition using AMA was higher in Ellisras boys with 95.1%, when compared to 82.1% for Ellisras girls. Ellisras Boys had 58.0% in the prevalence of undernutrition by MUAC when compared to 49.5% for Ellisras girls. Similar findings have reported the prevalence of undernutrition to be the highest in Limpopo province by (69.90%) in South Africa when compared to other provinces (Mkhize & Sibanda, 2020). In addition, South Africa is also faced with poor living conditions, and food insecurity ultimately, it leads to long-term effects such as delayed growth and mental development, and increased risk of cardiovascular diseases (Mphahlele *et al*., 2020; Mokone *et al*., 2022; Kubeka & Modjadji, 2023). In addition, Said-Mohamed *et al*., (2015), in a 40 years review highlighted that the trend of undernutrition over time differs, based on different settings. However, there are methods used to assess undernutrition, thus making it difficult to compare different surveys over time (Said-Mohamed *et al*., 2015; Gwelo *et al*., 2023). In addition, there are a limited number of longitudinal study that shows the trends of undernutrition over time and the impact on the growth and development of children over time in South Africa.

In line with the findings above, hypothesis 3 was therefore partially accepted.

Objective 4: To investigate seasonal variation (autumn and spring) in the development of fat and lean arm area from childhood into late adolescent over time (1997 to 2003).

Hypothesis 4: The development of fat and lean areas over the season will be those studied in the world.

The results of the current study showed that there was a significant median difference between AFA and AMA, in autumn and spring among Ellisras boys and girls. In addition, seasonal variation is observed from the mid-childhood to the adolescent stage. A study by (Żegleń *et al*., 2021), suggested that the AFA is the most suitable index to monitor obesity in prepubertal, and pubertal children and adolescents. Moreover, there was no seasonal median variation observed in MUAC for the current study. There was a positive correlation in AFA for boys and girls in spring compared to autumn, during the mid-childhood stage at the age range of 8 – 11 years. According to Kang (2018) highlighted that mid-adolescence is associated with high adiposity rebound after 7 years. On the other hand, both boys and girls aged 8 – 11 years had a negative correlation with AMA, indicating that the boys had a decrease in AMA for spring as compared to autumn. Dietz, (1994), reported that during the mid-adolescent stage, there is more fat gain than muscle mass. However, there was no seasonal variation observed in MUAC for both boys and girls in spring compared to autumn. There are a limited number of studies that have been done on seasonal variation of upper arm anthropometry.

In line with the findings above, hypothesis 4 was therefore partially accepted.

Objective 5: To determine the sensitivity and specificity of AFA, AMA and MUAC cut-off points among Ellisras rural children.

Hypothesis 5: The sensitivity and specificity cut-off points for AFA, AMA and MUAC will be established amongst Ellisras rural children aged 4 – 17 years.

The AUC, cut-off value, sensitivity, and specificity for underweight of each age and sex were established. The cut-off values for underweight in Ellisras children increase with age. Therefore, this current study was the first to establish AFA, AMA and MUAC cut-off points for underweight children from South Africa. Moreover, AFA, AMA and MUAC are simple techniques with good interrater reliability and could be used to screen underweight children.

In light of the findings above, hypothesis 5 was therefore partially accepted.

Objective 6: To track the trend of fat and lean arm area of the Ellisras rural population over time.

Hypothesis 6: The association between trends in the development of fat and lean areas between autumn and spring is similar to those studied in the world.

Boys and girls had a significant difference ($p \leq 0.05$) at age 7 from the first MUAC measurement in 1997 autumn with median values of 15.97 cm^2 and 15.86 cm^2 respectively. However, there were no statistical significant difference observed in the first MUAC measurement in early age and later for MUAC. Furthermore, there was a significant difference ($p \leq 0.05$) at age 9 at the first AMA measurement in 1997 autumn with median values of 1.88 cm^2 and 3.22 cm^2 in boys and girls respectively. However, there was no significant median difference in AMA across all the ages for both boys and girls at the first measurement in 1997 autumn. The trend of this study is that as the children grow there is a significant median development between AMA, AFA and MUAC. However, several studies looked at tracking the development of high AFA and AMA that is associated with obesity rather than undernutrition throughout the time (Monyeki *et al*., 2000, 2017; Deshmukh-Taskar *et al*., 2006; Singh *et al*., 2008; Li *et al*., 2009; Starc & Strel, 2011; Toselli *et al*., 2013; Zvonar *et al*., 2022). In addition, there are no longitudinal studies available that are well-designed to highlight the development of MUAC, AMA and AFA at the 5th percentile, as an indicator of undernutrition and as such it affects the direct comparison of the outcome of these studies. Most literature is available in Turkey, India and Bangladesh region (Shaikh *et* *al*., 2020). Nevertheless, there is a lot of inconsistency when the percentiles are used to define low MUAC, AFA and AMA.

In line with the findings above, hypothesis 6 was therefore partially accepted.

Objective 7: To assess if fat and lean arm mass in childhood can be used to predict fat and lean mass in adulthood.

Hypothesis 7: In the ELS population the fat and lean area of children can be predicted in the adult population.

The Longitudinal tracking coefficient for the association between the first and the subsequent measurements of Ellisras children aged 4 – 17 years for the cohort. There was a positive significant ($p < 0.001$) association between the first AFA, AMA and MUAC and the subsequent measurements for both boys and girls, throughout the period. AFA of $\beta = 0.01$, (95% CL: 0.00; 0.01) and $\beta = 0.03$, (95% CL: 0.03; 0.04) for boys and girls respectively. Moreover, girls had an elevated beta range when compared to boys. A similar trend was observed with AMA $\beta = -0.01$, (95% CL: -0.01; 0.01) and $\beta = 0.04$, (95% CL: 0.03; 0.04) for boys and girls respectively. However, MUAC for boys was elevated $\beta = 0.03$, (95% CL: 0.02; 0.04) when compared to girls $\beta = 0.01$, (95% CL: 0.00; 0.01). The tracking coefficient between the initial measurements and the subsequent measurements was higher for AMA and AFA when compared to MUAC. This could be supported by slightly higher tracking coefficients in Ellisras girls compared to boys over time. The six-year duration of the study with measurements carried out twice yearly not only provides accurate tracking measurements of the arm anthropometry. On the other hand, according to my knowledge, there are no longitudinal studies that have investigated the development of MUAC, arm muscle and fat area over the same length of time where the current study was carried out.

In line with the findings above, hypothesis 7 was therefore partially accepted.

In conclusion, the findings of this study suggest that there is high prevalence of undernutrition found in this study. Furthermore, there was a substantial seasonal variation in the growth and development of fat and lean arm areas among the Ellisras children. The Ellisras boys studied have a poor protein reserve while girls have poor calories when compared to the NHANES reference population. Arm anthropometry may be a valuable way to evaluate the nutritional status of children. This study shows for the first time measurement of fat and lean fat area tends to track into later life. The trend of undernutrition changes overtime, based on different setting. However, there are methods used to assess undernutrition, thus the making it difficult to compare different surveys overtime. The policy maker need to establish a common sampling methodology for national surveys and generate representative data at provincial levels to improve the national sampling framework. In addition there are a limited number of longitudinal study that shows the trends of undernutrition over time and the impact on growth and development of children over time. Further studies are needed to focus on service delivery, socioeconomic dynamics, dietary habits, physical activities, and hormonal changes of these children for a better understanding of growth status in this population.

5.4. RECOMMENDATIONS

We recommend that:

i. There is a need for the new proposed standard reference cut-off point that is aligned with sex and age for the African populations.

ii. In addition, there is a need for more recent longitudinal studies on the development of lower degrees of muscularity and low adiposity using arm anthropometry to assess undernutrition.

iii. There is a need for regular screening of AMA, AFA and MUAC to determine undernutrition in early life of children.

iv. A limited number of studies have been done on seasonal variation of upper arm anthropometry. There is a need to investigate all seasons of the year to determine the variation it has on fat and lean fat areas.

v. Early intervention and management of undernutrition in Ellisras rural children could benefit the growing rural South African population as risk factors associated with undernutrition will be combated at an early age.

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APPENDICES

APPENDIX A: DATA FORM

Subject number: ☐☐☐☐☐☐

Birth Date: DD MM YY ☐☐☐☐☐☐

Observation date: DD MM YY ☐☐☐☐☐☐

Gender: M/F

ANTHROPOMETRY DATA FORM

Mid-upper arm circumference (cm)			
Biceps skinfold (cm)			
Triceps skinfold (cm)			

APPENDIX B: CONSENT FORM

CONSENT FORM

Project title: **<u>Investigation on the development and tracking of lean and fat area on the arm from childhood to adulthood: Ellisras longitudinal study.</u>**

Project leader: **Prof KD Monyeki**

Researcher: **Ms MMK Mabogoana**

I   hereby voluntarily consent to participate in the following project:" Tracking the development of Lean and Fat areas of the arm from childhood to adulthood in a cohort of the Ellisras Longitudinal Study."

I understand that:

1. The study deals with anthropometric measurements of the arm circumference, biceps, and triceps skinfolds.

2. The procedure may hold some risks for me that cannot be foreseen at this stage.

Anthropometric measurements will be carried out according to the International Society for the Advancement of Kinanthropometry (ISAK) (Norton & Olds, 1996). The triceps and biceps skinfolds will be measured using a plastic Slim Guide skinfold calliper. Correct anatomical landmarks will be carefully located at the skinfold site and marked on the subject's skin using a surgical marking pen. At the landmark's site, the skinfold will be picked up and grabbed in such a way that a double fold of skin plus the underlying subcutaneous adipose tissue will be held between the thumb and index finger. Measurements will be recorded after two seconds of full pressure of the calliper. The dial of the calliper will be read to the nearest 0.1 mm. Average values of 2 − 3 measurements will be taken at each site for any further calculations. The arm circumference will be measured with a flexible steel tape to the nearest 0.1 cm. (Monyeki *et al*., 2002). The measurements be done in the Ellisras rural area during May and November 2022.

3. The Ethics Committee has approved that individuals may be approached to participate in the study.

4. The research project, aims and methods of the research, have been explained to me.

5. I will be informed of any new information that may become available during the research that may influence my willingness to continue my participation.

6. Access to the records that pertain to my participation in the study will be restricted to persons directly involved in the research.

7. Any questions that I may have regarding the research or related matters, will be answered by the researcher/s.

8. Participation in this research is voluntary and I can withdraw my participation at any stage.

9. If any medical problem is identified at any stage during the research, or when I am vetted for participation, such condition will be discussed with me in confidence by a qualified person and/or I will be referred to my doctor.

10. I indemnify the University of Limpopo and all persons involved with the above project from any liability that may arise from my participation in the above project or that may be related to it, for whatever reasons, including negligence on the part of the mentioned persons.

Signature of interviewee **Signature of witness**

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Signature of interviewer--------------------------------------

PEER-REVIEWED ARTICLES EMANATING FROM THE DISSERTATION

1. **Makhubedu, M.M., Matshipi, M., Mphwekgwana, P.M., Makgae, P.J., & Monyeki, K.D. (2024). Seasonal variation of lean arm fat and fat arm area among Ellisras population from childhood into young adulthood. *African Journal for Physical Activity and Health Sciences*, 30(1), 51-71. DOI:https://doi.org/10.37597/ajphes.2024.30.1.429**

2. **Makhubedu, M.M., Matshipi, M., & Monyeki, K.D. (2023). Tracking the development of Lean Arm Fat and Fat Arm Area among Ellisras population from childhood into young adulthood. (Under review)**