The double burden of malnutrition in South Africa: risk factors for undernutrition and overnutrition and the development of a novel mid-upper arm circumference (MUAC) screening tool in children

Shawn William McLaren

A thesis submitted in partial fulfilment of the requirements of London Metropolitan University for the degree of Doctor of Philosophy

May 2022

DECLARATIONS

I am submitting the following six original peer reviewed journal articles for the award of PhD by prior output.

List of original publications

1. McLaren S, Steenkamp L, Feeley A, Nyarko J, Venter D (2018). Food insecurity, social welfare and low birth weight: Implications for childhood malnutrition in an urban Eastern Cape Province township. *South African Journal of Child Health* 12(3): 95-99. H-index 14; Impact factor 0.522.
2. McLaren SW, Steenkamp L (2021). Coverage of vitamin A supplementation, deworming and immunisations: Associations with nutritional status among urban children younger than five years in Nelson Mandela Bay, Eastern Cape. *South African Journal of Child Health.* H-index 14; Impact factor 0.522
3. McLaren SW (2021). The relationship between haemoglobin level and socio-economic indicators among women of childbearing age in South Africa: A secondary analysis of DHS data. *Ecology of Food and Nutrition*. Impact factor 0.894
4. McLaren SW, Steenkamp L, Venter D (2017). Use of Mid Upper- Arm Circumference (MUAC) as screening tool in an urban township in the Eastern Cape: rationale for testing changed cut-off values to identify malnutrition. *South African Journal of Clinical Nutrition*, 30:4, 118-119. DOI: 10.1080/16070658.2017.1376859. Impact factor 0.64
5. McLaren S, Steenkamp L, McCarthy HD, Rutsihauser-Perera A (2020). Screening for overweight using mid-upper arm circumference (MUAC) among children younger than two years in the Eastern Cape, South Africa. *South African Journal of Clinical Nutrition*, DOI: 10.1080/16070658.2020.1782027. Impact factor 0.64.
6. McLaren S, Steenkamp L, McCarthy HD (2021). Design and validation of the double-burden mid-upper arm circumference (MUAC) tape for South African children aged six to 24 months. *Proceedings of the Nutrition Society* 81(E11): OCE1. DOI:10.1017/S0029665122000118.

The aims of this submission are to ensure that it fulfils the criteria for a PhD in both volume and academic content. This sub-set of my publications constitutes a coherent whole and includes independent and original contribution to knowledge.

ABSTRACT

The World Health Organisation has produced recommendations for screening for malnutrition in childhood. However, evidence is emerging that the performance of these tools is region-specific. The aim of this set of six studies were to identify contextual factors which contribute to childhood malnutrition and assess the performance of a malnutrition screening tool in a South African population.

The first study was conducted on 400 infants and children younger than 24 months of age from primary health facilities in the Eastern Cape, South Africa. The aim was to assess whether household food security, social welfare, and birth weight were associated with childhood nutritional status. Low birth weight was associated with height-for-age, and that this effect was still applicable even when controlling for food security and social welfare ($p<0.05$). Low birth weight could therefore be considered as an indicator from birth to triage children as high risk for stunting.

The second study was conducted on 1496 infants and young children between birth and 59 months of age, living in the Eastern Cape, South Africa. This study aimed to identify whether vitamin A supplementation, anti-helminth chemotherapy, and vaccination coverage, are associated with childhood nutritional status. We found that coverage of vitamin A supplementation (60.4%) and deworming (61.5%) were poor among this sample, with one third of participants having missed their most recent dose, however vaccination coverage was stronger (86.2%). Having a history of delayed vitamin A, deworming or vaccinations was not associated with anthropometric indicators of nutritional status among these children ($X^2=23.79$, df=19, n=840, p=0.204). However, a significant relationship was observed between delayed vitamin A supplementation and age category ($X^2=32.105$, df=19, n=836, p=0.03) as well as between delayed deworming and age category ($X^2=45.257$, df=17, n=558, $p<0.01$) and older children were more likely to have missed doses. We found that low birth weight was associated with a greater risk of stunting in this population ($p<0.05$).

As birth weight was associated with indicators of nutritional status among children, the next study aimed to examine the nutritional status of women of childbearing age in South Africa. This study made use of DHS data on 2640 women between 15 and 49 years of age, obtained using a stratified, nationally representative sample in 2016. It was found that anaemia was common (28.9%) among South African women, and that haemoglobin level is higher among women with a higher body mass index (Independent Kruskall-Wallis test= 27.014; df=5; $p<0.001$), access to improved sanitation (Mann-Whitney U test p=0.017; n=2690), and increased wealth status (Kruskall-Wallis =29.568; df=4; $P<0.01$).

The fourth study assessed MUAC's performance in identifying cases of acute malnutrition in the South African population of infants and young children aged 6 to 24 months (n=400). It was found that the cut-off values currently recommended by the WHO perform poorly in this context. The sensitivity of the current MUAC for moderate acute malnutrition was 0%, and the specificity was 99.6% Correlation analysis for the relationship between WHZ and MUAC suggested a strong, positive, dependent relationship between these two indicators (r=0.78). The least squares regression formula ($Y=15.409+0.803x$ (males); $Y=15.13+0.83x$ (females)) was then used to predict where WHZ=-2 is most likely to correspond with a MUAC value in cm. The new predicted MUAC values of 13.8cm (males) and 13.5cm (females) were subsequently tested for sensitivity and specificity. The sample was too small to calculate sensitivity for both sexes, but 96.4% specificity was achieved for females. A sensitivity of 100% and specificity of 94.5% was achieved with the male MUAC cut- off. Thus, the proposed cut-offs identified all the wasted children (WHZ<-2), while identifying an acceptably low number of false positives.

The fifth study investigated the potential of a MUAC tape for identifying overweight and obesity among this population. The area under the curve (AUC) for identifying overweight males 0-6

months old (n=58) was 0.766. The MUAC cut-off value at 14.5 cm had a sensitivity of 88.9% and specificity of 63.3% (J=0.542). Female children 0-6 months old had an AUC of 0.788 for overweight. The MUAC cut-off with the highest J-value (J=0.585) was 14.2 cm (100% sensitivity, and 58.5% specificity). Data obtained from males aged six to 24 months (n=139) generated ROC curves with AUC of 0.821 for overweight (+2<WLZ<+3) and 0.905 for obesity (WLZ>+3). The MUAC cut-off value of 16.5 cm had the highest J-value (0.589) and a sensitivity of 85% and specificity of 71.4% for identifying overweight. The optimum MUAC cut-off value for identifying obesity among males six to 24 months old was 17.2 cm (88.9% sensitivity, 80.8% specificity, J=0.697). A MUAC cut-off for identifying overweight female children aged six to 24 months (n=130) was determined at 16.5 cm (AUC=0.938). This cut-off value had a sensitivity of 100% and specificity of 76.7% (J=0.767). The optimum MUAC cut-off value for identifying obesity was 17.0 cm (J=0.758). This novel application of MUAC resulted in new cut-off values for identifying overweight and obesity among South African children.

The final study aimed to validate the new cut-off values for under and overnutrition. A validation dataset of 247 infants and young children from the Eastern Cape, South Africa. It was found that the new MUAC values performed well for identifying acute malnutrition (100% sensitivity, 99.1% specificity, PPV=0.25, NPV=1.0) and obesity (90.1% sensitivity, 80.1% specificity, PPV=0.235, NPV=0.992) but performed poorly in identifying overweight (11.1% sensitivity, 86.8% specificity, PPV=0.111, NPV=0.868).

In summary, these studies, which have been published in peer-reviewed scientific journals, have provided information on the context of childhood malnutrition in South Africa. It was found that birth weight and maternal nutritional status were important indicators in determining anthropometric status among South African children. This research has also led to the development of a novel MUAC screening tool which can identify the full spectrum of anthropometric malnutrition in these children.

ACKNOWLEDGEMENTS

I would like to thank Dr Dee Bhakta, who supervised me for this dissertation. Dee has been tremendously supportive throughout this process. Dee has enhanced the quality of this work. Her careful attention to detail has been valuable in creating this dissertation, adding insight and value to the work it contains. Her advice has gone beyond producing this dissertation, as she has taken an interest in my development as an academic and researcher. I look forward to many future projects with Dee, and continued learning from her example.

I would like to extend my gratitude to Emeritus Professor David McCarthy, who has acted as my research mentor over the past few years, supporting and encouraging my research ambitions. David has been directly involved in producing the research that constitutes this portfolio. He has been influential in developing my research skills. He has gone beyond expectations and continued to support me in my research even after his retirement from academia.

I would like to thank Dr Liana Steenkamp, who has been a collaborator for over five years. Dr Steenkamp has been influential in my development as a scientist, and I owe a great debt of gratitude to her.

I would also like to thank Sarah Illingworth, for her help and support in reaching this stage in my academic career. Sarah has opened the institutional doors that have made this work possible.

I would like to extend my thanks to Dr Elizabeth Opara, and to London Metropolitan University, for their support in producing this dissertation, and for granting the time and staff fee waiver that has made this work possible. I would like to thank Professor Ken White and Dr Una Fairbrother for their support. The small grants provided by London Metropolitan University made open access publication possible.

Thank you to my partner Georgina Wileman, who has encouraged me throughout this project.

Thank you to my parents Bruce and Lorian McLaren, who have always supported me and my educational aspirations.

Thank you to all of my co-authors: Alexandra Rutishauser-Perera, Dr Danie Venter, Joyce Nyarko, Dr Alison Feeley; who improved the quality of the work with their insightful contributions and extensive field experience.

Finally, I would like to thank the anonymous peer-reviewers and editorial staff at the journals where this work was originally published. The contributions from the peer-reviewers has strengthened the work and improved its scientific rigour.

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ABBREVIATIONS

AIDS	Acquired Immunodeficiency Syndrome
AUC	Area under the curve
BMI	Body mass index
BMIFA	Body mass index for age Z-score
CCHIP	Community Childhood Hunger Identification Project
CI	Confidence interval
CP	Cerebral palsy
DHS	Demographic and Health Survey
FAS	Foetal alcohol syndrome
GMP	Growth monitoring and promotion
HAZ	Height-for-age Z-score
HHFIS	Household food insecurity
HIV	Human immunodeficiency virus
HR	Hazard ratio
INP	Integrated nutrition programme
LBW	Low birth weight
MAM	Moderate acute malnutrition
MDGs	Millennium Development Goals
MUAC	Mid-upper arm circumference
NCHS	National Centre for Health Statistics
NFCS	National Food Consumption Survey
NMBHD	Nelson Mandela Bay Health District
NMMM	Nelson Mandela Metropolitan Municipality

OR	Odds ratio
ROC	Receiver's operating characteristic
RR	Relative risk
RtHB	Road to health booklet
RUSF	Ready to use supplementary food
RUTF	Ready to use therapeutic food
RVD	Retroviral disease
SAM	Severe Acute Malnutrition
SANHANES-1	South African National Health and Nutrition Examination Survey
SD	Standard deviation
T2DM	Type 2 diabetes mellitus
TB	Tuberculosis
UNAIDS	The Joint United Nations Programme on HIV/AIDS
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
VAD	Vitamin A deficiency
WAZ	Weight-for-age Z-score
WFH	Weight-for-height
WFL	Weight-for-length
WHO	World Health Organisation
WHZ	Weight-for-height Z-score

DEFINITIONS

Height for age: An indicator of nutritional status based on an index involving a child's height and age. It is used to classify a child as stunted, severely stunted or growing normally. Height for age (HFA) is usually expressed in terms of the nearest Z-score standard deviation from the WHO standard for children younger than five years of age. Children older than five years of age are assessed using the CDC growth reference.

Mid-upper arm circumference: Mid-upper arm circumference (MUAC) is a measure of nutritional status. It involves measuring the circumference of the arm between the shoulder and elbow, and comparing the measurement obtained to a known norm for age and sex. MUAC is usually expressed in centimetres (cm) to the nearest 0.1cm and can be termed absolute MUAC.

MUAC for age: MUAC for age (MAZ) is an index-based indicator of nutritional status. MAZ is directly age related, based on the expected MUAC for a given age compared with the WHO standard. It differs from absolute MUAC in that it is expressed in terms of standard deviations instead of centimetres.

Stunting: Condition of nutritional deficiency where a child has not met his or her linear growth potential. Moderate stunting is defined as a height for age Z-score (HFAZ) plotted below the -2 standard deviation (SD) line from the WHO reference, while severe stunting is defined as a HFAZ of less than -3 SD from the WHO reference (WHO and UNICEF, 2009). Stunting is sometimes also referred to as chronic malnutrition.

Underweight: Underweight for age is defined as a low weight for age, diagnosed using the growth chart. A weight for age Z-score (WFAZ) plotted below -2 SD from the WHO reference is classified as underweight for age, while a WFAZ plotted below the -3 SD line from the reference is classified as severely underweight for age (WHO and UNICEF, 2009).

Weight for age: An indicator of nutritional status based on an index involving a child's weight and age. It is used to classify a child as underweight for age, severely underweight for age or growing normally. Weight for age (WAZ) is usually expressed in terms of the nearest Z-score standard deviation from the WHO standard.

Weight for height: An index based on a child's weight and height used to determine whether the child is wasted or has an appropriate level of nutritional reserves. It is alternatively known as weight for length. Weight for height (WHZ) is usually expressed in terms of the nearest Z-score standard deviation from the WHO standard.

Wasting: Moderate wasting is classified as a weight for height Z-score (WFHZ) plotted below -2 SD of the WHO reference. Moderate wasting is also referred to as moderate acute malnutrition (MAM). Severe wasting, or severe acute malnutrition (SAM) is defined as a WFHZ plotted below -3 SD line on the WFHZ chart (WHO and UNICEF, 2009).

Coloured: People of a mixed European, Khoi, San, black African and Asian ancestry descended from intermarriage between these groups during the 17th century, when Indian, Malay, and black African people were brought into the Cape colony as slaves. These people adopted European cultural customs but were later subjected to discriminatory Apartheid laws based on race during the second half of the 20th century.

amaXhosa: People from the Xhosa kingdom. Descended from the Nguni tribes of the Great Lakes in central Africa, the Xhosa kingdom was established in the Eastern Cape of South Africa by King Tshawe in the 15th century.

isiXhosa: The language spoken by amaXhosa people.

Bantustan homelands: Term derived from "Bantu", meaning "people" in many Nguni languages, the Bantustan homelands were reserves designated for non-whites by the apartheid government in South Africa during the second half of the 20th century. The South African government attempted to legitimise the homelands as independent states with their own representative governments, however these states were not recognised by the international community. The homelands were re-incorporated into South Africa in 1994.

Official unemployment rate: The number of people who are unemployed at the time of measurement.

Expanded unemployment rate: The number of people who are unemployed and not looking for work, includes "discouraged work seekers" and those who are not economically active.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The United Nations has begun implementing the Global Action Plan (GAP) framework for child wasting. It has identified actions and outcomes which are necessary to meet Sustainable Development Goals related to eliminating hunger by 2030 (WHO 2020). Among these priorities are the need to improve early detection and treatment for children who are wasted or at risk of wasting. In addition, a reduction in the incidence of low birth weight, improved child health, improved infant and young child feeding and improvements in treatment for wasting are necessary (WHO 2020).

South Africa is a middle-income country in sub-Saharan Africa. Despite being a middle-income country, it suffers from widespread inequality, with the most recent Gini coefficient measured at 63.4 (The World Bank 2017). In contrast, the Gini coefficient for the United Kingdom (UK) is 35.1. A Gini coefficient of 0 represents perfect equality, where all members of the population earn and consume the same amount, whereas a Gini coefficient of 100 represents perfect inequality, where a single member of a population earns and consumes all resources. Inequality is a major impediment to economic growth (Mo 2000). Inequality results in poverty and associated malnutrition, which is particularly detrimental to the development of children. Economic losses from malnutrition began receding from North America and Europe by the 1930s, and from South America at the beginning of the 21st century. Projections of economic losses resulting from malnutrition predict a reduction in losses in Asia from 2020, however, models predict little change in the African region until at least 2050 (Horta and Steckel 2013). South Africa is the second largest economy in sub-Saharan Africa after Nigeria (World Bank 2020). Being a middle-income country with such widespread inequality, South Africa presents a unique aetiological setting for childhood malnutrition.

1.2 Problem setting

South Africa is divided into nine provinces. The main industries include mining, transport, and tourism (South African Government 2022). South Africa has a total population of 60 142 978 people (Statistics South Africa 2021a).

Approximately 80.9% (n=48 640 329) of the population is of a black African ethnicity (Table 1.1) (Statistics South Africa 2021a). There were 39.7 million people of working age (15-65 years) in South Africa in 2021 (Statistics South African 2021b). However, the unemployment rate is estimated to be 34.9% (Statistics South African 2021b). Mean life expectancy at birth is 59.3 years for males and 64.6 years for females (Statistics South Africa 2021a).

Table 1.1: South African demographics by ethnicity and sex (adapted from Statistics South Africa 2021a).

Population group	Male		Female		Total	
	Number	% distribution of males	Number	% distribution of females	Number	% distribution of total
Black African	23 761 051	80.9	24 879 278	80.9	48 640 329	80.9
Coloured*	2 578 930	8.8	2 716 038	8.8	5 294 968	8.8
Indian/Asian	790 412	2.7	754 810	2.5	1 545 222	2.6
White	2 257 654	7.7	2 404 805	7.8	4 662 459	7.8
Total	29 388 047	100	30 754 831	100	60 142 978	100

*see definitions

The Eastern Cape is a province on the south east coast of the country. There were an estimated 6.76 million people living in the Eastern Cape in 2021 (Statistics South Africa 2021a). This province has the second highest proportion of children younger than 15 years of age at 32.6%, and the highest proportion of elderly people older than 60 years at 11.5% (Statistics South African 2021a). This may be due to a large migrant adult workforce leaving the province. The unemployment rate in the Eastern Cape was 47.4% in 2021 (Table 1.2), compared with 26.3% in the Western Cape and 37.0% in Gauteng (Statistics South Africa 2021b). Estimates suggest that while 192 839 people moved into the Eastern Cape between 2016 and 2021, 512 506 left the province, largely for the Western Cape (176 181), and Gauteng Province (147 216) (Statistics South African 2021b). While this outflow is lower than the rate recorded between 2011 to 2016 which was 325 633, it is likely that this is the result of COVID-19 lockdowns which took place from March 2020 (Statistics South Africa 2021a).

Table 1.2: Employment in South Africa by province (adapted from Statistics South Africa 2021b).

	Official unemployment rate					**Expanded unemployment rate**				
	July-Sep 2020	April-June 2021	July-Sep 2021	Quarter to quarter change	Year on year change	July-Sep 2020	April-June 2021	July-Sep 2021	Quarter to quarter change	Year on year change
	Percent (%)			Percentage points		Percent (%)			Percentage points	
South Africa	30.8	34.4	34.9	0.5	4.1	43.1	44.4	46.6	2.2	3.5
Western Cape	21.6	25.8	26.3	0.5	4.7	29.1	29.1	30.3	1.2	1.2
Eastern Cape	45.8	47.1	47.4	0.3	1..6	51.2	53.0	54.5	1.5	3.3
Northern Cape	23.1	28.1	24.9	-3.2	1.8	44.0	50.3	49.1	-1.2	5.1
Free State	35.5	36.5	38.1	1.6	2.6	42.6	45.2	45.8	0.6	3.2
KwaZulu-Natal	26.4	32.5	28.7	-3.8	2.3	47.5	47.1	48.6	1.5	1.1
North West	28.3	35.2	35.7	0.5	7.4	46.5	46.9	52.2	5.3	5.7
Gauteng	33.7	35.4	37.0	1.6	3.3	41.0	42.7	44.9	2.2	3.9
Mpumalanga	27.8	35.2	37.5	2.3	9.7	45.6	46.5	49.7	3.2	4.1
Limpopo	26.3	30.2	32.5	2.1	6.2	46.9	49.9	54.5	4.6	7.6

Large parts of the Eastern Cape were assigned as "Bantustan homelands" (figure 1.1) under the apartheid regime. Land to the east and west of the Kei River had been named the Transkei and Ciskei during the frontier wars fought between the British and amaXhosa in the 1770's. In 1962, the apartheid National Party government designated the Transkei and Ciskei as independent republics, intended for settlement by displaced amaXhosa people, but these "countries" were not recognised as sovereign states by the international community. These areas were placed under the tenure of traditional leaders, responsible for rural land administration (Winkler 2021). The South African state continues to hold this land in trust, under the custody of the traditional leaders. However, the traditional leaders' powers for administering the land are limited, resulting in problems in developing infrastructure and economic development. Municipal services and economic opportunities continue to be under-developed in the rural Eastern Cape (Winkler 2021).

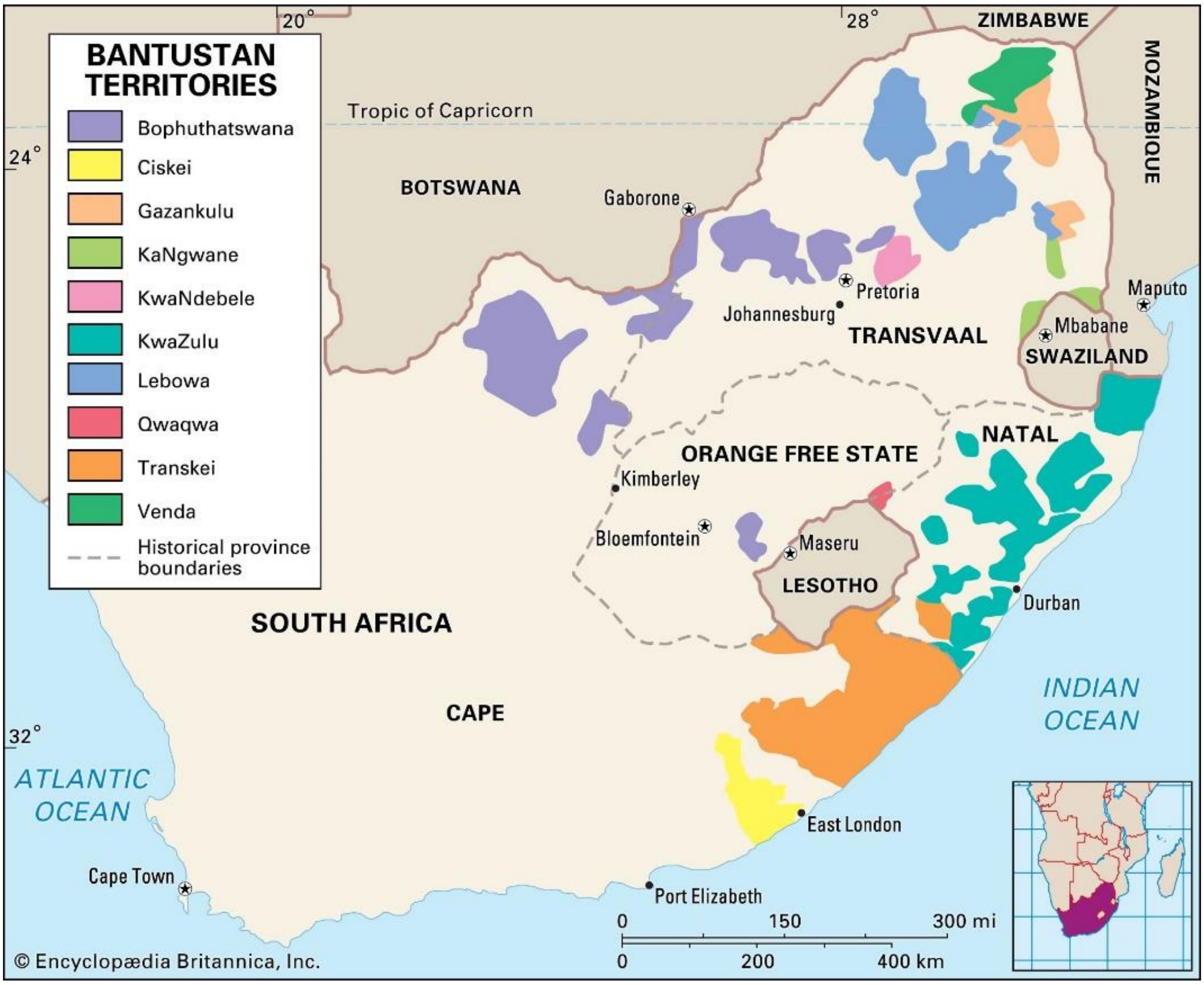


Figure 1.1: Map of the former Bantustan homelands in South Africa (https://www.britannica.com/place/Transkei).

Informal settlements have developed on the outskirts of towns and cities across South Africa. It has been suggested that population growth, government economic policies, economic variables, housing shortages and unavailability of land are drivers of the growth of informal settlements in South Africa (Marutlulle 2017). Under the Policy of Orderly Urbanisation which was introduced by the apartheid government in the mid-1980s, shack dwellers in informal settlements were relocated to designated land where later development of housing and services would be implemented (Huchzermeyer 2004). Motherwell, a peri-urban settlement on the outskirts of

Gqerberha is an example of the results of this policy. The settlement was developed during the 1980s after informal residents were evicted from Zwide in Port Elizabeth (renamed Gqeberha in 2021).

South Africa is considered a middle-income country (World Bank 2020) and is food secure (Du Toit et al 2011). Still, the problem of childhood malnutrition persists alongside inequality and deprivation. Approximately 22% of South African children were stunted in 2020 (UNICEF, World Health Organisation, World Bank Group 2021). Simultaneously, the country faces an increase in the rate of childhood obesity (World Obesity Federation 2020). The prevalence of severe acute malnutrition is approximately 1.3% of children younger than five years (UNICEF, World Health Organisation, World Bank Group 2021).

1.3 The nutritional double burden of malnutrition

The double burden of malnutrition refers to “the phenomenon of undernutrition, wasting, stunting, micronutrient deficiency coinciding with overweight, obesity, and diet-related non-communicable diseases, within individuals, households and populations throughout the lifecycle” (WHO, 2017). It is estimated that 55% of the world population lives in urban environments, with as many as 50% of people in low- and middle-income countries living in urban settings (World Bank, 2017). Urbanisation and economic growth can result in improvements in the nutritional status of populations, but it can also be a significant factor in worsening nutritional status. The latter is particularly relevant for countries and regions in advanced stages of the nutrition transition (Popkin and Gordon-Larson 2004).

In urban environments where infrastructure, water and sanitation are inadequate, people are at a higher risk of contracting water-borne diseases, which result in malnutrition. Infectious diseases which result from poor hygiene and sanitation and poor water quality, are among significant contributors to anaemia. Micronutrient deficiency is one of the hallmark features of the double-burden of malnutrition.

Rapid urbanisation is among the changes occurring in South Africa which are causing a rapid increase in overweight and obesity (Kagura *et al.,* 2018). Achieving optimal nutrition, through nutritionally balanced diets is constrained by accessibility and availability in South Africa (Govender *et al.,* 2018). Among South Africa’s poor communities, balanced diets may not be affordable (Govender *et al.,* 2018). While accessibility and availability of more nutrient-dense diets and higher dietary diversity may be improved through household and community gardens in rural parts of the country (Govender *et al*., 2018), there are limitations to this approach in urban environments. Food security and dietary diversity are significantly higher in urban locations than peri-urban and rural ones (Chakona and Shackleton 2017). However, peri-urban settlements are at the highest risk of food insecurity resulting from higher levels of unemployment and poverty in combination with a lack of access to land (Chakona and Shackleton 2017). High sugar and high fat foods are however, readily available to South Africans (Igumbor *et al*., 2012), particularly through supermarkets (Igumbor *et al*., 2012, Battersby 2017). Carbonated beverages are the third most commonly consumed food item after maize meal and tea among young South Africans, potentially displacing other more nutrient dense foods from the diet (Igumbor *et al*., 2012). Low levels of physical activity are another cause of disturbance in energy balance which results in overweight and obesity. Joubert *et al*., (2021) found that 40% of South African children do not meet global physical activity recommendations. The combination of overweight and obesity and failure to meet physical activity levels in this sample was significantly associated with hypertension (Joubert *et al*., 2021).

South African dietary patterns have changed over the past few decades. Goedecke, Jennings and Lambert (2005) reported that carbohydrate consumption among South African adults living in urban areas decreased by 10.9% between 1940 and 1990, while fat intake increased by 59.7%. In comparison, fat intake among South African adults in rural areas increased by only 8%, while carbohydrate intake decreased by 10% between 1970 and 1990 (Goedecke, Jennings and Lambert, 2005).

1.4 Causes of malnutrition

The UNICEF conceptual framework on malnutrition (Figure 1.2), developed in 1990, outlines the complex drivers of childhood malnutrition. It identifies the relationship between disease and inadequate diet as the immediate causes of malnutrition and death. The conceptual framework outlines basic and underlying causes of malnutrition which are responsible for the immediate causes. Basic causes of malnutrition are related to the distribution of resources and social and political structures. Underlying causes include poor access to health services, unhealthy environments and inadequate care for mothers and children.

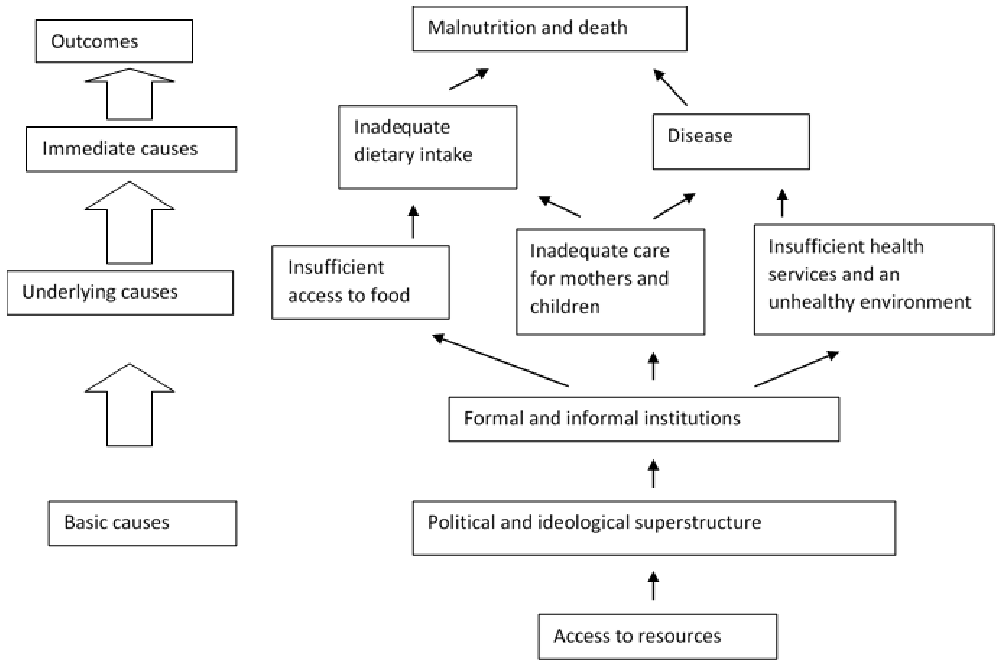


Figure 1.2: Interventions in the context of the UNICEF Conceptual Framework on the Causes of Malnutrition (adapted from UNICEF 1990).

1.4.1 Food affordability

The benchmark healthy and sustainable diet (Willet *et al*., 2019) is unaffordable for at least 1.5 billion people across the globe (Hirvonen *et al*., 2020). South Africa is considered an upper-middle income country, where gross national (GNI) is between US$4046 and US$12535 (World Bank 2021). According to Hirvonen *et al*., (2020), 24.5% of mean income is required to purchase the EAT-Lancet reference diet, contributing 2500 kcal per day (Willet *et al*., 2019), in upper-middle income countries. The EAT-Lancet diet represents the minimum acceptable diet derived from sustainable sources. This contrasts with 52.4% of mean income in lower-middle income countries (Hirvonen *et al*., 2020) such as Ethiopia and India, where GNI is between US$1036 and US$4045. Meeting the EAT-Lancet reference diet costs 26-42.8% of daily household income for South Africans, which also contrasts to the median for sub-Sarahan Africa, which is the highest in the world at 72.7% (Hirvonen *et al*., 2020). The higher affordability of an adequate diet in South Africa may help to explain the relatively low rates of stunting and wasting in this country compared with the rest of its region. In an analysis comparing countries in sub-Saharan Africa, it was found that food costs contributed 58-65% of total household expenditure for people in

Ethiopia, Mozambique, Tanzania, Uganda, and Zambia, compared with just 30% in South Africa (Ryckman *et al*., 2021).

1.4.2 Food security in South Africa

South Africa is "food self-sufficient or nearly self-sufficient in almost all the major food products, with the ability to import shortages when necessary" according to the Department of Agriculture, Forestry and Fisheries data, South Africa (Du Toit, Ramonyai, Lubbe and Ntushelo, 2011). However, according to findings from Statistics South Africa, while South Africa is food secure on a national level, there is a high level of household food insecurity (Statistics South Africa 2019). Approximately 20% of South Africans experience inadequate or severely inadequate access to food. There were 1.6 million households experiencing hunger in 2017, with a higher rate of hunger in urban communities, and female headed households were at a higher risk (Statistics South Africa 2019). Among these, more than 500 000 households with children younger than five years of age experienced hunger (Statistics South Africa 2019).

Household food security is supplemented by subsistence agriculture in South Africa, where approximately 16% of households practice agricultural activities (Statistics South Africa 2019). Social grants are the main source of income for these households (Statistics South Africa 2019). These findings were like those observed by Dunga (2020), who found that among female headed households, income, age, agricultural activities, household size and population group contribute to food security. Food security was poorer among households with a lower income, but higher among those who participate in agriculture (Dunga 2020). Household incomes, and therefore food security, have been disrupted by the COVID-19 pandemic. Arndt *et al*., (2020) assert that food security among households with lower education levels who are more dependent on labour for income will be more severely affected by disruptions to work and earning, however, low-income households will be less severely affected as they are insulated by government transfer schemes. Research by Dunga (2020) suggests that receiving social grants is not a significant determinant for food security. However, other forms of government support have been found to have an impact on food security, including receiving infrastructural support such as irrigation systems, and participation in schemes such as the "one home one garden" programme which distributes seeds and fertiliser to communities (Ngema *et al*., 2018). Education was found to have a positive influence on food security (Ngema *et al*., 2018). As household income and access to credit increase, food security decreases among South Africans (Ngema *et al*., 2018). Therefore, income transfers may not provide enough protection against household food insecurity among hungry households in South Africa, but other social issues such as education and subsistence agriculture should be supported to improve food security among the most vulnerable.

1.4.3 Climate change and food security in South Africa

Climate change is predicted to impact nutritional status of populations across the world. It is anticipated that global temperatures will rise by 0.2°C every decade as a result of greenhouse gas emissions (Hansen *et al*., 2006). Higher temperatures will interfere with crop production. It has been demonstrated that higher night temperatures and divergence from normal seasonal temperatures interferes with plant respiration, resulting in smaller yields from otherwise healthy plants (Rasul *et al*., 2011). As a result, global consumption of vegetables and fruit, as well as red meat is predicted to decrease (Springman *et al*., 2016). Rising global temperatures are also predicted to affect global weather patterns, including El Nino events. The El Nino effect is a cyclical rise in ocean temperatures in the equatorial Pacific, which forms part of the larger El Nino Southern Oscillation phenomenon. El Nino events can have dramatic effects on weather conditions across the world, causing flooding in some regions and droughts in others. Warm sea surface temperatures in the equatorial Pacific are associated with dry seasons in Ethiopia and a slower Indian monsoon system (Gleixner *et al.,* 2016). Strong El Nino effects took place in 1983 and 1998. It is thought that increased global temperatures and raised temperatures in the eastern Pacific Ocean in particular, will result in more extreme El Nino effects in coming years (Hansen *et al*., 2006). South Africa is already prone to drought (Baudoin *et al*., 2017). Previous severe droughts in the 1990s resulted in significant reductions in agricultural yields and losses of agricultural jobs, as well as depleted groundwater reserves, resulting in people relying on unimproved water sources (Baudoin *et al*., 2017). Water security is an important dimension of food security. As urban populations grow, challenges in maintaining safe and adequate water supplies increase. The anticipated impacts of climate change are now included in guidelines for planning drinking water supplies. The Stockholm Framework incorporates risk assessment into planning water use (WHO 2017).

Evidence is beginning to emerge that weather events including seasonality, rainfall, temperature are associated with child stunting. This association is mediated by socio-economic, demographic and agricultural factors suggesting that segments of the population are at a higher risk of malnutrition resulting from climate change (Phalkey *et al*., 2016).

1.4.4 Inadequate dietary intake and disease

Disease-malnutrition-poverty cycle (figure 1.3) describes the inter-generational nature of the relationship between these three factors. A consequence of malnutrition during childhood is impaired development and immune system function, predisposing individuals to disease and reduced productivity, inhibiting people from meeting their full potential and perpetuating the cycle of poor education, poverty and malnutrition (Schaible and Kaufmann 2007).

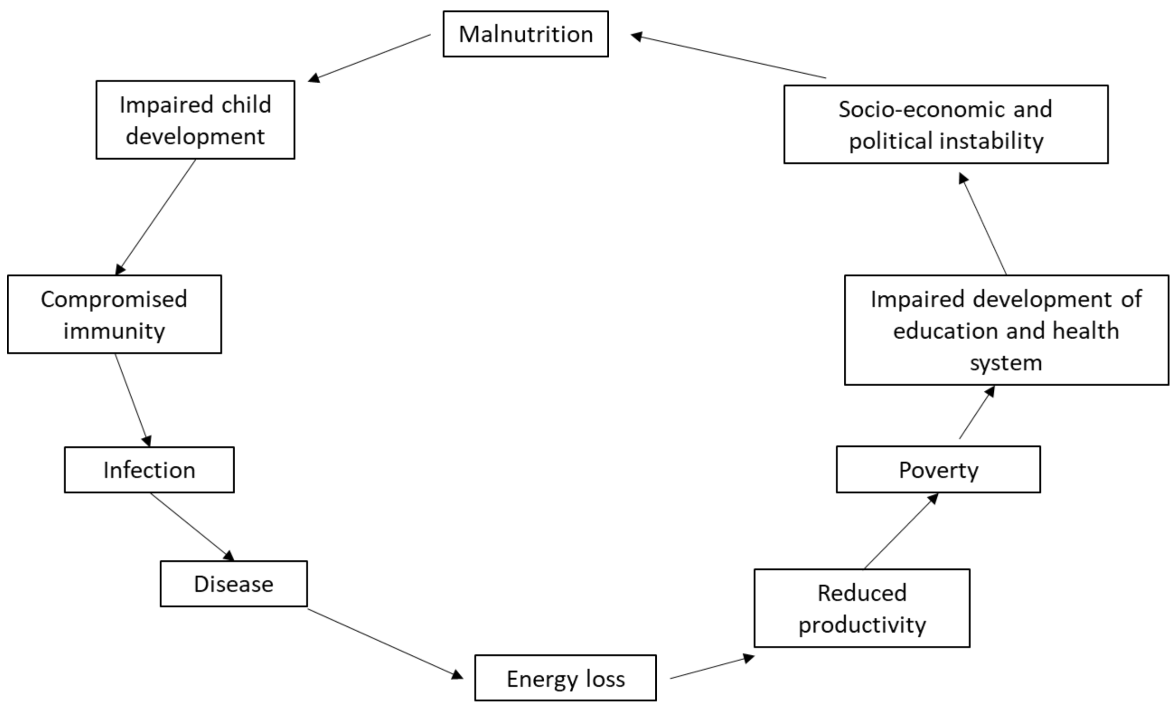


Figure 1.3: Cycle of poor education, poverty and malnutrition (adapted from Schaible and Kaufmann 2007).

1.4.5 Insufficient health services and an unhealthy environment

Access to health services and a healthy environment are underlying determinants of malnutrition. Only 45% of the global population has access to a safely managed sanitation service, with 2 billion people living without basic sanitation facilities (WHO 2021). This lack of basic services predisposes people to enteric infections and diarrhoea, a risk factor for malabsorption and malnutrition. Communities without adequate sanitation are more likely to be exposed to harmful pathogens in water, soil, and in peri-urban communities, make use of untreated wastewater for irrigation (WHO 2021). Sustained exposure to enteric pathogens and poor water, sanitation and hygiene conditions are damaging to child growth and development (Cumming and Cairncross 2016). According to Dearden *et al*., (2017), access to improved sanitation is potentially more important for preventing stunting among children than access to improved water. Approximately three quarters of the South African population have access to at least basic sanitation (WHO 2021).

Evidence from Nepal suggests that improved access to health services, particularly during pregnancy, is associated with an improvement in anthropometric indicators of nutritional status among children (Cunningham *et al*., 2017). Even knowledge about access to community health care among mothers has been shown to positively affect childhood anthropometry, but this effect is moderated by actual access to health services (Agee 2010). Proximity to health services is a barrier to access in many communities in low- and middle-income countries, particularly in sub-Saharan Africa where many people live in rural areas (Headey *et al*., 2018).

It is estimated that approximately 75.5% of pregnant women in South Africa attend at least four antenatal visits (WHO 2021). Evidence suggests that antenatal care (ANC) attendance is good in both urban and rural areas in South Africa, but that early attendance at ANC services (before 20 weeks gestation) is poorer among rural communities (Wabiri *et al*., 2013). In the urban Tshwane community, there is good utilisation and access to community health care centres (Nteta *et al*., 2010), related to access to public transport such as taxis. However, users of the Integrated Nutrition Programme in South Africa display high dropout rates from the programme, which is designed to treat and manage malnutrition among children (Brits *et al*., 2017). Only 1% of participants in the programme complete the six-month supplemental feeding programme, with two thirds of participants only attend the initial visit. Reasons for high dropout rates from the programme include long waiting times at clinics, long distances to travel to clinics, stigmatisation, and supplemental foods being unavailable at primary health centres when participants attend (Brits *et al*., 2017).

In many of the studies investigating the relationship between access to health services and child nutrition status, differences in child growth outcomes are diminished when maternal education and wealth are controlled for (Agee 2010). Among South Africans, there are differences in maternal health across population groups which were related to quality of care, HIV infection and social determinants of health (Wabiri *et al*., 2013).

1.5 Interventions

1.5.1 Nutrition sensitive and nutrition specific interventions

Nutrition interventions may either aim to address direct causes of malnutrition or malnutrition directly; or aim to address the underlying causes of malnutrition. Interventions which are aimed at treating malnutrition directly are termed nutrition-specific interventions, while those targeting the underlying causes of malnutrition are known as nutrition-sensitive interventions. Direct causes of malnutrition are inadequate dietary intake and disease, as per the UNICEF conceptual framework for malnutrition. Underlying causes of malnutrition include insufficient access to food, inadequate care for mothers and children and an unhealthy environment. Nutrition-specific interventions are carried out by nutrition and medical services, whereas nutrition-sensitive interventions may involve a much broader range of sectors, including water and sanitation, education, agriculture, and economics (Ruel and Alderman 2013). Sectors which may be involved in nutrition-sensitive interventions include women's empowerment, agriculture, food systems, education, employment, and social safety nets (Bhutta *et al*., 2013). Nutrition sensitive interventions aim to address problems with food security, caregiving resources and hygienic environments (Ruel and Alderman 2013).

1.5.2 Integrated Management of Childhood Illness and the Integrated Nutrition Programme

Strategies for addressing childhood malnutrition from a health and medical perspective have been embedded within Integrated Management of Childhood Illness (IMCI) and the integrated nutrition programme (INP) in South Africa. IMCI was developed by UNICEF in the mid-1990s and has been adopted by 102 countries worldwide. It aims to deliver primary healthcare services to children younger than five years of age. IMCI incorporates both prevention and treatment of childhood illness, and interventions include vaccinations, provision of vitamin A and deworming chemotherapy as measures to prevent childhood illness and malnutrition. Under IMCI, specific diagnosis of disease is less important than severity of illness, based on the recognition that children in LMICs will present with symptoms of multiple pathologies, and severity of illness is a more important predictor of mortality risk. Therefore, children seen in primary healthcare facilities are assessed for IMCI danger signs including vomiting, convulsions and loss of consciousness, and referred for appropriate care at secondary facilities as required. Nutrition assessment of infant and young child feeding is also part of the IMCI assessment, where questions need to be asked on whether the child is breastfeeding, how often, and whether the child is breastfed at night, as well as whether the child is receiving any other foods or fluids.

The Integrated Nutrition Programme was introduced in South Africa in 1994. The programme was designed to replace previous programmes which were fragmented and not equitably distributed to all population groups in South Africa during the Apartheid regime (Iversen *et al*., 2012). The Protein Energy Malnutrition scheme from pre-1994 provided supplementary foods to malnourished children, pregnant and lactating women. This scheme was later revised and renamed the Nutrition Supplementation Programme (NSP) and incorporated into the Health Facility Based Nutrition Programme as part of the INP (Iversen *et al*., 2012). Evidence suggests that there is poor monitoring and implementation of the programme, with high rates of patient incompliance and dropout (Brits *et al*., 2017). However, among children who do attend more than one appointment, approximately 50% will recover from severe malnutrition or meet their target weight, indicating that the programme can be an effective community-based management of childhood malnutrition strategy (Brits *et al.,* 2017).

Another arm of the INP is the Primary School Nutrition Programme (PSNP). This programme aimed to address short-term hunger and improve school performance among learners (Iversen *et al*., 2012).

These strategies for intervening in the direct causes of malnutrition are necessary, but other strategies will be required to meet the Sustainable Development Goals by 2030. Prevention of malnutrition relies on many sectors, under nutrition-sensitive interventions. Among these interventions, water, sanitation and hygiene may play an important role in reducing the number of stunted and wasted children in South Africa, complementary to nutrition-specific interventions, as shown in figure 1.4.

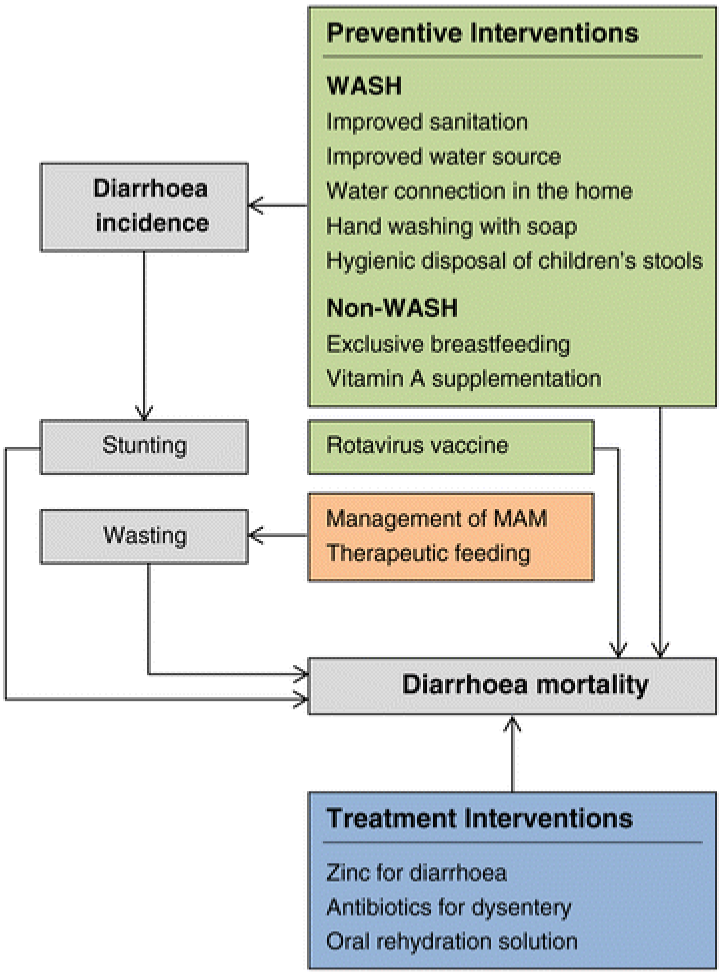


Figure 1.4: LiST interventions for reducing the risk of diarrhoea mortality (Walker and Walker 2014).

Chola *et al*., (2015) have shown that investing in WaSH strategies in South Africa can have a significant effect on mortality related to diarrhoea among children. Increasing coverage of WaSH interventions can result in a reduction in diarrhoea-related deaths from 5500 in 2014 to between 100 (99% coverage) and 2400 (increased coverage by 10%) deaths in 2030, with an investment of as little as $1 per capita (Chola *et al*., 2015).

The advantage of nutrition-sensitive interventions is that they are often able to address several overlapping causes of malnutrition simultaneously (Sclar *et al*., 2017). Improving sanitation in school and work environments addresses both exposure to harmful pathogens, and improvements in school and work attendance, thereby improving education and income simultaneously (Sclar *et al*., 2017). Careful targeting of these interventions has yielded positive results in the field. Nepal gained significant improvements in stunting prevalence when sanitation improvement schemes shifted from supplying home sanitation towards a greater emphasis on providing improved sanitation services to schools and other public infrastructure (Cunningham *et al*., 2017). The prevalence of stunting among infants and children younger than 24 months in Nepal decreased from 47.8% in 1996 to 27.0% in 2011 (Cunningham *et al*., 2017).

Investing in nutrition specific interventions is important in preventing maternal and childhood malnutrition and the positive impacts can be amplified by linking these interventions with nutrition-sensitive interventions (Bhutta *et al*., 2013).

1.5.3 Primary care and prevention

The WHO definition refers to health as "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity" (WHO 1948). Huber *et al*., (2011) have suggested that this definition should be adapted to include recognition that not all people will be healthy under this definition, but can be healthy within their own social, physical and emotional context. While prevention of nutritional disorders and malnutrition and the associated developmental delays has been emphasised in the literature, researchers have also begun to suggest that the focus should shift from basic child survival towards thriving (Black *et al*., 2020). Therefore, Black *et al*., (2020) have developed a conceptual framework focused on children surviving and thriving (figure 1.5), which identifies enabling environments as well as proximal components including safe and nutritious food, health care and learning opportunities as important parts of improving child survival, as well as ensuring that children grow and develop to meet their full potential (Black *et al*., 2020).

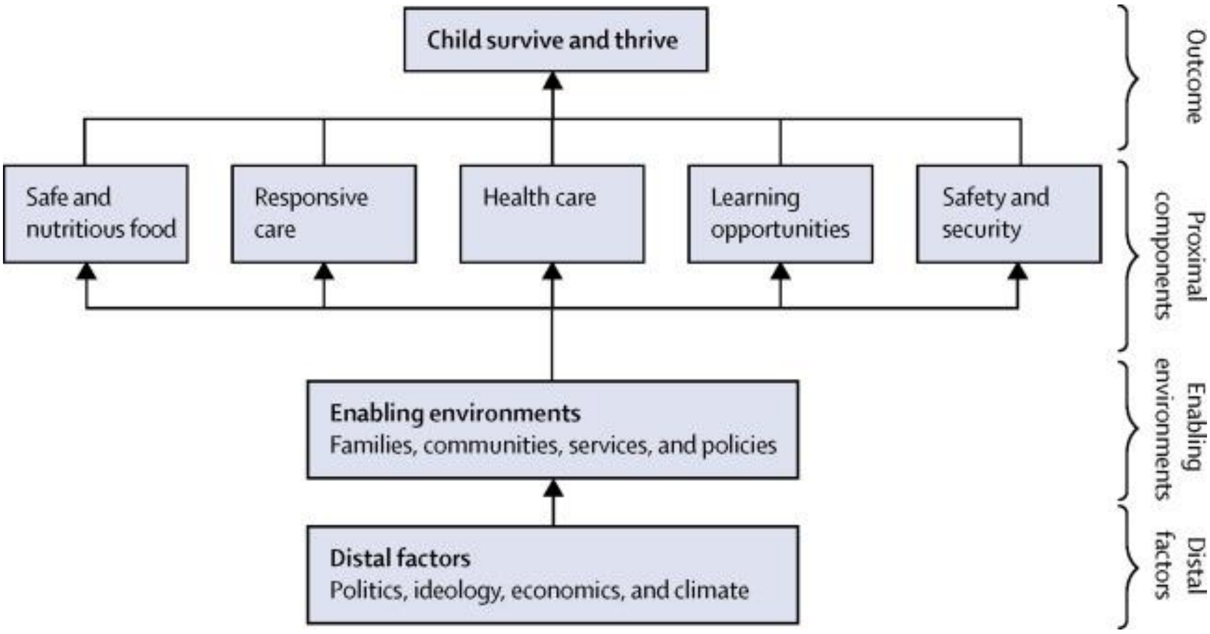


Figure 1.5: Conceptual framework of children surviving and thriving (Black et al., 2020).

1.6 Childhood malnutrition

During the 20th century, acute malnutrition was thought to present in three distinct forms- kwashiorkor, marasmus and marasmic kwashiorkor. Kwashiorkor was attributed to deficiency of protein and presented with oedema while marasmus was attributed to deficiency in energy intake. These two forms were known together as protein energy malnutrition. However, it was found that the diets of children with either marasmus or kwashiorkor did not differ significantly, and that clinical treatment based on protein or energy respectively were not improving clinical outcomes. The term severe acute malnutrition has now replaced these terms (Lenters *et al*., 2016).

Initially the index weight-for-age (WFA) was introduced to quantify growth retardation and had important consequences for health and policy planning (Gopolan and Rao 1984). Subsequently, Waterlow introduced the terms “wasting” and “stunting” to assist in differentiating types of growth retardation (Gopolan and Rao 1984). These terms have been adopted by the World Health Organisation.

There are three forms of childhood undernutrition which are commonly used as global health indicators. Stunting refers to a deficit in linear growth and has traditionally been attributed to chronic undernutrition in children (WHO 2006). Wasting refers to children who are too thin for their attained height and is also known as acute malnutrition (WHO

2006). Underweight refers to a lower-than-expected weight for age (WHO 2006). The spectrum of malnutrition also includes overnutrition, of which overweight and obesity are the most tracked indicators.

Stunting, wasting and underweight can occur simultaneously in individuals (Garenne *et al*., 2018). The concurrence of wasting and stunting is associated with an increased mortality risk and tends to present in younger children (Khara *et al*., 2017). There is also evidence of an overlap between stunting and overweight (Fernald and Neufeld 2007). Therefore, the landscape of childhood malnutrition is complex.

Underweight, wasting and stunting are important markers of childhood malnutrition. WHO growth charts developed in 2006 which provide means for comparing the growth of children against a standard. Stunting is defined as a height-for-age Z-score (HAZ) more than two standard deviations below the median. Stunting is a severely compromised deficit in growth in stature. Wasting is a low weight for height and is defined as a weight-for-height Z-score (WHZ) more than two standard deviations below the median (WHO 2006). Underweight, or underweight-for-age is defined as a weight-for-age (WAZ) greater than two standard deviations below the median (WHO 2006). Underweight refers to a low weight attainment for age, which may be a result of a low height attainment (stunting), being too thin for attained height (wasting), or a combination of these. WAZ is not suitable to identify children as overweight or obese (WHO 2008). Overweight can be defined as a weight-for-height Z-score greater than two standard deviations above the median (WHO 2006). Body mass index is calculated using weight and height, from the equation BMI (kg/m^2) = $\frac{weight\ (kg)}{height\ (m)^2}$. Due to the dynamic growth of infants and children, body-mass-index-for-age (BMIFA) is used in this reference population. BMIFA greater than two standard deviations above the median according to World Obesity Forum standards (Cole and Lobstein 2012). The World Health Organisation recommendations on identifying malnourished children were updated in 2013 to include mid-upper arm circumference (MUAC) assessed using a measuring tape with a cut-off of less than 12.5 cm as an independent indicator of moderate wasting and MUAC cut-off of less than 11.5 cm as an indicator for severe wasting among infants and children aged 6-59 months (WHO 2013).

Stunting is associated with increased risks of morbidity and mortality, as well as cognitive developmental delay, likely to impact the whole lifecycle (Black *et al*., 2013).

Overweight is associated with an increased risk of NCDs among South African adolescents (Pedro *et al*., 2014).

The incidence of acute malnutrition remains high across the world, while overweight and obesity incidence is increasing. New tools are required to address the double burden of disease, characterised by the nutrition transition, epidemiological transition and demographic transition. It is becoming apparent that there is a large area of overlap between under and overnutrition, and that the driving factors for these nutritional problems are common to both. Resources in communities, including screening equipment and personnel are also shared between patients who are under or over-nourished.

Since the introduction of the updated WHO guideline in 2013, there has been increasing interest in the use of MUAC for screening for acute malnutrition. This is because MUAC offers many practical advantages for use in the field due to its simplicity (Goosens *et al*., 2012). Although MUAC and WHZ reveal similar rates of acute malnutrition, research has demonstrated that these two indicators identify different groups of children as malnourished (Grellety and Golden 2016). In addition, there has been interest in using MUAC to identify overweight and obese children (Talma *et al*., 2019). However, no formal cut-off recommendations for identifying overweight and obesity have been published.

Current MUAC recommendations may be valuable in emergency settings where the immediate mortality risk is high. However, the applicability of the current MUAC cut-off values for identifying acute malnutrition may not be appropriate for non-emergency settings with a different level of mortality risk, due to better resourced health systems (Tessema *et al*., 2020, Laillou *et al*., 2014). Given the context of malnutrition in South Africa, identifying risk factors for childhood malnutrition relating to birth outcomes, food security, social welfare, access to health services and a clean, safe environment may assist in improving targeting nutrition interventions.

1.6.1 Prevalence and trends in malnutrition

There were 45.4 million children wasted, 149.2 million stunted and 38.9 million children with overweight under the age of five years globally in 2020 (UNICEF, World Health Organisation, World Bank Group 2021). The absolute number of stunted children has decreased from 203 million in 2000, to 149 million in 2020 (UNICEF, World Health

Organisation, World Bank Group 2021). However, this improvement in childhood malnutrition prevalence has not been uniformly spread across the world, and most stunted and wasted children reside in the African and Asian regions (UNICEF, World Health Organisation, World Bank Group 2021). It is likely that global targets for childhood malnutrition will be missed, with only a quarter of countries on track to meet the Sustainable Development Goals for stunting, wasting and overweight by 2030 (UNICEF, World Health Organisation, World Bank Group 2021).

1.6.2 Stunting

The global prevalence of stunting was 40% in 1990, with an estimated 257.7 million children stunted (WHO 2020). The global prevalence of stunting was 149.2 million children younger than five years in 2020 representing approximately 22% of the global population (UNICEF, World Health Organisation, World Bank Group 2021). While this figure remains high, it has been decreasing (Black *et al*., 2013; WHO, 2020). However, the reduction in stunting prevalence has not been consistent across the world. Latin and central America have halved the prevalence of stunting since 1990. There were 61.4 million stunted children in the African region, a prevalence of 30.7% of children younger than five years (WHO 2020). This is a reduction from 44.9% of children on 1990, but the absolute number of stunted children in this region has grown from 49.3 million children as the total population has grown (WHO 2020). The prevalence of stunting in southern Africa was 23.3% in 2020, a reduction from 31.8% in 1990, as presented in figure 1.6. There are 1.6 million stunted children in this region according to WHO (2020) estimates. This is lower than the current prevalence in Eastern Africa where the stunting prevalence is 32.6%, or 22.1 million children, and western Africa where the stunting prevalence is 30.9%, representing 20.2 million children (WHO 2020).

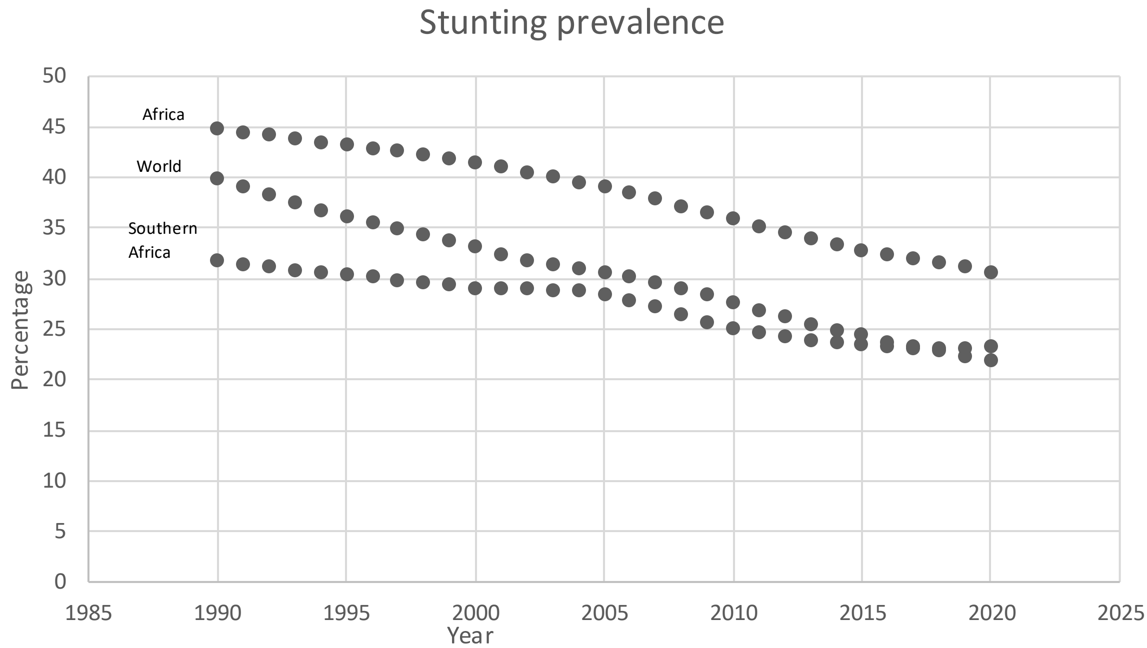


Figure 1.6: Under-5 stunting prevalence trends globally, in Africa and Southern Africa for 1990 to 2020 (WHO 2020).

Fink and Rockers (2014) have found that stunting during childhood is associated with diminished cognitive development and poorer schooling outcomes in later adolescence. Stunting has been associated with reduced human capital and intergenerational poverty (Prendergast and Humphrey, 2014). Stunting has been associated with an increased risk of mortality among children (McDonald *et al*., 2013).

1.6.2.1 Causes of stunting

Traditionally stunting was thought to be caused by macronutrient deficit, and later by micronutrient deficiency (Frongillo 1999). The role of infant feeding, and the differences in growth between breastfed and formula feeding was also thought to play a role in stunting risk (Frongillo 1999). This is partly because stunting appears most frequently in the first three years of life (Frongillo 1999). The relationship between infection and nutritional status was thought to play a role in the development of stunting (Frongillo 1999).

The view that stunting is a result of chronic undernutrition has been challenged by Raiten and Bremer (2020). Stunting has generally been considered to result from inadequate or low-quality diets, food insecurity and poor infant feeding practices

(Raiten and Bremer 2020). However, other social and biological risk factors for stunting have been identified, including intrauterine growth retardation, poor nutritional status among pregnant and breastfeeding women and infectious disease (Raiten and Bremer 2020). Alongside food insecurity, the physical, economic, and social environment plays a role in determining stunting risk (Raiten and Bremer 2020).

Evidence from Rwanda suggests that maternal education attainment is a determinant of stunting risk among children (Nshimyiryo *et al*., 2019). In this sample, illiterate mothers and mothers with primary education were three and two times more likely to have stunted children respectively (Nshimyiryo *et al*., 2019). Low birth weight was found to double the risk of stunting among children while short maternal stature tripled stunting risk (Nshimyiryo *et al*., 2019). Poverty was also significantly associated with stunting risk (Nshimyiryo *et al*., 2019).

Attention is still being paid to infant and young child feeding practices in addition to maternal nutritional status and the implications of birth weight and the intrauterine environment, however, there is also now growing speculation that environmental enteric dysfunction (EED) plays an important role in stunting development (Black and Heidkamp 2018). EED refers to a subclinical state of intestinal inflammation (Budge *et al*., 2019). Budge *et al*., (2019) suggest that poor sanitation and stunting may be causally linked via EED. Treating stunting with nutritional supplements has been shown to be ineffective in a variety of settings, and current thinking supports the use of nutrition-sensitive interventions such as water, sanitation and hygiene (WaSH) as treatment and prevention of stunting among children (Prentice 2019). Vonaesch *et al*., (2018) have suggested that as treatment of stunting has proven challenging, environmental enteropathy may be the underlying aetiological role in stunting development through chronic inflammation of the small intestine. This may result in changes to the gut microbiome, simultaneously explaining the failure of nutrition interventions and reduced response to oral vaccines among stunted children (Vonaesch *et al.,* 2018).

Given that stunting may be a result of either poor birth outcomes or later environmental risk factors associated with child feeding and WaSH practices, and that stunting is associated with indicators of child development, Leroy and Frongillo (2019) suggest that stunting should be used as an indicator for two distinct purposes. One as an indicator of child developmental outcomes, and second as a marker of poor birth outcomes (Leroy and Frongillo 2019).

1.6.2.2 Stunting reduction

Stunting appears in most children before the age of two years, which has led to strategies focused on interventions in the first 1000 days (conception to the second birthday) as the window of opportunity for preventing stunting (Prentice *et al*., 2013). Evidence suggests that catch-up growth can occur in mid childhood and through to adolescence, providing more opportunities to correct stunting in children (Prentice *et al*., 2013).

As stunting generally appears before the age of 24 months, interventions aimed at this age group focus on optimal infant feeding and complementary feeding. Common intervention strategies include nutrition education and provision of complementary foods. Research suggests that educational interventions focusing on complementary feeding practices have a modest effect on linear growth (Dewey and Adu-Afarwuah 2008). There are inconsistent results from investigations into the effectiveness of provision of complementary food supplements on linear growth (Dewey and Adu-Afarwuah 2008). It has been suggested that increasing coverage of nutrition-specific interventions including micronutrient supplementation, breastfeeding and complementary feeding practices, energy and macronutrient supplementation to 90%, would only result in a 20% reduction in the global prevalence of stunting (Bhutta *et al*., 2013).

There have been substantial reductions in stunting prevalence in Latin and central America since 1990 (UNICEF, World Health Organisation, The World Bank Group 2021). The greatest improvements in stunting prevalence were observed among children in the lowest wealth quintile, those living in rural areas and those with mothers who are poorly educated (Huicho *et al*., 2020). Huicho *et al*., (2020) suggest that these improvements in stunting prevalence are a result of economic growth, improvements in democratic stability and health policies which recognise that food supplementation is a limited approach to preventing and treating stunting. These changes in basic determinants of childhood malnutrition have resulted in improved maternal height, urbanisation, improved maternal education and healthcare and reduced fertility (Huicho *et al*., 2020).

However, Leroy and Frongillo (2019) have questioned the utility of using linear growth retardation as an outcome measure in health interventions. This is argued because focusing on height attainment may not necessarily result in improvements in clinical and wellbeing health outcomes. This may be because of heterogeneity in the causes of stunting. Stunting has been associated with low birth weight, as well as environmental enteric dysfunction, two distinct causal pathways.

1.6.3 Wasting

There were 45.4 million children under five years old wasted globally in 2020 (UNICEF, World Health Organisation, World Bank Group 2021). Among these children, 13.6 million are severely wasted. South Asia has an estimated wasting prevalence of 14.1% (UNICEF, World Health Organisation, World Bank Group 2021). There are 31.9 million wasted children in Asia, and 12.1 million wasted children in Africa, with these two regions representing most cases of wasting in the world (UNICEF, World Health Organisation, World Bank Group 2021). The prevalence of wasting was 3.2% in southern Africa, 6.9% in Western Africa and 5.2% in eastern Africa in 2021 (UNICEF, World Health Organisation, World Bank Group 2021).

Malnutrition is implicated in approximately 45% of under-five child deaths (WHO 2017). Children with multiple anthropometric deficits are at a greatly increased risk of death (McDonald *et al*., 2013). Severe acute malnutrition (SAM) is a common co-morbidity among children younger than five years old in hospitals in developing regions (Gachau *et al*., 2018). Alongside reductions in childhood malnutrition, there has been a decrease in the global number of under-five child deaths. This figure has reduced by 58% since 1990. However, the rate of under-five child death is 39 per 1000 live births globally, translating to 5.4 million deaths per year (WHO 2017). The infant mortality rate (between birth and the first birthday) for South Africa is 27.52 per 1000 live births (WHO 2021). The under-5 mortality rate is 34.46 per 1000 live births for South Africa (WHO 2021). The SAM mortality rate was 30.9% in South Africa in 2018 (Massyn *et al*., 2019). Common complications which increase mortality risk in this context include diarrhoea and lower respiratory tract infections (Gavhi *et al*., 2020). In addition, herbal medication use, poor appetite, anaemia, and HIV infection are all factors which increase the likelihood of death among children with SAM in South Africa (Gavhi *et al*., 2020). Predictors of SAM mortality are different in other regions with high rates of acute malnutrition. The mortality rate from SAM in Ethiopia ranges from 7% (Yohannes *et al*., 2017) to 12.5% (Wagnew *et al*., 2018). Predictors of increased mortality risk in Ethiopia include shock and anaemia (Wagnew *et al*., 2018) and repeated admissions for SAM increased mortality risk (Yohannes *et al*., 2017). In India, the SAM mortality rate was 1.2% (Prost *et al*., 2019). Prost *et al*., (2019) found that case mortality rates in India are lower than expected when compared to WHO estimates. According to Prost et al (2019), the WHO SAM mortality estimates are based on older studies in African populations.

The long-term health effects among survivors of SAM are relatively unclear. Leljiveld *et al*., (2016) found that survivors of SAM have lower height for age Z-scores, weaker hand grip strength, perform more poorly on exercise tests, have less lean body mass and lower MUAC than healthy community controls. However, they did find evidence of catch-up growth among these children. These results suggest that SAM survivors may therefore be at a higher risk of developing chronic diseases later in life, associated with reduced components of lean tissue mass (Briend and Berkely 2016). Evidence suggests that survivors of SAM have an increased risk of hypertension in adulthood related to changes in circulatory system morphology, particularly in the context of overweight and obesity (Tennant *et al*., 2014). While this evidence suggests an association between SAM, changes to body composition and later chronic disease risk, a causal relationship has not yet been established. Severe acute malnutrition has also been associated with cognitive developmental delay among children (Khandelwal *et al*., 2020). Severe acute malnutrition in the first year of life has been associated with a reduction in the number of brain cells present compared with healthy controls, with implications for brain and cognitive development through the lifecycle (Winick and Rosso 1969). These differences were more pronounced among children born below 2000 g, who would be classified as small for gestational age (Winick and Rosso 1969). More recent evidence suggests that cerebral cortical grey matter is significantly reduced among premature infants (Tolsa *et al*., 2004).

Disparities in malnutrition prevalence between regions, sub-regions and countries have been identified by Ssentongo *et al*., (2021), with West Africa, South and South-eastern Asia presenting substantially higher prevalence estimates. Disparities in prevalence were linked to human development index (HDI) and United Nations region

(Ssentongo *et al*., 2021). The HDI first appeared in the 1990 Human Development Report of the United Nations (Sagar and Najim 1998). The HDI is calculated from three dimensions of development- knowledge, health and standard of living. The index makes use of data on adult literacy and enrolment ratios, life expectancy at birth and an adjusted gross domestic product (GDP) (Sagar and Najim, 1998). Higher HDI was associated with lower prevalence of stunting, wasting and underweight across the world (Ssentongo *et al*., 2021). HDI was significantly associated with stunting and underweight in Eastern Africa, but only stunting in Southern Africa (Ssentongo *et al*., 2021). HDI was significantly associated with all three forms of malnutrition in south Asia (Ssentongo *et al*., 2021).

Estimates of SAM prevalence in southern Africa are relatively low compared with other regions which face challenges with the condition, however, case mortality rates are much higher. The COVID-19 pandemic has affected the most recent estimates of childhood malnutrition, largely due to the impact of social restrictions on obtaining data (UNICEF, World Health Organisation, World Bank Group 2021). Osendarp *et al*., (2020) have estimated that the pandemic will result in an additional 2.6 million cases of stunting and 9.3 million cases of wasting worldwide, which will be associated with 168 000 additional child deaths by 2022.

1.6.3.1 Causes of wasting

Risk factors for wasting vary considerably between countries (Frongillo, De Onis and Hanson 1997). Immunisation coverage is a common risk factor for wasting across the world (Frongillo, De Onis and Hanson 1997). Globally, wasting risk is higher among children who are from poor backgrounds, were born low birth weight and whose parents are not educated or unemployed (Fagbamigbe *et al*., 2020). However, risk factors for SAM vary between countries and communities and contextual factors play a role in SAM risk among children (Fagbamigbe *et al*., 2020).

Among Indian children, risk factors for SAM include poverty, young (less than 20 years) or older (more than 35 years) mother at birth, small birth spacing (less than 24 months), illiterate fathers, bottle feeding and early or late introduction of complementary foods (Pravana *et al*., 2017). According to Mishra *et al*., (2014), the consistency of complementary feeding foods is a more important risk factor for SAM than age of initiation of complimentary feeding. Illiteracy among mothers, incomplete vaccinations and bottle feeding were also significant risk factors for SAM (Mishra *et al*., 2014).

Among South African children, HIV infection, acute gastroenteritis, diarrhoea, dehydration and previous malnutrition diagnosis are risk factors for SAM (Ferguson 2016). Inappropriate infant foods after early cessation of breastfeeding, early and late introduction of complementary were risk factors for acute malnutrition in South Africa (Ferguson 2016). History of missed immunisations, vitamin A and deworming and larger numbers of children in the house were risk factors for SAM among South African children (Ferguson 2016). Breastfeeding for four to six months was protective against SAM (Ferguson 2016).

South Africa shares risk factors that are common in other countries including incomplete vaccination history. Poor infant feeding practices and inappropriate introduction of complementary foods are also risk factors shared with other regions. The South African situation is complicated by high prevalence of HIV, and this infectious disease increases the risk of SAM among children. HIV also affects successful treatment of the condition (Fergusson and Tomkins 2009).

1.6.3.2 Management of severe acute malnutrition

Children are screened for malnutrition using the WHO (2013) protocols. A child who presents with bilateral pitting oedema or a MUAC<11.5 cm or WHZ<-3 is immediately sent for a full assessment. The full assessment includes further anthropometric investigation, an appetite test, and a clinical examination using the IMCI danger signs to establish whether a child has complicated or uncomplicated SAM. A child who has failed an appetite test, presents with IMCI danger signs or presents with oedema is categorised as having complicated SAM, and must be treated in an in-patient facility. A child who does not present with these conditions is categorised as uncomplicated SAM and can be treated in the community (WHO 2013). In-patient management of SAM follows the WHO 10 steps for treating severe acute malnutrition (Ashworth *et al*., 2003). The WHO 10 steps were introduced in South Africa in 2005 by the Department of Health. Community based management of acute malnutrition (CMAM) is used for uncomplicated cases and forms part of the INP.

1.6.3.3 In-patient treatment of acute malnutrition

The WHO 10 steps for treating severe acute malnutrition is divided into two phases. The first phase focuses on stabilisation care. This stage involves treating hypoglycaemia, hypothermia and dehydration, correcting micronutrient deficiencies and beginning cautious feeding (Ashworth *et al*., 2003). Iron is not corrected in the first phase due to risks of bacterial overgrowth. Children are treated with F75 in the initial phase of treatment. F75 is a combination of milk, sugar, oil and a vitamin and mineral mix, which can be produced using locally sourced ingredients or obtained as a commercial formulation, supplying 75 kcal and 0.9 g protein per 100 mL. During this phase, there is no attempt at weight gain. Once the child has begun to show signs of metabolic recovery, which may include disappearance of oedema, return of appetite, the feed is changed to F100, and the recovery phase can begin (Ashworth *et al*., 2003). F100 provides 100 kcal and 2.9 g protein per 100 mL. During this phase, iron can be introduced, and feeds can be gradually increased to stimulate catchup growth. Once the child has achieved the necessary catch-up growth, plans for discharge back to the community can begin.

Until at least 2012, commercially prepared ready-to-use (RTU) F75 and F100 formulations were not widely available to clinicians in South Africa, and therefore WHO protocols were not closely followed in many cases (Biggs 2012). Instead, dietitians were likely to opt for commercially prepared lactose free infant formula. This provides approximately 67 kcal and 1.6 g protein per 100 mL of prepared formula. This formula has a lower energy density than F-75, but higher protein content per 100 mL. As a result, the stabilisation phase was not adequately implemented, placing infants and young children at a high risk of refeeding syndrome (Biggs 2012). Poor adherence to medical and nutritional therapies have been identified as predictors of mortality among children with SAM in other populations (Wagnew *et al*., 2018).

In the years immediately after the implementation of the WHO 10 steps, South African hospitals adopted the new clinical and dietary management tasks but with limited performance (Karaolis *et al*., 2007). Factors affecting the effectiveness of the WHO 10 steps included poor knowledge among doctors and nurses, inadequate training on implementing the 10 steps, understaffing and high staff turnover rates (Karaolis *et al*., 2007). Dietetic staff are now trained on the WHO 10 steps as part of their undergraduate studies in South Africa (Biggs 2012). However, barriers which may still be present include low levels of clinical experience, as many dietitians in the field have less than a few years of practical experience, and isolation, as many dietitians manage rural hospital caseloads on their own (Biggs 2012). In addition, there are problems with availability of supplements, distribution and equipment (Britz *et al*., 2017). Later research on the high mortality rate among children treated for SAM in South African hospitals identified that many of the same barriers were present in 2018. Clinicians identified a lack of continuity in training of rotating clinicians and inadequate staff numbers as factors associated with poor treatment outcomes in these children (Muzigaba, van Wyk and Puoane 2018). In addition, intermittent shortages of therapeutic supplies affect management of cases (Muzigaba, van Wyk and Poane 2018), a similar complaint to which undermines community management of acute malnutrition in South Africa (Brits *et al*., 2017). Another barriers is early discharge of SAM patients because of lack of hospital bed capacity (Muzigaba, van Wyk and Poane 2018)

Research on this topic is consistent on the point that the WHO 10 steps are easy to implement (Muzigaba, van Wyk and Puoane 2018; Karaolis *et al*., 2007), however, infrastructural support in the South African setting undermines the effectiveness of the intervention strategy.

1.6.3.4 Community-based management of acute malnutrition

The WHO in-patient model for treating severe acute malnutrition is effective in reducing case mortalities. However, resource-poor environments are unable to meet demands for skilled staff (Collins *et al.,* 2006; Muzigaba, van Wyk and Puoane 2018; Karaolis *et al.,* 2007). Barriers to successful treatment in resource-poor areas include inadequate feeding, poor management of rehydration and infection, lack of resources and the lack of knowledge and motivated staff (Puoane *et al.,* 2001).

Triaging SAM cases with complications for hospital care while treating uncomplicated acute malnutrition in the community reduces in-patient caseloads while increasing coverage rates (Collins *et al.,* 2006). Children with severe acute malnutrition and good appetite can be managed as ambulatory patients by infection treatment and the use of ready-to-use therapeutic foods (RUTF) or appropriately formulated home diets. Optimal management of children with moderate acute malnutrition (namely use of

RUTF versus specialized home-prepared diets) is being investigated to develop simple, effective and affordable dietary regimens (Brown *et al*., 2009).

Prost *et al*., (2019) have suggested that as case mortality for SAM in community settings is low, RUTF use in community may not be an effective intervention for preventing a large number of SAM deaths. These researchers suggest that preventing SAM from occurring with multisectoral primary prevention strategies is more important and that good access to SAM treatment when prevention is not effective is a necessary contingency (Prost *et al*., 2019).

The Community Management of Acute Malnutrition (CMAM) model was developed by Valid International and Concern Worldwide. The decentralised nature of CMAM allows programmes to reach even highly dispersed rural populations in harsh environments (Valid International 2006). The advantages of the CMAM model are that it maximises coverage and access to services, allows for the early detection of malnutrition, provides care which is appropriate for patients and provides prolonged care and integration into child health and social services.

Outpatient therapeutic programmes bring the service of management of SAM closer to the community (Yebyo *et al*., 2013). Under this system, services are available at decentralized health facilities or primary health care units (Yebyo *et al*., 2013). This reduces the need for children to attend hospitals for care. Community health centres and health posts provide nutrition services to their catchment areas including screening for malnutrition, providing ready to use therapeutic foods, vitamin A and deworming treatments. Triaging SAM cases with complications for hospital care while treating uncomplicated acute malnutrition in the community reduces in-patient caseloads while increasing coverage rates (Collins *et al.,* 2006).

There has been a high rate of relapse into malnutrition observed among children successfully treated for SAM within one year (Chang *et al*., 2013). However, this phenomenon is not often measured in nutritional programmes. The rate of relapse is estimated to be as high as 37%, with the majority of relapse into acute malnutrition taking place within six months of discharge (Strobaugh *et al*., 2018). Having lower anthropometric measurements at discharge from SAM treatment is associated with a greater risk of relapse, and re-admission for SAM treatment often coincides with illness (Strobaugh *et al*., 2018).

Community health workers (CHWs) are employed in many low- and middle-income countries as part of the health system. They have been used to address the shortage of skilled health workers in these countries (Lehmann and Sanders 2007). CHWs are community members who provide basic health services within their own communities (Lehmann and Sanders 2007). CHWs are involved in community management of acute malnutrition, and are often relied upon to identify and refer SAM cases in the community. They play a role in rehabilitating children with SAM. However, research has shown that CHWs lack adequate training, require better supervision and essential resources, and are inhibited from performing stabilisation care before referral by restrictive policies (Mambulu-Chikankheni *et al*., 2018). These factors undermine the effectiveness of community-based management of SAM.

1.6.4 Overweight and obesity

Overweight and obesity may be defined as a “condition of abnormal or excessive fat accumulation in adipose tissue, to the extent that health may be impaired” (Garrow 1988). The global prevalence of overweight was 5.7% or 38.9 million children younger than five years of age in 2020 (UNICEF, World Health Organisation, World Bank Group 2021), similar to the prevalence in 2000, which was 5.4%, approximately 33.3 million children. Substantial increases in childhood overweight and obesity have been seen in South Asia and North Africa since 2000 (UNICEF, World Health Organisation, World Bank Group 2021). The African region has seen a small increase in the number of overweight children from 8.2 million to 10.6 million children between 2000 and 2020 (UNICEF, World Health Organisation, World Bank Group 2021). There were 800 000 children with overweight and obesity in southern Africa in 2020. The most recent national estimate of childhood overweight and obesity is found in the SANHANES-1 study (Shisana *et al*., 2013). The combined prevalence of overweight and obesity among schoolchildren aged six to 14 years was 13.5% (Shisana *et al*., 2013). The prevalence of overweight among South African boys is 11.5%, of which 4.7% are obese, while 16.5% of girls are overweight, of which 7.1% are obese (World Obesity Federation 2020). South Africa’s target overweight and obesity prevalence of 5.7% for five- to 19-year-olds in 2025 is likely to be missed, as the World Obesity Federation currently predicts a prevalence of 22.1% for this age group in 2025 (World Obesity Federation 2020).

Overweight and obesity are risk factors for chronic diseases of lifestyle such as type 2 diabetes and hypertension. Evidence is emerging that overweight and obesity during childhood and adolescence is predisposing children to chronic diseases of lifestyle (Kim, Lee and Sungwon 2017). Features of the metabolic syndrome have been observed in adolescents in Mthatha in South Africa and are associated with higher adiposity (Sekokotla *et al*., 2017). Negash *et al*., (2017) found that overweight and obesity increased the odds of hypertension, hypertriglyceridemia, and low HDL cholesterol among Capetonian school children. Pedro *et al*., (2014) found evidence of prehypertension, impaired fasting glucose and low HDL cholesterol levels among South African adolescents. The challenge of childhood hypertension in South Africa is growing, however, practical challenges in identifying children with hypertension are problematic (Kagura *et al*., 2018). This is related to the requirement for blood pressure readings to be interpreted against centile scores adjusting for height, age and sex, and require three consistent readings on three separate occasions, resulting in a complicated screening process coupled with uncertainty over cost-benefit analyses for treatment (Kagura *et al*., 2018). These factors are thought to increase the risk of cardiometabolic disease. In addition, obesity is associated with non-alcoholic steatohepatitis (NASH), (Nachit *et al*., 2021). This chronic condition is life threatening. It is estimated that South Africa spent US$3.5 billion on healthcare costs attributed to obesity in 2016 (World Obesity Federation 2020).

1.6.4.1 Causes of overweight and obesity

A positive energy balance over an extensive period of time results in weight gain, which can result in overweight and obesity (Garrow 1988). However, there are many factors related to energy intake and expenditure patterns. People may have unmodifiable risk factors for becoming overweight or obese, including genetics, ethnicity, gestational weight and intrauterine conditions (Ang *et al*., 2013). Individual behaviours may increase the risk of overweight and obesity, including physical activity and sleep (Ang *et al*., 2013). It has been speculated that short sleep duration interferes with normal leptin and grehlin regulation, increasing the risk for higher BMI (Taheri *et al*., 2004). Diet and physical activity are modifiable risk factors that are directly related to energy balance. Energy intake and physical activity are the only components of energy balance which can be changed by the individual (Donelly and Smith 2005).

However, energy intake and physical activity take place within a wider social, economic and cultural context, and many regions of the world are fast becoming "obesogenic" environments, including both rural and urban parts of South Africa. Sedentary lifestyles, excessive energy intakes and consumption of foods high in fat and sugar are seen in both adults and children in South Africa (Kagura *et al*., 2018).

According to Munthali *et al*., (2019), excessive weight gain in infancy and early childhood is associated with a greater risk of obesity in adulthood. Experimental evidence suggests that more rapid weight gain in infancy is associated with higher fat mass in later childhood (Singhal *et al*., 2010). Consuming an enriched formula in infancy with a higher caloric density was associated with greater fat mass in two randomised controlled trials (Singhal *et al*., 2010). Therefore, early exposure to an obesogenic environment will result in a larger overweight and obesity disease burden in the future. However, Singhal (2017) has suggested that in certain cases such as preterm infants, accelerated growth in infancy is beneficial as it promotes neurological development. Similarly, in low- and middle-income countries, the short-term risk of mortality from infant undernutrition may be more important than the long-term implications of overweight and obesity.

It is increasingly likely that there are direct links between forms of both under- and overnutrition. Long *et al*., (2021) have found that reduced height attainment is associated with higher fat mass and lower fat free mass among South African children. Girls who are stunted have a higher truncal fat mass than non-stunted girls (Long *et al*., 2021). This increased truncal adiposity among stunted children may predispose malnourished children to later chronic diseases of lifestyle. Excess abdominal fat is associated with an increased risk of hypertension and diabetes.

1.6.4.2 Management of paediatric overweight and obesity

Given that the prevalence of childhood overweight and obesity is rising, there is increasing interest in developing effective interventions to treat and prevent this problem. However, it is difficult to establish whether interventions are successful as many studies and interventions are implemented with inadequate evaluation planning or lack rigorous designs (Klingberg *et al*., 2019, Bleich *et al*., 2018, Errisuriz *et al*., 2018). Intervention methods focus on dietary modification (Kim and Lim 2019), physical activity (Errisuriz *et al*., 2018), or a combination of dietary modification and physical activity (Errisuriz *et al*., 2018). It is also recognised that risk for overweight and obesity may begin in gestation and early infancy with excessive gestational weight gain, high birth weight and formula feeding practices associated with an increased risk of overweight and obesity in childhood (Lanigan 2018). Therefore, interventions could focus on prenatal and early infancy stages of the lifecycle (Lanigan 2018).

Areas for intervention which have been demonstrated to be effective focus on individual and family behaviour change. These interventions may take to form of home visits, individual counselling or group therapy in clinical and community settings (Blake-Lamb *et al*., 2016). Dietary modification interventions commonly focus on nutrition education and counselling, communicating key messages and the use of Mediterranean and hypocaloric diets (Kim and Lim 2019). Childhood overweight and obesity interventions are implemented in schools and pre-schools, community and clinical settings. There is evidence that the most effective interventions are school-based interventions, which make use of a combination of diet modification and physical activity (Bleich *et al*., 2018). Nqweniso *et al*., (2021) showed that physical activity and health education interventions can prevent normal weight children from becoming overweight in school settings and prevent overweight and obese children from gaining more weight. However, these researchers note that more evidence is needed for participants in resource-poor settings to determine the effectiveness of these interventions in lower socioeconomic areas (Nqweniso *et al*., 2021). In the African setting, Klingberg *et al*., (2018) have identified that there is a lack of research in settings outside of schools, therefore limiting the evidence supporting interventions in other settings.

According to Klingberg *et al*., (2019), resource availability is important in determining the success of obesity interventions. The cost-effectiveness of childhood obesity interventions based in schools in the UK is unclear (Canaway *et al*., 2019). This is because each quality-adjusted life year (QALY) gained would cost almost £30 000 over a 30-month period. In spite of this, evidence suggests that early primary health intervention and education strategies are effective in reducing hypertension among overweight children in South Africa, and important long-term health indicator (Joubert *et al*., 2021).

Research has shown that cultural considerations need to be incorporated into childhood obesity interventions if they are to be successful (Schroeder and Smaldone 2017). Among black Africans in urban settings in South Africa, overweight and obesity are perceived as signs of beauty and wealth (Bosire *et al*., 2020). Therefore, addressing overweight and obesity in South Africa faces an additional challenge on top of the emerging obesogenic environment (Bosire *et al*., 2020).

1.10 Screening for malnutrition

Anthropometric assessments are frequently used as part of nutritional assessment of individuals and populations (UNICEF 2009). Anthropometry refers to the measurement of body dimensions and morphology. Other components of nutrition assessment include biochemistry which gives an indication of the body's interaction with nutrients; clinical assessment which evaluates the physical manifestations of nutritional intake; and dietary assessment which estimates nutritional intake in the form of food and nutrients (Patterson and Pietinen, 2004). Anthropometry is the most universally applicable, non-invasive method of assessing growth in children (De Onis, 2015).

1.7.1 Development of the growth charts

The US National Centre for Health Statistics (NCHS) growth reference was developed using longitudinal data on infant and child growth from the Ohio Fels Research Institute in the years before 1975. The NCHS, Centre for Disease Control (CDC) (2000) and WHO (1983) growth reference charts were developed in order to assess child growth. However, there were problems associated with these growth charts. As they were growth references, they could only represent a child's growth in relation to how other children grow, but not how they should be growing optimally. In addition, these reference charts were based on samples from the USA only, used formula fed children and were not therefore representative of children in other countries and did not represent the dynamic growth trajectory of the breastfed infant accurately. This had led to an overdiagnosis of growth faltering among breastfed infants at approximately four months of age. This was associated with early introduction of complementary foods. Early initiation of complementary foods has been associated with growth faltering and higher rates of infection (Cohen *et al*., 1994) due to poor quality of complementary foods. These considerations led to the development of the WHO (2006) growth standard, which made use of a multinational sample of children likely to meet their full growth potential. The WHO (2006) growth standard aimed to correct the problems associated with the WHO (1983) and CDC (2000) growth references. The changes to the charts resulted in a shift in the prevalence of SAM, stunting and overweight among children internationally. De Onis et al (2007) found that infants who are exclusively breastfed track better along the WHO growth standard than the CDC growth reference. Martorell and Young (2012) found that adopting the WHO (2006) increased the prevalence of wasting among infants younger than six months threefold, and increased the prevalence of stunting among children younger than 12 months in India when compared with estimated based on the NCHS reference. The WHO (2013) update to the guidelines included mid-upper arm circumference as an independent criterion for identifying acute malnutrition in children.

1.7.2 Mid-upper arm circumference

The WHO (2013) update on the guidelines for identifying and treating acute malnutrition outlines community level and primary care screening strategies. At community level, health workers should assess children for bilateral, pitting oedema. If MUAC is less than 11.5 cm or WHZ<-3, children should be referred to a primary care facility for a full assessment. In primary care facilities, children should be assessed for oedema, and screened or assessed for malnutrition using MUAC or WHZ.

Mid-upper arm circumference measures all tissues in this region, including bone, skeletal muscle, adipose tissue and skin (figure 1.7). In acute malnutrition, some catabolism of skeletal muscle occurs to liberate amino acids from which glucose is generated through gluconeogenic pathways. Triglycerides in adipose tissue are catabolised to liberate free fatty acids and glycerol, the former being converted to ketone bodies and the latter to glucose (McCray *et al*.,; Mehanna *et al*., 2009). This mobilisation of body fat contributes to the weight loss in severe acute malnutrition. Changes in MUAC weight are closely correlated among children with SAM and hence is a vital marker in the assessment of nutritional status in these infants and young children (Binns *et al*., 2015).

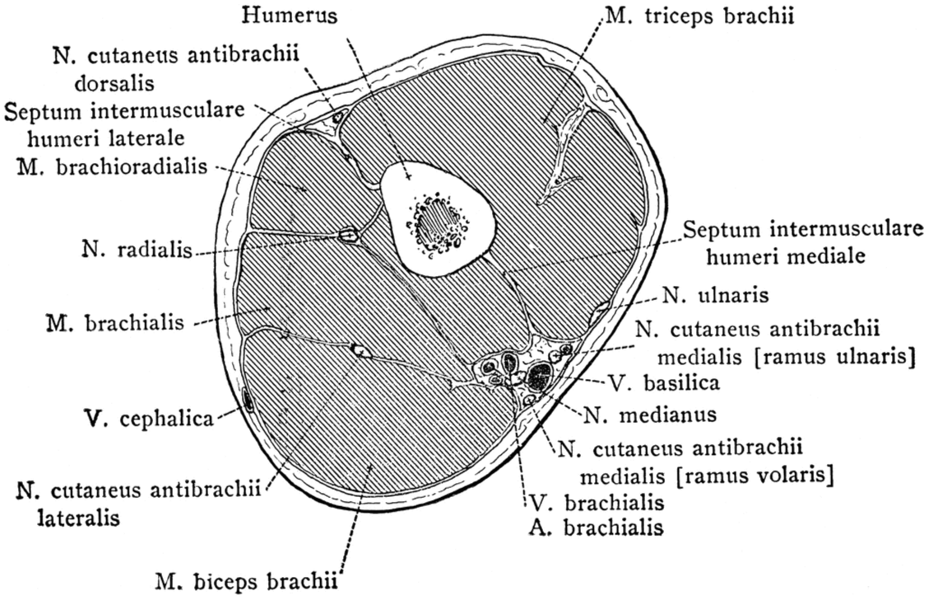


Figure 1.7: Cross section through the upper arm (Division of General Surgery, Medical Departments US Army and Navy 1918).

Misdiagnosis of SAM at the first point of care has been identified as a challenge to successfully managing the condition (Muzigaba *et al*., 2018). Grellety and Golden (2016) analysed data from 1832 anthropometric surveys in 47 countries. It was found that only a small percentage of children were identified as malnourished by both WHZ and MUAC. Therefore, there is a poor level of overlap between the two indicators. In some countries, most children were identified as acutely malnourished by MUAC, whereas in others WHZ was more sensitive to acute malnutrition. MUAC can be measured with a high level of precision by well-trained anthropometrists (Moss *et al*., 2020). However, the diagnostic accuracy of MUAC is frequently measured in comparison to WHZ in the literature (Talapallawar and Garg 2016; Fernandes, Delchevalerie and Van Herp 2010), limiting interpretation of this measurement for SAM. Grellety and Golden concluded that the indicators should not be used as alternate measures of acute malnutrition and that both indicators should be used to reveal the true prevalence of SAM in surveys. Briend *et al*., (2016) conceded that MUAC and WHZ do not identify the same individuals as malnourished and conceded that regional variations are not well understood. However, these researchers proposed that MUAC is more sensitive to identifying children at a higher risk of death than WHZ. Grellety and Golden (2018) conducted a systematic review which concluded that mortality risk is not different between children identified by MUAC and those identified by WHZ and recommended against the abandonment of WHZ. Briend *et al*., (2016) argue that children identified as acutely malnourished by MUAC respond better to treatment. MUAC also has the advantage of increasing coverage of nutrition programmes and that the priority should be the detection of the most severe cases of SAM, which MUAC is effective at achieving (Briend *et al*., 2016).

Reasons for the greater sensitivity of MUAC to risk of death among acutely malnourished children may be associated with the links between stunting and wasting (Briend *et al*., 2015). Wasting and stunting are often conceptualised differently in their identification and treatment approaches, however, these two conditions often occur in the same communities and individuals and share common drivers (Briend *et al*., 2015). The two conditions are associated with an increased risk of mortality, especially in combination. Garenne *et al*., (2018) have suggested that the risk of mortality from combined stunting and wasting is equivalent to the sum of the two mortality risks. Therefore, Briend *et al*., (2015) have argued that as stunting and wasting present with reduced muscle mass, screening for malnutrition using MUAC will identify the most at-risk children. However, MUAC on its own is more likely to miss older and taller children who may also be wasted.

Current MUAC recommendations may be valuable in emergency settings where there are large numbers of children to screen. However, the applicability of the current MUAC cut-off values for identifying acute malnutrition may not be appropriate for non-emergency settings with a different level of mortality risk, due to better resourced health systems and different socio-economic risk factors (Tessema *et al*., 2020, Laillou *et al*., 2014). Laillou *et al*., (2014) found that the current MUAC cut-off of 11.5 cm missed 90% of children with a WHZ<-3 in Cambodia (Table 1.3). WHZ<3 missed 80% of children with a MUAC of less than 11.5 cm in the same dataset (Laillou *et al*., 2014). Another study in Cambodia revealed that current MUAC cut-off values fail to identify two thirds of acutely malnourished children (Weiringa *et al*., 2018). Therefore, researchers have suggested revising the cut-off values for identifying cases of SAM to improve the level of agreement between the two indicators. Tessema *et al*., (2020) have suggested that increasing the MUAC cut-off values for acute malnutrition from the WHO recommendations of 11.5 cm for SAM and 12.5 cm for MAM in non-emergency contexts may improve current practice. Raising the MUAC cut-off value to

13.3 cm improved the agreement between the two indicators to greater than 65% in Cambodia (Laillou *et al*., 2014). An Indian study found that MUAC at 11.5 cm had a sensitivity of 13.6% and specificity of 99.3% (Talapalliwar and Garg 2016). Raising the MUAC cut-off to 12.8 cm improved the sensitivity to 50% but resulted in a lower specificity at 90.8% (Talapalliwar and Garg 2016).

Grellety and Golden (2016) have demonstrated that MUAC and WHZ perform differently in different regions and with different populations. The level of agreement between the two indicators appears to be specific to the population. While there is some data available from sub-Saharan Africa, little is published on the sensitivity and specificity of MUAC in South Africa. Dukhi *et al*., (2017) reported that MUAC-for-age and WHZ had a fair level of agreement in identifying acute malnutrition among South African children at 53.69% (k=0.27). However, this study did not report the level of agreement using absolute MUAC measurements, nor did it report on the sensitivity and specificity of MUAC for identifying acute malnutrition. Sensitivity and specificity are important considerations for diagnostic test accuracy. Sensitivity refers to the ability of a test to identify a subject who has the condition. Specificity refers to the ability of a test to identify a subject who does not have the condition. A good diagnostic test will have a high sensitivity and specificity. A test that lacks specificity will result in many false positives, who will be turned away from health facilities and may undermine confidence in the health system (Kapil *et al*., 2017). However, a test that lacks sensitivity will fail to identify children who are acutely malnourished and in need of treatment. The prevalence of acute malnutrition is low in South Africa compared with the rest of the region, but the case fatality rate is high. Therefore, identifying children at a high risk of acute malnutrition may be priority in the South African context.

There is an implicit bias in the current MUAC cut-off values which makes the test more sensitive to identifying children at a high risk of death (Briend *et al*., 2015). This accepted bias is related to age - younger children tend to have smaller MUAC and are simultaneously at a higher risk of deterioration and mortality.

Table 1.3: Studies investigating the sensitivity and specificity of MUAC for acute malnutrition.

First author	Year	Country	Setting	Sample size	SAM prevalence (% WHZ<-3)	Mean age (months)	Sex (%female)	Sensitivity	Specificity
Fernandes	2010	International*	Nutrition surveys	34937	3.9	Not reported	Not reported	0.25	0.997
John	2017	Nigeria	Mixed*	413	3.4	22.4	50.4	0	0.985
Kapil	2018	India	Community	18456	2.2	32.64	46.6	0.232	0.997
Laillou	2014	Cambodia	Health survey data	11818	1.4	26.3	49	0.061	0.997
Sougaijam	2019	India	Community	2650	8.0	Not reported	48	0.236	0.985
Tadesse	2017	Ethiopia	Population based survey	4297	1.0	31	49	0.364	0.988
Tessema	2020	Ethiopia	Community	25755	1.3	31.7	49	0.161	0.99
Dasgupta	2013	India	Community health centres	1879	8.5	Not reported	48	0.175	0.963

* Angola, Burundi, Malawi, Sierra Leone, Ethiopia, Niger, Burkina Faso, Chad, India, Afghanistan

** Hospital outpatients, immunization clinics and pre-primary schools

1.8 Research questions

The following research questions form the basis of this dissertation as a result of research conducted by the researcher:

How can the nutritional, social, economic and educational factors associated with indicators of under- and overnutrition among children in South Africa be used to improve nutritional interventions in the context of the double-burden of malnutrition in South Africa?

In the context of the double-burden of malnutrition in South Africa, how must the MUAC measuring tape have to be adapted to screen children younger than five years for overweight and obesity as well as acute malnutrition?

Study 1	Investigate the associations between food insecurity, social welfare and low birth weight with childhood malnutrition. 400 infants and young children (0-24 months) from a peri-urban Eastern Cape Province township
Study 2	Investigate coverage of vitamin A supplementation, deworming and immunisations and their associations with nutritional status among urban children 1496 infants and young children (0-59 months) in Nelson Mandela Bay, Eastern Cape
Study 3	Assess the relationship between haemoglobin level and socio-economic indicators among women of childbearing age in South Africa Secondary analysis of 2690 women of childbearing age (15-49 years) from a nationally representative sample
Study 4	Investigate the sensitivity and specificity of Mid Upper- Arm Circumference (MUAC) as screening tool for wasting rationale for testing changed cut-off values to identify malnutrition Develop new MUAC cut-off values for identifying wasting in this population 400 infants and young children (0-24 months) in a peri-urban township in the Eastern Cape
Study 5	Investigate the sensitivity and specificity of MUAC for screening for overweight among children younger than two years in the Eastern Cape, South Africa Develop new MUAC cut-off values for identifying overweight and obesity in this population 400 infants (<6 months) and 350 infants and young children (6-24 months)
Study 6	Design and validation of the double-burden mid-upper arm circumference (MUAC) tape for South African children aged six to 24 months 248 infants and young children (6-24 months)

Figure 1.8: Phases of development of the research portfolio.

1.9 Research aims

This portfolio of published work explores underlying risk factors for undernutrition and over-nutrition in the context of double-burden South Africa. The aim of this work is to assess the ability of mid upper-arm circumference (MUAC) as a screening tool across the spectrum of malnutrition in children, and to adapt this tool for optimal screening of both under and overnutrition in South Africa.

1.10 Importance of the research

This work will contribute to the development of improved tools for identifying childhood malnutrition in South Africa, in the context of the double burden of malnutrition. The pooled results of the work will provide clarity on areas for targeting nutrition interventions in South Africa.

1.11 Conclusion

This chapter outlined the main forms of malnutrition affecting children. The prevalence of stunting, wasting and overweight have changed over time. While the relative number of malnourished children has reduced since 1990, the absolute number of malnourished children across the world has increased as the population has grown. The sub-Saharan African region and south Asian region have high prevalence of childhood malnutrition, but different incidence of childhood mortality. South Africa has a lower prevalence of stunting and acute malnutrition than the rest of the sub-Saharan African region, however a quarter of children younger than five years of age are stunted. The SAM case mortality rate is higher in South Africa than the rest of the region. Food affordability is higher in South Africa than the rest of the sub-Saharan African region, however there is a high proportion of people suffering from hunger. Screening for acute malnutrition makes use of WHZ and MUAC. There is poor agreement between these two indicators in the field. Researchers have suggested alternative MUAC cut-off values to improve the agreement between the two indicators. In addition, there is increasing interest in MUAC as an indicator of childhood overweight and obesity. South African methods for treating childhood malnutrition are based on international approaches. Current treatment approaches are effective; however, effectiveness is undermined by poor follow up and poor patient adherence to treatment.

The current work is relevant to childhood malnutrition in South Africa as it explores the contextual factors which contribute to its development in all forms in the country. This work identifies factors which are related to the development of childhood malnutrition in a peri-urban environment in South Africa. The work identifies explores current public health approaches aimed at reducing the burden of underweight, stunting and wasting through preventing environmental enteric dysfunction. This body of work also identified mid-upper arm circumference as an anthropometric tool for identifying acute malnutrition, as well as overweight and obesity. Early identification of acute malnutrition may assist in reducing the risk of mortality arising from the condition, as well as attenuating the developmental delay associated with it. MUAC is a simple tool which is familiar to community health workers and may be adapted to better identify cases of acute malnutrition in this population. As the rates of overweight and obesity among South African children are rising, MUAC may also be an effective tool for identifying these conditions, as the tool is familiar to community health workers.

Targeting in interventions is an important aspect of their design. Effective targeting reduces the cost of nutritional interventions while simultaneously ensuring that those who would benefit most are included. This set of studies sought to determine the diagnostic screening value of mid-upper arm circumference for wasting and overweight among children. The sensitivity and specificity of MUAC as a screening tool are explored. Basic and underlying risk factors for stunting as a condition of undernutrition, and overweight as a condition of overweight in the context of the double burden of malnutrition are explored. This section describes the methods employed in the portfolio of published articles. Where primary data was used, the methods of obtaining the data are described. Where secondary data was analysed, an overview of the surveys used is given. The statistical analyses, validity, reliability and ethical considerations of the studies are considered.

CHAPTER 2

GENERAL METHODS

2.5 Methods

The studies conducted using primary data made use of quantitative, cross-sectional designs. The author was instrumental in designing the studies, undertook the fieldwork, analysed the data and interpreted the findings of the studies. The studies which made use of secondary data made use of quantitative, cross-sectional designs.

The results of the individual studies were synthesised into an overarching theme which directly relates to the aims and objectives stated above.

2.5.1 Data collection

2.5.1.1 Data for studies 1, 4, 5, 6

Inclusion criteria:

- Any children below the age of two years residing in Motherwell;
- Children could only be included in the sample if their parents or guardians gave consent;
- Both male and female infants and children, regardless of socio-economic status; and
- Black African infants and young children were included in the study to create a homogenous study sample and prevent bias in the interpretation of the results.

Exclusion criteria:

- Children who are older than 24 months at the time of measurement;
- Children who have a WHZ, HAZ, WAZ or MUAC measurement above or below five standard deviations of the sample mean;
- Children with incomplete anthropometric data available were excluded;
- Children who have foetal alcohol syndrome (FAS), cerebral palsy (CP), or history of tuberculosis (TB) were excluded from the study as these conditions affect nutritional status; and

- Children of ethnicity other than African, including coloured, white or others, were excluded in order to create a homogenous sample which is representative of the study population.

The population that was investigated in this study was infants and children younger than two years old, residing in Motherwell, in the Nelson Mandela Metropolitan Municipality Health District. Motherwell has an area of approximately 25.86km^2 and a population of 140 351 people (Census 2011). The population is 52.48% female, and 47.52% male. People of black African ethnicity constitute 99.2% (n=139229) of the population (Census 2011). The population of children younger than two years in Motherwell was 5817 in 2016 (Personal communication Nutrition Manager NMB). Therefore, an estimated 6.9% of the population participated in this study. The community is comprised of lower income residents. Six clinics provide primary healthcare services in Motherwell (DHIS). These clinics are Motherwell Community Health Centre (CHC), Motherwell NU11 clinic, Motherwell NU2 clinic, Motherwell NU8 clinic, Ikamvalihle clinic and Wells Estate clinic. Sites identified for data collection are presented in Figure 2.1.

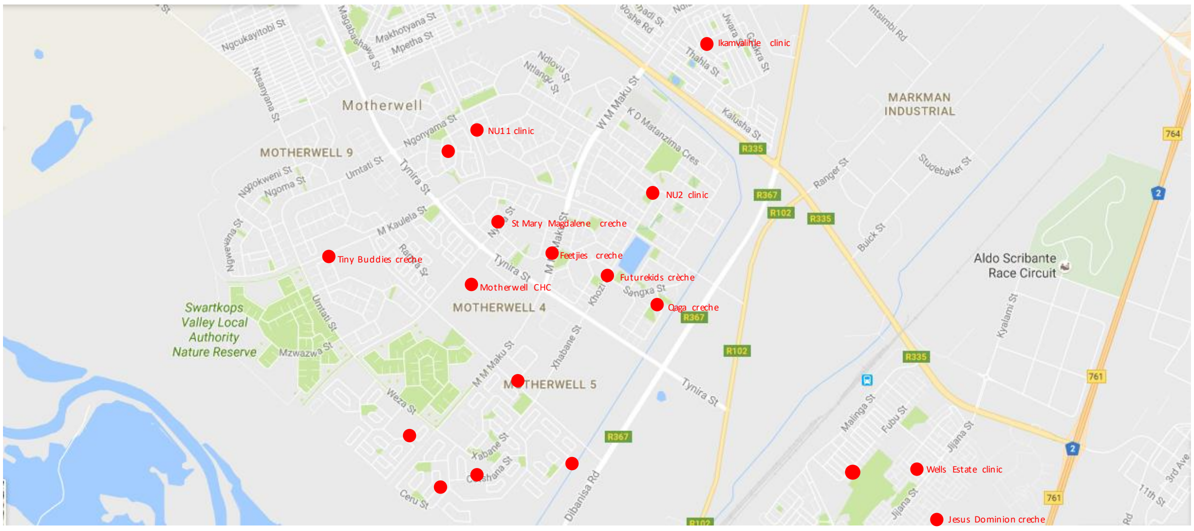


Figure 2.1: Distribution of sampling sites in Motherwell, NMBHD.

Data for studies 1, 4, 5, 6 were collected from a sample in Motherwell, Nelson Mandela Bay between October 2015 and February 2016. This descriptive study was undertaken using a cross sectional design. Ethical approval was obtained from the Research Ethics Committee (Human), Nelson Mandela University, as well as the Eastern Cape Department of Health (ref. no H15-HEA-002). Inclusion in the study required written informed consent from the primary caregiver of the participant. Data on weight, length and MUAC was collected from infants and young children living in a South African resource-poor peri-urban settlement, aged from birth to two years (n=408) between October 2015 and February 2016. Since the population of children younger than two years in Motherwell was estimated at 5 817 in 2016 (personal communication, Nutrition Manager NMB, June 2016), an estimated 6.9% of the population participated in the survey. Date of birth and date of measurement were recorded, and participant age calculated as an age in decimals. Procedures for obtaining anthropometric data followed protocols described by the Centres for Disease Control and Prevention (CDC 2007). Weight was measured in kilograms (kg) with a Nagata BW 2010 infant scale (capacity 20 kg x 10 g) and recorded to the nearest 0.01 kg. Length was measured in centimetres (cm) using a Seca infantometer to the nearest 0.1 cm. Non-stretch MUAC tapes were used to measure arm circumference in cm to the nearest 0.1cm. Scales were calibrated before measurements were taken, and measurements were taken at eye level to avoid parallax errors. Measurements were taken by trained fieldworkers. Fieldworkers were registered dietitians and dietetic students who received training before commencing data collection and throughout the data collection period. Fieldworkers collected data under direct supervision of the principal investigator. Anthropometric data were used to calculate Z-scores for weight for age (WAZ), height for age (HAZ), weight for length (WLZ) using WHO Anthro software (WHO, Switzerland). Data cleaning criteria were applied according to WHO guidelines (WHO 2005).

The study also involved the use of structured questionnaires including demographic information and the household food security (HHFS) by means of the Community Childhood Hunger Identification Project (CCHIP) questionnaire (Wehler *et al*., 1996). This questionnaire is composed of 8 questions, with each affirmative answer adding one point to a household's score. A CCHIP score of 0 indicates food security, a score of 1 to 4 indicates that a household is at risk of hunger, and a score of >5 indicates hunger (Wehler *et al*., 1996). Where needed, the CCHIP questions were translated into isiXhosa and captured by a trained fieldworker.

2.5.1.2 Data for studies 2 and 4

A cross-sectional study was conducted between September 2015 and February 2016 in classes from 32 pre-schools or creches. Ethics approval (H15-HEA-DIET-003) was obtained from the Nelson Mandela University (NMU) Research Ethics Committee (Human) and institutional permission was obtained from the Eastern Cape, Department of Education as well as principals and teachers from all the schools. Parents of all the children in the classes of the ECD practitioners received a letter explaining the purpose of the research and inviting them to provide informed, written consent for their children to participate in the study. Parents were requested to send their children's clinic cards to the pre-school. A convenience sample was obtained including all children who possessed signed informed consent letters, clinic cards, and agreed to undergo the anthropometric measurements on the day of data collection. All schools included in the sample fell under the no-fee paying school category.

Weight and height were measured using standardised techniques (CDC 2007) by trained fieldworkers, under supervision, using calibrated equipment. Weight was measured in kilograms (kg) to the nearest 0.01 kg using a calibrated Seca electronic scale (Model 874) and height was measured in centimetres (cm) to the nearest 0.1 cm using a Seca (Model 217) stadiometer. Date of birth, date of visit, sex of the child, last date of vitamin A supplementation, last date of deworming and vaccination records were collected from participants' clinic cards. Data collection tools were piloted prior to the study, and data was recorded onto an electronic database.

Weight-for-age z-scores, height-for-age z-scores (HAZ), weight-for-height z-scores (for children below 60 months of age) and BMI-for-age z-scores (BAZ) were subsequently generated using the National Center for Health Statistics/WHO reference with the WHO Anthro- and WHO Anthro plus programmes (version 1.0.4) (WHO 2006) to determine stunting (HAZ < -2 SD), wasting (WHZ < -2 SD) and overweight (WHZ > +2 SD for children up to 60 months or BAZ > +1 SD for children older than 60 months. Data was cleaned according to WHO (2006) criteria.

2.5.1.3 Data for study 3

Data was taken from the Demographic and Health Survey (DHS) South Africa 2016 public access dataset with permission from the DHS Programme (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF, 2019). The aim of the DHS programme is to provide estimates of basic demographic and health indicators. The data is collected to allow policy makers and programme managers in designing and evaluating programmes to improve population health. Surveys have been undertaken in South Africa in 1998, 2003 and 2016. Data is collected on key aspects of child health and nutritional status, use of maternal and child health services, fertility and contraceptive use, tobacco and alcohol use, prevalence of chronic diseases of lifestyle, violence against women and HIV. The survey covers all children between birth and five years, women between 15 and 49 years and men between the ages of 15 and 59 years. The DHS uses a stratified, cluster sampling method. The survey is designed to obtain a representative national estimate for South Africa, as well as for each of the nine provinces in the country. There were 15 292 households selected for the sample, of which 11 083 were successfully interviewed. Among these, 8514 interviews were completed with women between the ages of 15 and 49 years (Stats SA, 2019).

The DHS uses standard model questionnaires to collect nationally representative and internationally comparable data (DHS). The three core questionnaires are a household questionnaire, a women's questionnaire and men's questionnaire. The DHS includes modular questionnaires which can be deployed in addition to the core questionnaires. These include a service provision assessment to obtain information about the health and family planning services available to communities. The second modular questionnaire is the AIDS indicator survey and the third is the malaria indicator survey. In addition, biomarkers are collected from the field. Biomarkers include weight and height to evaluate nutritional status among adults and children, indicators or infections, sexually transmitted diseases, chronic diseases and micronutrient deficiencies. The specific questionnaire used in country is adapted for the local health priorities for the country (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF, 2019).

2.6 Validity and reliability

2.6.1 Internal validity

Scales, stadiometers, infantometers and mid-upper arm circumference tapes for studies 1, 2, 4, 5 and 6 were the same measuring tools used in the field to assess weight, height, length and mid-upper arm circumference. The same scales, stadiometers, infantometers and mid-upper arm circumference tapes were used at the data collection sites for studies 1, 2, 4, 5 and 6 to ensure consistency across measurement sites. Data was collected by the same researchers at all sites, under the supervision of the principal investigator. Research tools were piloted prior to data collection to ensure that the tools used could measure the outcomes required.

2.6.2 External validity

Measures of nutritional status that were used are endorsed by the World Health Organisation, including weight for age, length/height for age, and weight for height. Procedures for measuring anthropometry followed published guidelines (CDC 2007). Questionnaires used to assess household food security for study 1 were validated externally and found to be able to accurately classify categories of exposure to household food insecurity. Data on deworming, vitamin A and vaccination history were obtained from the health records of children included in study 2.

2.6.3 Reliability

Scales were calibrated prior to data collection using recommended techniques (CDC 2007). Non-stretch, fibreglass MUAC tapes designed for the purpose of identifying malnutrition among children were used in studies 1, 2, 4, 5 and 6. Anthropometric measurements were taken by trained fieldworkers with experience in anthropometry, under the supervision of the principle investigator. Measurements were recorded in duplicate.

2.7 Ethics

This research has made use of human subjects, who are part of a vulnerable population. Research was conducted according to the ethical principles outlined in the Declaration of Helsinki (World Medical Association 2013). Research has been already conducted and ethics approval (Appendix A) and gatekeepers' permission (Appendix B and D) has been obtained.

Secondary analysis of data was conducted with permission from the Demographic and Health Survey (Appendix C).

CHAPTER 3

IDENTIFYING ASSOCIATIONS BETWEEN NUTRITIONAL STATUS AND FOOD SECURITY AND SOCIAL WELFARE IN THE CONTEXT OF LOW BIRTH WEIGHT

Overview

This study aimed to assess the associations between indicators of nutritional status among children, and contextual factors including food security, social welfare, and low birth weight. These underlying causes for malnutrition were assessed for this urban population to identify potential associations between nutrition sensitive interventions and nutritional status. It was found that low birth weight was associated with later stunting risk, and that this effect was still applicable even when controlling for food security and social welfare. Low birth weight could be used as an indicator from birth to triage children as high risk for stunting.

3.1 Introduction

3.1.1 Causes of malnutrition

The UNICEF conceptual framework outlines the basic, underlying and immediate causes of malnutrition among children (UNICEF 1990). Inadequate dietary intake and disease are immediate causes of malnutrition. Insufficient household food security is an underlying cause of inadequate dietary intake. The distribution of resources is a basic cause of malnutrition (UNICEF 1990).

Interventions may be categorised according to whether they target underlying or immediate causes of malnutrition. Interventions targeting immediate causes of malnutrition are known as nutrition specific interventions, and those targeting the underlying causes of malnutrition are known as nutrition sensitive interventions (Ogden *et al*., 2017). Sectors which may be involved in nutrition-sensitive interventions include women's empowerment, agriculture, food systems, education, employment, and social safety nets (Bhutta *et al*., 2013). Childhood malnutrition stems from a multitude of aetiologies, and therefore targeting interventions effectively is a challenge (Mosites *et al*., 2016). More effective prevention and treatment strategies can be developed if the aetiology of childhood malnutrition is more clearly identified for a given population (Mosites *et al*., 2016).

3.1.2 Household food security

Approximately 10% of the global population suffers from severe food insecurity (FAO, 2018). There are approximately 45 million children suffering from wasting and 150 million children who are stunted worldwide (UNICEF, World Health Organisation, World Bank Group 2021). Accessibility, affordability, utilisation and stability of food systems affect food security. Food security refers to the availability of food, the ability to access food, and the adequacy of available food for human health.

South Africa (SA) is one of the most unequal societies in the world, with a Gini coefficient of 63.4 (The World Bank 2017). A Gini coefficient of 0 represents perfect equality, where all members of the population earn and consume the same amount, whereas a Gini coefficient of 100 represents perfect inequality, where a single member of a population earns and consumes all resources. One of the direct results of inequality is insufficient access to food, which is also one of the underlying causes of malnutrition (UNICEF 1991). According to the results of the 2016 General Household Survey, 22.3% of SA households had inadequate or severely inadequate access to food (Statistics South Africa 2013). In the Eastern Cape Province, 26.4% had inadequate access to food and 5.9% suffered severe inadequate access to food, indicating a high level of vulnerability (Statistics South Africa 2013). Shisana *et al., (*2013) reported that the national prevalence of hunger was the highest in informal urban settings with an estimated 32.4% of people experiencing food insecurity.

The Community Childhood Hunger Identification Project (CCHIP) questionnaire has been used to assess food security in the National Food Consumption Survey (NFCS) in 1999 and 2005, as well as the 2008 South African Social Attitudes Survey. There was a trend across these surveys of poor diet among children in poorer households, indicated by low dietary diversity scores. Dietary diversity is vastly different between food secure and food insecure households, which consume 16 compared with 8 different foods respectively over 24 hours (Labadarios *et al*., 2011). It was found that women in poorer households tend to skip meals in order for their children to eat (Labadarios *et al*., 2011). Approximately 16% of South African households supplement their dietary intakes through agricultural practices (Statistics South Africa 2019). It is thought that urban and peri-urban dwellers are at a higher risk of household food insecurity as there is less land available for subsistence agricultural practices, although access to food is higher in urban settlements. There is evidence of greater dietary diversity among urban and peri-urban households which practice subsistence agriculture, with 54% of households practicing agriculture reporting consuming more than six food groups compared with 40% of those not practicing agriculture, however the difference in household dietary diversity scores between these two groups is not significantly different. There was however, a statistically significant difference in access to food between these two groups (Khumalo and Sibanda 2019).

3.1.3 Child support grants and social security

Conditional cash transfers have been shown to improve uptake of health services to which the cash transfers are connected. However, uptake and attendance at health services has been found not to necessarily translate to improved health and nutrition outcomes when cash transfers are used (Gaarder, Glassman and Todd 2010). This suggests that cash incentives to encourage attendance at health services requires effective health services in order to bring about improvements in health and nutrition status (Gaarder, Glassman and Todd 2010). Where improvements in health and nutritional status have been observed in programmes supported by conditional cash transfer schemes, it has been difficult to attribute these improvements directly to the cash transfers due to confounding factors (Lagarde, Haines and Palmer 2009). In extremely deprived areas, poor health primary health services and ineffective systems for distributing payments are likely to confound the effect of cash transfers (Lagarde, Haines and Palmer 2009). However, they appear to be an effective approach to improve access to health services (Lagarde, Haines and Palmer 2009). Cash transfers intended to improve health outcomes can also include social assistance and social insurance, Sun *et al*., (2021) identified strategies including universal basic income and universal child development accounts as valuable cash transfer strategies.

Initiated in 1998, the SA Child Support Grant (CSG) provided a safety net to 2.5 million children from vulnerable households (Aguero *et al*., 2006). The CSG is an unconditional, means-tested grant awarded monthly to beneficiaries through the South African Social Security Agency. In 2015, 11 792 900 children were registered as CSG beneficiaries (South Africa Social Security Agency 2016), and this figure was projected to rise to 12.3 million by 2017 (National Treasury 2015). While social grants have made some impact on SA household food security, (Coetzee 2013) others argue that the effect of the CSG on nutritional status ‘may have been eroded by food price inflation and limited progress in the provision of other important interventions and social services’ (Zembe-Mkabile *et al*., 2016).

Koornhoff (2014) stated that CSG-receiving households in the Western Cape Province reported significantly lower household income and more child stunting than households in the same area not receiving CSGs. In a study in urban townships in the Eastern Cape, (Steenkamp *et al*., 2014) CSG-receiving households reported a higher monthly income than non-CSG-receiving ones. However, Steenkamp *et al*., (2014) showed that significantly more households with people receiving the CSG spent less than ZAR8 a day on food, compared with those not receiving the CSG. Households with children who received the CSG spent more money on non-food items, which may have contributed to the fact that they also experienced hunger more often, indicating that the CSG grant does not necessarily act as a safety net against hunger. According to Zembe-Mkabile *et al*., (2018), this may be because the child support grant is too small to make an impact on childhood nutrition, as other priorities compete for finances. However, it should be noted that qualitative evidence suggests that the CSG does improve women’s control of household finances and decision making. Often the CSG money is also pooled with other income (including other grants) to pay for household expenses such as food and electricity (Zembe-Mkabile *et al*., 2018).

3.1.4 Birth weight and malnutrition outcomes

Stunting has been associated with low birth weight, as well as environmental enteric dysfunction, two distinct causal pathways (Leroy and Frongillo 2019). Apart from food insecurity contributing to malnutrition in children, women’s health during the antenatal period may also impact foetal growth and development. A meta-analysis of 19 longitudinal birth cohorts from low- and middle-income countries revealed that children who were small for gestational age (birth weight less than 10th percentile for gestational age) were 2.4 times more likely to be stunted later in life, while preterm (less than 37 weeks’ gestation) children had 1.9 times increased odds of stunting (Christian *et al*., 2013). Children who were both small for gestational age (SGA) and preterm had a 4.5 times increased risk of stunting when compared with normal birth weight and term children (Christian *et al*., 2013). Maternal health and nutrition are therefore both important factors in the development of chronic child undernutrition. In South Africa, LBW was prevalent among 9.9% and preterm birth occurred in 11.4% of participants (Christian *et al*., 2013). The LBW rate in Nelson Mandela Bay health district (NMBHD) was 16% during the 2016 calendar year (District Health Information Software, Eastern Cape Department of Health).

Despite the available data on maternal and child outcomes, limited information is available regarding the impact of food insecurity, LBW, the protective effect of CSGs on malnutrition risk during the first 1000 days and the complex associations between these variables. The aim of the present study was to describe malnutrition risk among children younger than 2 years age residing in Motherwell, NMBHD, in the context of food insecurity, CSG and LBW history.

3.2 Methods

This was a descriptive study using a cross-sectional design. It involved measuring the weight, length or height and mid-upper arm circumference (MUAC) of children younger than 2 years residing in Motherwell. Motherwell is an area of ~25.86 km2 and with a population of 140 351 people (Massyn *et al*., 2015), with 5 817 children younger than 2 years in 2016. This community comprises lower-income residents with 6 clinics providing primary healthcare services. Procedures for obtaining anthropometric data followed protocols described by the Centers for Disease Control and Prevention (CDC) (McDowell *et al*., 2008). Measurements were carried out by trained fieldworkers. Weight was measured using a Nagata BW-2010 infant scale. A Seca infantometer with a movable foot piece was used for measuring length. Non-stretch MUAC tapes were used in the study. The study also involved the use of structured questionnaires including demographic information and the household food security (HHFS) by means of the Community Childhood Hunger Identification Project (CCHIP) questionnaire (Wehler *et al*., 1996). This questionnaire is composed of 8 questions, with each affirmative answer adding one point to a household's score. A CCHIP score of 0 indicates food security, a score of 1 to 4 indicates that a household is at risk of hunger, and a score of >5 indicates hunger (Wehler *et al*., 1996). Where needed, the CCHIP questions were translated into isiXhosa and captured by a trained fieldworker. A non-probability sampling method was employed (convenience sampling) resulting in a sample of 400 infants and young children. This sample was obtained from 5 clinics and 15 Early Childhood Development (ECD) centres over the period October 2015 to February 2016. Ethical approval was obtained from the Research Ethics Committee (Human) (ref. no. H15-HEA-002), Nelson Mandela University and the Eastern Cape

Department of Health. Inclusion in the study required written informed consent from the primary caregiver of the participant. Although the primary caregivers had to provide consent, not all were available at the ECD centres at the time of data collection to complete the CCHIP questionnaire or provide grant information.

Anthropometric data were used to calculate *z*-scores for weight-for-height (WHZ), weight-for-age (WAZ) and height-for-age (HAZ) using World Health Organization (WHO) Anthro software (WHO, Switzerland). For the purpose of this study, data cleaning criteria according to WHO (2006) were applied. Z-scores less than or greater than 5 SD of the mean were excluded as these are statistically implausible and more likely to be the result of measurement or transcribing errors. Descriptive statistics i.e. frequencies and percentages, were used to describe outcomes of categorical data. Inferential statistics included *t*-tests to compare anthropometric data from different birth weight categories and ANCOVA to allow for the effect of covariates.

3.3 Results

Nine records were removed from the sample as they had implausible *z*-scores. A further 10 records were removed due to incomplete data or not meeting the inclusion criteria.

All of the children included in this study were of black ethnicity and younger than 2 years of age. Half of the sample were male (*n*=199). The mean (standard deviation (SD)) participant age was 9.78 (6.13) months (median 9 months).

Of the sample, 9% were stunted, 1% were wasted and 16% were overweight. The mean (SD) WAZ was 0.44 (1.26), the mean (SD) WHZ was 0.83 (1.28) and the mean (SD) HAZ was –0.24 (1.26). The mean WAZ, HAZ and WHZ did not differ significantly between males and females in the sample or between age categories when using 3-month age intervals. Furthermore, there were no significant differences between the age of stunted compared with non-stunted children.

3.3.1 Birth weight

As illustrated in Table 3.1, 5.7% (n=22) of the sample with birth weight information available (n=386) reported a LBW (<2500g).

Table 3.1: Differences in birth weight category for anthropometric indicators of nutritional status (n=366).

Nutrition variable	Birth Weight Category	N	Mean	SD	Difference	t	d.f.	p	Cohen's d
WAZ	LBW Normal	22 362	-0.64 0.50	1.64 1.21	-1.13	-4.17	382	<.0005	0.91 Large*
HAZ	LBW Normal	22 360	-1.81 -0.16	1.81 1.24	-1.65	-5.90	380	<.0005	1.30 Large*
WHZ	LBW Normal	22 364	0.67 0.84	1.34 1.29	-0.17	-0.59	384	.555	n/a
MUAC	LBW Normal	22 366	15.39 15.37	1.70 1.76	0.02	0.05	386	.964	n/a

* Large practical significance

As expected, LBW participants had a significantly lower WAZ (p<.0005) and HAZ (p<.0005) than normal birth weight (NBW) participants (Table 3.1). However, no significant differences could be observed between LBW and NBW participants for WHZ and MUAC. LBW therefore, during the first 1000 days, seems to be significantly associated with lower height-for-age z-scores and not with lower weight-for-age z-scores. Interestingly, only 3% (n=12) of the NBW children deteriorated later into being stunted from birth till the survey date. These children represented 35% of the total number of stunted children (n=34) in this sample.

3.3.2 Food security

Responses to the CCHIP questionnaire were obtained from 76% (n=305) of the participant caregivers. The results from questions of the CCHIP questionnaire (Table 1) were collated and revealed that 23% of the sample were food secure, 47% were at risk of hunger, while 31% were classified as hungry. As illustrated in Table 3.2, more caregivers reported food insecurity at household level (45-60%) than child hunger (15-34%).

Children in the “Food secure” category had a mean WHZ of +1.0 (SD=1.4) compared with children in the “hungry” category with a mean WHZ of +0.7 (SD=1.2). Similarly, children in the "Food secure" category had a mean HAZ of -0.2 (SD=1.3) compared with a mean HAZ of -0.5 (SD=1.4) in the "Hungry" category.

Table 3.2: Results of the CCHIP questionnaire by question (n=305).

Answer to CCHIP questions	**No**		**Yes**	
Household-level food insecurity	n	%	n	%
Does your household ever run out of money for food?	122	40	183	60
Do you ever rely on a limited number of foods to feed your children because you are running out of money to buy food for a meal?	132	43	173	57
Do you ever cut the size of meals or skip meals because there is not enough money for food?	169	55	136	45
Individual-level food insecurity				
Do you ever eat less than you should because there is not enough money for food?	165	54	140	46
Child hunger				
Do your children ever eat less than you feel they should because there is not enough money?	206	68	99	32
Do your children ever say they are hungry because there is not enough food in the house?	226	74	79	26
Do you ever cut the size of your children's meals or do they ever skip meals because there is not enough money to buy food?	201	66	104	34
Do any of your children ever go to bed because there is not enough money to buy food?	260	85	45	15

3.3.3 Child Support Grants (CSG)

CSG data was available from 327 of the 400 participants. It was found that 67% (n=221) of participants with CSG information available were grant holders (Table 3.3). CSG holders showed a significant ($p<.05$) lower mean HAZ score than non-CSG holders (Table 3.3). There were no significant differences between grant recipients and non-recipients for mean WAZ and WHZ. Of the CSG holders, 10% (n=22) was classified as stunted while only 5.6% (n=6) of the non-CSG holders was classified as stunted.

Table 3.3: Differences in grant holder category for anthropometric indicators of nutritional status.

Nutritional Indicator	Grant holder	n	Mean	SD	Difference	t	d.f.	p	Cohen's d
WAZ	Yes	220	0.30	1.18	-0.25	-1.66	322	.099	n/a
	No	104	0.55	1.48					
HAZ	Yes	219	-0.38	1.27	-0.36	-2.23	321	.026	0.27
	No	104	-0.03	1.47					Small*
WHZ	Yes	221	0.73	1.23	-0.16	-1.05	325	.296	n/a
	No	106	0.89	1.48					

* Small practical significance

To appropriately account for all variables related to the nutritional indicators (WAZ, HAZ, WHZ) univariate ANCOVA's were conducted with CSG and CCHIP category the independent variables and birth weight the covariate. The results are reported in Table 3.4.

Table 3.4: Trends in WAZ, HAZ and WHZ related to CSG and CCHIP category when controlling for birthweight (n=298).

WAZ		Descriptive Statistics			ANCOVA Results		
Factor	Category	n	Mean	Std.Dev.	F-value	D.F.	p
Total		298	0.38	1.29			
CS Grant	No	96	0.60	1.46	1.31	1; 293	.253
	Yes	202	0.28	1.19			
CCHIP Cat.	Hungry	91	0.22	1.32	0.78	2; 293	.462
	At risk	138	0.36	1.31			
	Food secure	69	0.63	1.17			
Birth Weight (Covariate)					58.72	1; 293	<.0005
HAZ		Descriptive Statistics			ANCOVA Results		
Factor	Category	n	Mean	Std.Dev.	F-value	D.F.	p
Total		298	-0.27	1.34			
CS Grant	No	96	-0.03	1.46	1.90	1; 293	.170
	Yes	202	-0.39	1.27			
CCHIP Cat.	Hungry	91	-0.50	1.36	1.80	2; 293	.167
	At risk	138	-0.16	1.34			
	Food secure	69	-0.19	1.30			
Birth Weight (Covariate)					63.22	1; 293	<.0005
WHZ		Descriptive Statistics			ANCOVA Results		
Factor	Category	n	Mean	Std.Dev.	F-value	D.F.	p
Total		298	0.78	1.34			
CS Grant	No	96	0.95	1.48	0.95	1; 293	.331
	Yes	202	0.70	1.27			
CCHIP Cat.	Hungry	91	0.74	1.23	1.10	2; 293	.335
	At risk	138	0.68	1.33			
	Food secure	69	1.04	1.48			
Birth Weight (Covariate)					8.77	1; 293	.003

From Table 3.4 it is clear that birth weight was the only variable significantly related to the nutritional indicators. This shows that the effect of being born LBW results in a much larger negative effect on nutritional risk than the potential impact of food insecurity or the effect of being a CSG holder.

3.4 Discussion

Stunting affected almost 10% of the participants of this study, which was lower than expected when compared with other SA studies (Shisana *et al*., 2013). The WHO Conceptual Framework on Childhood Stunting suggests that poor micronutrient quality, low dietary diversity and inadequate intake of animal foods as well as the low energy content of complementary foods contribute to stunting (Stewart *et al*., 2013). However, in this sample, only a minority of children deteriorated into stunting after being born NBW. The majority of the stunted children had a history of LBW. Since LBW may be caused by intrauterine growth restriction secondary to hypertension (Braham *et al*., 2014), anaemia, teenage pregnancy (Ganchimeg *et al*., 2014), smoking and snuff use, as well as alcohol abuse during gestation, optimal antenatal care during pregnancy may have a much larger impact in reversing the high stunting prevalence among children than any of the available nutrition-specific interventions, i.e. supplementation programmes to address stunting after birth.

Catch-up growth in LBW infants is important and associated with an increase in the number of years of education that children received (Martorell *et al*., 2009). This emphasises the importance of early identification and treatment of children who fit into high-risk categories. Community health workers or caregivers who are part of the screening process by ward-based outreach teams have a limited capacity to measure and plot the growth of children accurately. It is easier to identify food-insecure infants as well as LBW infants as potential high-risk cases and refer those cases for health facility assessments, than to screen for stunting in the community. Even though hunger affected more than half of the households in our sample, findings suggest that LBW plays a more important role than food insecurity in lower mean height-for-age *z*-scores observed in infants and young children and therefore strategies and actions to prevent LBW in infants in this health district should be prioritised by healthcare professionals. Low birth weight has also been associated with low maternal body mass index (BMI) (Zembe-Mbakile *et al*., 2015), underlining the need for nutritional intervention for underweight women of childbearing age. Unfortunately, maternal nutritional status history was not available for this sample and longitudinal data in this district are necessary to provide adequate data to assess the impact of maternal nutritional status on birth outcomes.

As mentioned previously, a high percentage of caregivers in our sample reported hunger and risk of hunger in the households, with less than a quarter of the households being food secure. However, interestingly, the caregivers reported less children to be at risk of hunger than the number that reported households to be at risk. As stated previously, household food insecurity puts children at a high risk of malnutrition. Qualitative research to explore reasons for the lower prevalence of children at risk should be conducted since it may be related to children still receiving breastmilk during the first 1000 days, or a reluctance to acknowledge inadequate care on the caregivers' side. However, the food insecurity situation indicates that these children will experience continued problems and that any catch-up growth among LBW children will be highly unlikely, making it almost impossible to undo the long-term effects of LBW.

Since the CSG was implemented to protect poor households against the effects of unemployment and poverty, one would expect CSG holders to be protected against hunger. In our sample, CSG holders were significantly more stunted than non-CSG holders, but when LBW covariate is controlled for, the relationship was attenuated and became non-significant. However, the CSG alone could not undo the negative impact of IUGR, and was not sufficient to allow for catch-up growth in the first 1 000 days in the older age categories in this sample. Recent economic developments may result in higher food, education and transport costs for South Africans. The resulting increase in buying power among beneficiaries may therefore be disrupted. CSG recipients were far more likely to be hungry or at risk of hunger while non-recipients were more likely to be food-secure. Zembe-Mbakile *et al*., (2016) concluded that provision of the CSG has not provided any protection against stunting in SA. Children younger than two years have lower take-up rates for the CSG than older children (Zembe-Mbakile *et al*., 2015), the stage of the life cycle where most of the irreversible damage to cognitive development caused by stunting occurs. In this otherwise homogenous sample, the CSG was not enough to level the variances in income with regard to food security. The results also leave us with the question whether the CSG, which can only be applied for once the child is born and registered, is not needed much earlier during gestation as suggested in a recent systematic review from programmes in 27 countries (Chersich *et al*., 2016). This will ensure that the pregnant mother has sufficient funds to prevent hunger and support regular clinic visits to reduce the risk of preterm deliveries associated with SGA/LBW infants.

3.4.1 Study strengths

This study made use of gold standard methods of childhood anthropometry. The sample captured a large proportion of the target population in this setting. The method for assessing household food security has been validated and is a reliable measure. This questionnaire has been used in three previous national nutrition surveys in South Africa. The questionnaire was translated to isiXhosa where required, limiting the risk of misinterpreting the questions.

3.4.2 Limitations

Cross-sectional studies are not the study design of choice to determine growth patterns in children and this should be considered a limitation. Measuring infants and young children in clinics and crèches inherently excludes children who do not attend clinics and crèches and thus the results cannot be generalised. This study does not differentiate low birth weight as a consequence of small for gestational age or preterm birth. In addition, a confounding factor for the study is that it did not directly measure nutritional intake and its relationship with nutritional status.

3.5 Conclusion

Maternal health is important to prevent LBW and later malnourished children. Reducing the burden of childhood malnutrition will require the Department of Health to recognise the large impact of LBW and thus the need for improvements in antenatal care and healthcare for women of childbearing age. Policymakers could aim to make CSGs available to mothers as close to the time of birth as possible, or during pregnancy, to be effective during the first 1000 days of growth and development.

The results of this study suggest that birth weight and not underlying causes of malnutrition is the leading aetiological determinant of stunting in this South African population. Therefore, targeting nutrition interventions for stunting could be made more effective by prioritising children with low birth weight for growth monitoring.

CHAPTER 4

COVERAGE OF VITAMIN A SUPPLEMENTATION, DEWORMING AND IMMUNISATIONS: ASSOCIATIONS WITH NUTRITIONAL STATUS AMONG URBAN CHILDREN YOUNGER THAN FIVE YEARS IN NELSON MANDELA BAY, EASTERN CAPE

Overview

Nutrition specific interventions aim to address the immediate causes of malnutrition. These immediate causes include disease and poor dietary intake. The objective of the study was to describe coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children. There is previous evidence of stunting being associated with LBW in this population.

4.1 Introduction

Sub-Saharan Africa accounts for one third of all undernourished children globally with approximately 39% stunted, 10% wasted and 25% underweight children under-five years of age (UNICEF, WHO and World Bank 2020). Despite a decline in the global prevalence of stunting, the absolute number of stunted children in the African region has increased from 46.3 million children in 1990 to 57.4 million children in 2020 (UNICEF, WHO and World Bank 2020).

Conventional approaches to understanding the causes of childhood malnutrition have focused on infant and young child feeding practices and food security, with stunting perceived to be a result of chronic undernutrition (Raiten and Bremer 2020). Raiten and Bremer (2020) have challenged this conventional approach, and recently more attention has been paid to wider contextual factors which result in childhood malnutrition, including intrauterine growth restriction, poor nutritional status among pregnant and breastfeeding women and factors related to women's empowerment including education and access to resources. In addition, there is increasing interest in environmental enteric dysfunction in the aetiology of stunting (Black and Heidkamp 2018). Environmental enteric dysfunction refers to a subclinical state of intestinal inflammation, which results in poor nutrient absorption (Budge *et al*., 2019). Budge *et al*., (2019) suggest that poor sanitation and stunting may be causally linked via environmental enteric dysfunction. Vitamin A deficiency results in poor epithelial cell differentiation, which has an impact on gut mucosal integrity and nutrient absorption. Vitamin A deficiency and rotavirus infection are among the leading causes of diarrhoea in children (Lui *et al*., 2016). Soil transmitted helminth infestation, which may cause anaemia, diarrhoea and reduced appetite, can negatively affect the nutritional intake and growth and development of children even in urban areas (Lui *et al*., 2016).

4.1.1 Vitamin A physiology

Dietary vitamin A is available in a variety of forms. Preformed vitamin A is found in foods derived from animal sources. Preformed vitamin A exists as retinol, retinal and retinoic acid. These forms of vitamin A are highly bioavailable. Provitamin A refers to plant sources of vitamin A. The carotenoids are sources of provitamin A. These compounds are responsible for the yellow and orange pigments of plant foods. β-carotene is the most important dietary provitamin A carotenoid, but it is less bioavailable than preformed vitamin A. Approximately 50% of ingested B-carotene is absorbed, of which approximately 50% is converted to retinol (Blomstrand and Werner 1967). Other carotenoids have even less bioavailability. Provitamin A compounds are converted to retinol in the body. The vitamin A content of foods is often expressed in retinol equivalents (RE), to allow comparison between provitamin A and previtamin A content of foods.

Preformed vitamin A or retinol is absorbed into the enterocyte and binds to retinol binding protein (RBP). Provitamin A enters the enterocyte, and is incorporated into chylomicrons directly, or is converted to retinal before binding to RBP. Retinol binding protein, retinyl esters and carotenoids are incorporated into chylomicrons and transported via the lymphatic system to target cells or the liver. The retinyl esters are stored in the liver and released into the blood bound to RBP when needed. Homeostatic control of circulating serum retinol and retinyl esters creates challenges in assessing vitamin A status. Stored vitamin A is released from the liver bound to RBP, which results in serum retinol concentrations that do not reflect total body stores of vitamin A (Conaway *et al*., 2013). The exception is in cases of extreme vitamin A deficiency, when liver storage is depleted and serum concentrations begin to fall (Conaway *et al*., 2013).

Retinol is involved in cell differentiation and growth. Retinoids are converted to all-trans-retinoic acid, responsible for the majority of vitamin A's biological functions (Henning, Conaway and Lerner 2015). All-trans retinoic acid binds to retinoic acid receptors on proteins involved in DNA transcription in stem cells. This binding affects the presence and position of epigenetic marks and DNA methylation. Altering these epigenetic marks enables stem cells to begin differentiating into mature cells (Gudas 2013). This process is especially important for cells with a high turnover rate, such as epithelial cells. Vitamin A supports immune function through interactions with T-cells (Garbe, Buck and Hammerling 1992). Retinol is required for the normal proliferation of T-cells, including CD4+ and CD8+ thymic cells (Garbe *et al*., 1992). Initiating T-cell receptor activation appears to be dependant on the presence of retinol (Garbe *et al.,* 1992). All-trans retinoic acid is involved in osteoclast activity (Henning, Conaway and Lerner 2015). This compound moderates osteoclast activity, and therefore is an important factor in bone remodelling (Conaway, Henning and Lerner 2013). It can both stimulate osteoclast activity, and inhibit osteoclast formation (Conaway, Henning and Lerner 2013).

There is a large body of literature describing the effects of hypervitaminosis A on bone health. Evidence from epidemiological studies as well as animal models (Lionikaite *et al*., 2019; De Luca *et al*., 2000; Sommer 1982) suggests that excessive preformed vitamin A intake is associated with an increased rate of bone resorption, and clinical effects such as increased risk of fractures and osteoporosis. Evidence has emerged that hypervitaminosis A affected up to 63% of children in a Northern Cape population in South Africa (van Stuijvenberg *et al*., 2019), related to multiple vitamin A deficiency interventions converging on the population. Hypervitaminosis A can affect the height, size and activity of growth plates on bones, suggesting that this may result in linear growth retardation. A negative association has been observed between total liver vitamin A storage and indicators of nutritional status among children including height for age, weight for age and weight for height among South African children (Sheftel *et al*., 2022). It is concerning that variation in anthropometry is explained by liver vitamin A stores within 4 weeks of vitamin A supplementation among these children (Sheftel *et al*., 2022).

There is a paucity of evidence on the effects of vitamin A deficiency on bone growth and proliferation. Rats who are depleted of vitamin A display slower growth and eventually cessation of linear growth (Sommer 1982). Weight loss occurred in these rats only when severe depletion of vitamin A status took place (Sommer 1982). There may be a more direct link between vitamin A deficiency and growth retardation through the action of retinoic acid as a gene transcription activator. The retinoic acid receptor displays similarities to the thyroid hormone nuclear receptor, which has raised speculation that retinoic acid acts with thyroid hormone to regulate growth hormone. However, in vivo effects on growth are unclear (West 1991). Hadi *et al*., (2000) found that high dose vitamin A supplementation improves linear growth among children. However, this improvement is modest, and depends on vitamin A status prior to supplementation, breastfeeding status and age of the child (Hadi *et al*., 2000). Children with a serum retinol concentration of less than 35 umol/L, receiving a vitamin A supplement gained an additional 0.39 cm in height over a four month period compared with controls. However, there was no difference between treatments and controls when baseline serum retinol concentrations were greater than 35 umol/L (Hadi *et al*., 2000).

It is likely that the association observed between vitamin A deficiency and stunting, or linear growth retardation, is a result of disturbances to immune function and maintenance of epithelial tissue. Epithelial tissue includes all surface tissues internally and externally, and therefore, poor maintenance of the mucosal surface in the gastrointestinal tract may result in poorer nutrient absorption and ultimately stunting as a result of vitamin A deficiency. Deficiency of vitamin A exacerbates diarrhoeal disease among children with severe acute malnutrition (Tomkins 1993). Vitamin A is involved in normal proliferation of mucosal cells in the gut. Vitamin A in combination with vitamin D play a role in maintaining tight junction proteins between mucosal cells in the gut, and therefore are critical to maintaining the gut's barrier function in preventing bacteria from the gut from entering circulation (Cantorna *et al*., 2019).

Micronutrient deficiency, or 'hidden hunger' may result in a decreased immune function, and inadequate growth leading to stunting (Castejon *et al*., 2004). Vitamin A deficiency (VAD) has been identified as a global public health concern affecting about 30% of all children (Wirth *et al*., 2017). Therefore, national programmes have implemented high-dose vitamin A supplementation to children younger than five years at 6-month intervals, to reduce morbidity and mortality (Vosti *et al*., 2020). Despite inconclusive country-level evidence on the efficacy of vitamin A supplementation to reduce morbidity and mortality (Wirth *et al*., 2017), the WHO still recommends high dose vitamin A supplementation for infants and children between six and 59 months of age in areas with a high prevalence of vitamin A deficiency (WHO 2011). Despite this being a priority, a recent assessment of 82 countries revealed that two thirds either had no data about vitamin A coverage or VAD or data was older than 10 years at the time of assessment (Wirth *et al*., 2017). Although vitamin A supplementation according to recent evidence may have yield inconsistent results in relation to childhood mortality and morbidity (Gebremedhin 2017), many countries still support evidence that VAD may contribute to diarrhoea in children.

The South African Nutrition Roadmap 2013-2017 was introduced in 2013 as an important aspect of the Strategic Plan of the National Department of Health, under the South African government Medium Term Strategic Framework 2009-2014 (South African Department of Health 2013). These government strategies aimed to improve the health profile of all South Africans, as well as to decrease child and maternal mortality. The proportion of children receiving at least 2 doses of vitamin A supplementation was included as a core indicator for monitoring and evaluating the implementation of the South African Nutrition Roadmap 2013-2017 (South African Department of Health 2013). The aim over this period was to increase the proportion of children younger than five years old receiving high dose vitamin A supplements from 42% to 90% of infants younger than 11 months of age and 80% of children younger than five years of age (South African Department of Health 2013). The coverage rate among South African children 6-59 months old was 50% in 2018 (World Bank and UNICEF 2018).

4.1.2 Helminths

Evidence suggests that poor maternal education, poverty, low birth weight, using an unimproved water source, low maternal BMI, recurrent diarrhoeal episodes and living in a rural area are all amongst the risk factors for stunting (Raiten and Bremer 2020; Tahangacca *et al*., 2020).

Improved water sources refer to those that are designed and constructed to protect water from contamination, and in particular, from contamination with faecal matter.

Improved water sources include on-premises piped drinking water connections, including running water in dwellings, yards or on the plot, public standpipes, boreholes, protected dug wells, protected springs and rainwater collection. Unimproved drinking water sources include unprotected wells, unprotected springs, surface water from rivers, dams, lakes, ponds, streams, canals or irrigation channels, vendor provided water delivered by tanker truck or cart with a small tank, and bottled water.

In countries like South Africa, unimproved water sources are mostly limited to rural areas. However, even in urban areas, in poorer communities safe piped water is often only available in the yard, and not necessarily in the house or dwelling (Eastern Cape Socio Economic Consultative Council 2017), which makes optimal implementation of Water, Sanitation and Hygiene (WASH) practices challenging. Therefore, soil transmitted helminth infestation, which may cause anaemia, diarrhoea and reduced appetite, can negatively affect the nutritional intake and growth and development of children even in urban areas (Muller *et al*., 2016; UNICEF 2016). According to a randomised controlled trial, deworming with a single dose of 500mg mebendazole at 12 months of age had no effect on the growth of children at follow up (Joseph *et al*., 2015). Previous evidence however, suggests that the low efficacy associated with a single dose *Albendazole* may be due to a high rate of re-infection post treatment in developing countries (Adegnika *et al*., 2014). Therefore, the WHO and South African guidelines still recommend periodic treatment with antihelminthic protocols without previous individual diagnosis, to all at-risk preschool children living in endemic areas.

4.1.3 The Expanded Programme on Immunization (EPI)

The Expanded Programme on Immunization (EPI), begun in 1974 and is considered one of the world's most successful public health programmes (Wallace *et al*., 2012).

The South African Expanded Programme of Immunisation aims to prevent diseases including measles, polio, diphtheria, pertussis, tetanus, hepatitis B, haemophilus influenzae type B (HiB), tuberculosis, pneumococcal diseases and rotavirus (South African National Department of Health 2012). The EPI achieved the eradication of polio in South Africa in 2006 (South African National Department of Health 2012). Measles and neonatal tetanus are also being targeted for eradication under the programme (South African National Department of Health 2012).

Rotavirus is an RNA virus. This virus is transmitted from host to host via contact with contaminated substances, including surfaces of hands and water. The rotavirus invades columnar epithelial cells on the surface of the villi in the small intestine but does not affect crypt cells (Haffejee 1991). It causes the loss of absorptive capacity through destruction of villi cells, as well as disruption to differentiation of mucosal cells. This results in diarrhoea, fluid secretion into the bowel lumen and reduced absorption of sodium and glucose, necessary for osmotic absorption of water in the bowel. Brush border enzyme levels including lactase, maltase and sucrase are reduced due to the loss of intestinal villi cells (Haffejee 1991).

The rotavirus vaccine is given to South African infants at two, four and six months of age. In 2000, rotavirus infections were responsible for approximately half a million under-five child deaths a year. This figure was reduced to approximately 200 000 deaths among children in 2013 (Tate *et al*., 2016). The majority of cases occur before the child reaches twelve months of age. The proportion of rotavirus positive hospitalisations due to diarrhoea among infants has decreased from 41% to 21% between 2010 and 2015 following the introduction of rotavirus vaccines in East and Southern Africa (Weldegebriel *et al*., 2018). The rotavirus vaccine was included as part of the EPI in South Africa in 2009. Apart from the vaccine being associated with significant reductions in severe gastro enteritis in the first 2 years of life (Madhi *et al*., 2012), immunisation has been associated with improved height-for-age Z-scores (HAZ) among children (Loli *et al*., 2020).

Since the EPI is a platform from which it is possible to deliver additional health interventions, other primary healthcare services like deworming as well as vitamin A supplementation and growth monitoring were integrated to coincide with immunization where possible, as a strategy to increase coverage of these maternal and child health (MCH) interventions. Recovery from stunting in childhood has been associated with timely child immunisation (Faye, Fonn and Levin 2019), suggesting that prevention of childhood illnesses is an important component of preventing childhood malnutrition.

As children require less frequent vaccinations as they get older, visits to primary health care services may decline. Countries with constraint health resources therefore have to consider strategies like outreach visits to community pre-schools and creches, to ensure adequate coverage of these interventions. Although vaccination rates in

Nelson Mandela Bay have been improving (Massyn *et al*., 2015), the rate of childhood morbidity and mortality remains high (Nyarko 2014). Limited information was available at the time of the study with regards to coverage of vitamin A supplementation and deworming.

The objective of the study was to describe coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children. There is previous evidence of stunting being associated with LBW in this population (McLaren *et al*., 2018), therefore the authors will try to establish if a similar relationship can be observed from this larger sample, and if a significant relationship exists, control for LBW when doing the analysis.

4.2 Methods

A cross-sectional study was conducted between September 2015 and February 2016 in classes from 32 pre-schools or creches. Ethics approval (H15-HEA-DIET-003) was obtained from the Nelson Mandela University (NMU) Research Ethics Committee (Human) and institutional permission was obtained from the Eastern Cape, Department of Education as well as principals and teachers from all the schools. Parents of all the children in the classes of the ECD practitioners received a letter explaining the purpose of the research and inviting them to provide informed, written consent for their children to participate in the study. Parents were requested to send their children's clinic cards to the pre-school. A convenience sample was obtained including all children who possessed signed informed consent letters, clinic cards, and agreed to undergo the anthropometric measurements on the day of data collection. All schools included in the sample fell under the no-fee paying school category.

Weight and height or length were measured using standardised techniques (Centre for Disease Control 2007) by trained fieldworkers, under supervision, using calibrated equipment. Weight was measured in kilograms (kg) to the nearest 0.01 kg using a calibrated Seca electronic scale (Model 874), height was measured in centimetres (cm) to the nearest 0.1 cm using a Seca (Model 217) stadiometer for children older than 24 months and length was measured recumbently in centimetres to the nearest

0.1 cm using a Seca 210 mobile measuring mat for children younger than 24 months. Date of birth, date of visit, sex of the child, last date of vitamin A supplementation, last date of deworming and vaccination records were collected from participants' clinic cards. Data collection tools were piloted prior to the study, and data was recorded onto an electronic database.

Weight-for-age z-scores, height-for-age z-scores (HAZ), weight-for-height z-scores (for children below 60 months of age) and BMI-for-age z-scores (BAZ) were subsequently generated using the National Center for Health Statistics/WHO reference with the WHO Anthro- and WHO Anthro plus programmes (version 1.0.4) (WHO 2006), to determine stunting (HAZ < -2 SD), wasting (WHZ < -2 SD) and overweight (WHZ > +2 SD for children up to 60 months or BAZ > +1 SD for children older than 60 months. Data was cleaned according to WHO (2006) criteria. Deworming and vitamin A supplementation that was given more than seven months before the assessment date, were considered to be delayed. An immunisation that was due at the appropriate age at the time of assessment, but more than 30 days late according to the clinic card, was considered to be a missed vaccination. For the purpose of data analysis, the participants were split into age categories in three-month intervals.

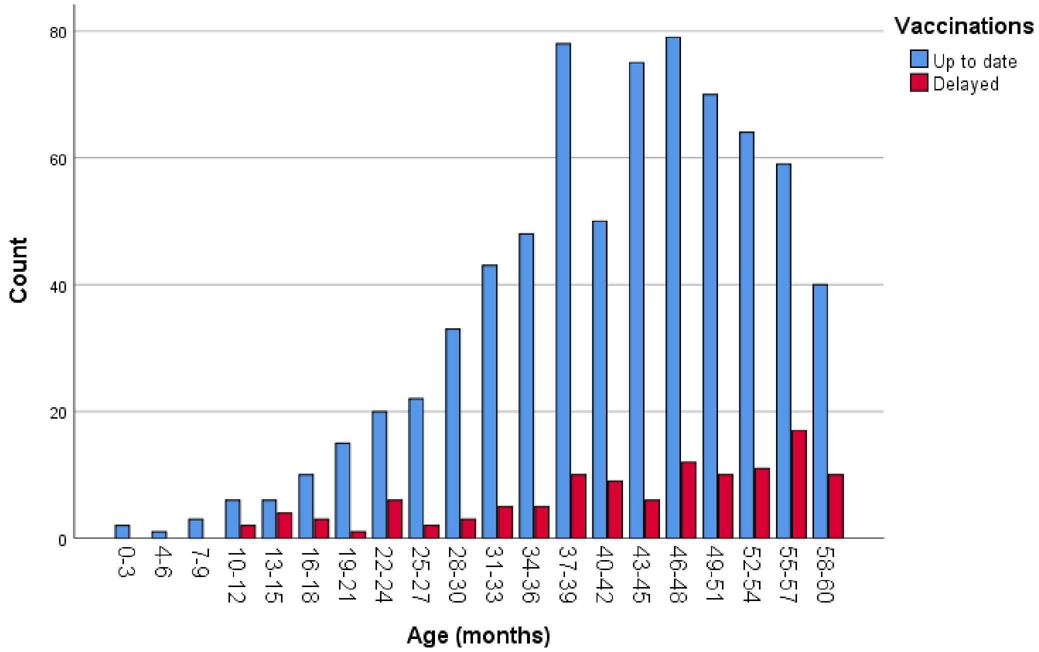
Data was analysed using SPSS v26 (IBM Corp 2017). Descriptive statistics including frequencies and percentages were used to describe outcomes of categorical data. Inferential statistics included t-tests to compare anthropometric data from different vitamin A, deworming, vaccination, and birth weight categories. Children were categorised into three-month age intervals to represent the dynamic growth of children and to facilitate data analysis. Associations between delayed vaccination, vitamin A and deworming and age categories were analysed using chi squares. Significance was set at α=0.05. Binomial regression analysis was used to assess stunting risk associated with birth weight for age categories and multinomial regression analysis was used to explore risk factors for stunting. The odds ratio (OR), 95% confidence interval (CI) and *p*-values were calculated using the model. The significance level was set to α <0.05

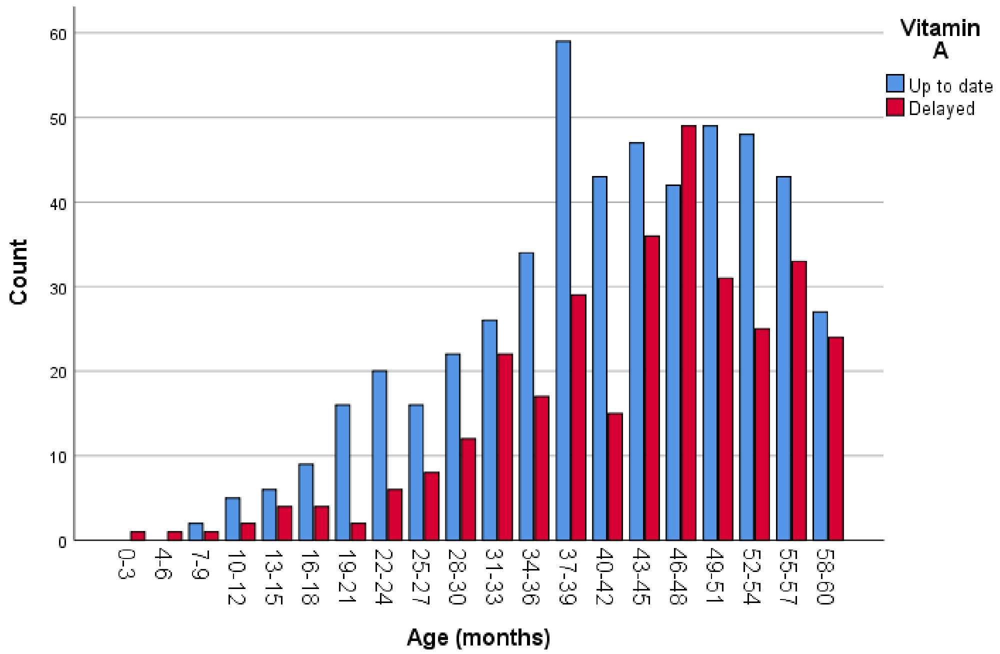
4.3 Results

Data was collected on 1513 children. There were 1496 children included in the analysis, as 17 children had implausible z-scores. The mean age of participants (n=1496) was 34.4 months (SD=17.93) and 50.0% of the sample was male (n=748). The mean birth weight was 3062 g (SD=577 g) and 14.0% of the children, according to the clinic cards, had a low birth weight (n=170). The mean WAZ was 0.12 (SD=1.16) with 2.5% (n=37) being underweight. The mean HAZ was -0.63 (SD=1.23) and 8.3% (n=126) were moderately stunted with a further 2.7% (n=41) severely stunted. The mean WHZ was 0.69 (SD=1.17). According to the WHO (2006) definitions, 0.3% (n=4) were severely wasted and 0.8% (n=12) were moderately wasted. Due to missing clinic cards or cards that were re-issued, vaccination data was only available for 840 participants, of which 13.8% (n=116) were not up to date with their vaccinations. Deworming data was available for 558 children, and 39.6% (n=221) of these children were not up to date with their deworming treatment. Data on vitamin A was available on 836 children, and 38.5% (n=322) had missed their last vitamin A dose.

4.3.1 Trends in vaccination, vitamin A and deworming coverage

Trends in vaccinations, vitamin A and deworming are presented in Figure 4.1. There was no relationship between the age category of children and vaccinations being up to date (X^2=23.79, df=19, n=840, p=0.204). However, a significant relationship was observed between delayed vitamin A supplementation and age category (X^2=32.105, df=19, n=836, p=0.03) as well as between delayed deworming and age category (X^2=45.257, df=17, n=558, p=0.00).


Vaccinations
Up to date
Delayed
Count
80
60
40
20
0
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
49-51
52-54
55-57
58-60
Age (months)


Vitamin A
Up to date
Delayed
Count
60
50
40
30
20
10
0
0-3
4-6
7-9
10-12
13-15
16-18
19-21
22-24
25-27
28-30
31-33
34-36
37-39
40-42
43-45
46-48
49-51
52-54
55-57
58-60
Age (months)

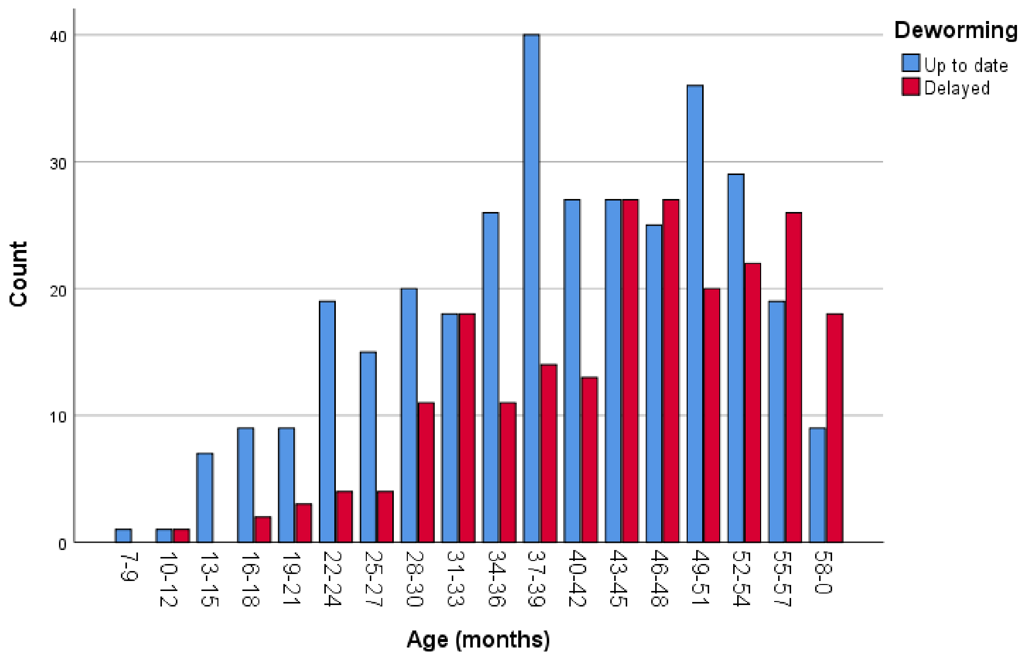


Figure 4.1: Delayed vs up-to-date vaccination, vitamin A and deworming by age (n=840).

4.3.2 Relationship between nutritional status and coverage

No significant differences in anthropometric indicators (WAZ, HAZ and WHZ) were observed for children who had received vitamin A and missed the most recent dose of vitamin A (Table 4.1). Similar trends were observed for up-to-date vaccinations and up-to date deworming, versus interventions that were late. Significant differences in WAZ, HAZ and WHZ were observed for children born LBW compared with those born with a normal birth weight.

Table 4.1: Differences in vitamin A category, vaccinations, deworming category and birth weight category for anthropometric indicators of nutritional status.

Nutrition variable	**Vitamin A**	**n**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	Up to date	513	-0.01 (1.12)	0.036	0.458	833	0.647
	Delayed	322	-0.05 (1.075)				
HAZ	Up to date	514	-0.815 (1.14)	0.019	0.244	834	0.807
	Delayed	322	-0.834 (1.041)				
WHZ	Up to date	513	0.652 (1.17)	0.025	0.313	833	0.754
	Delayed	322	0.625 (1.16)				
Nutrition variable	**Deworming**	**N**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	Up to date	337	0.16 (1.09)	0.119	1.242	556	0.215
	Delayed	221	0.04 (1.13)				
HAZ	Up to date	337	-0.743 (1.17)	0.033	-0.341	556	0.733
	Delayed	221	-0.77 (1.11)				
WHZ	Up to date	337	0.843 (1.11)	0.119	1.2	556	0.231
	Delayed	221	0.723 (1.21)				
Nutrition variable	**Vaccinations**	**n**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	Up to date	723	-0.0427 (1.11)	-0.065	-0.588	837	0.557
	Delayed	116	0.0227 (1.11)				
HAZ	Up to date	724	-0.826 (1.11)	0.0265	0.240	838	0.810
	Delayed	116	-0.852 (0.99)				
WHZ	Up to date	723	0.6284 (1.16)	-0.0938	-0.799	837	0.424
	Delayed	116	0.722 (1.24)				
Nutrition variable	**Birth weight**	**n**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	LBW	170	-0.635 (1.13)	-0.857	-9.150	1207	0.000
	NBW	1039	0.222 (1.13)				
HAZ	LBW	170	-1.44 (1.19)	-0.917	-9.582	1208	0.000
	NBW	1040	-0.535 (1.16)				
WHZ	LBW	170	0.325 (1.29)	-0.424	-4.301	1207	0.000
	LBW	1039	0.749 (1.17)				

4.3.3 LBW and nutritional status

Children with LBW were at an increased risk of stunting (OR= 4.658, p>0.01) (Table 4.2). Among children younger than 12 months, there was an increased risk of being stunted given LBW history (OR=29.318, p>0.01), however, among children with a history of LBW above the age of 48 months, the odds of being stunted were not significant (OR=0.911. p=0.885).

Table 4.2: Risk of stunting for low-birth-weight children at any age, 12 months and 48 months.

Stunted at follow up (any age) (n=1223)			
Risk factor	**OR**	**95% CI**	**p-value**
Low birth weight[a]	4.658	3.132-6.927	>0.01*
Stunted at <12 months (n=261)			
Low birth weight[a]	29.318	10.542-81.534	>0.01*
Stunted at >48 months (n=299)			
Low birth weight[a]	0.911	0.257-3.226	0.885
* Statistically significant at p<0.05 a. Reference category is normal birth weight			

Low birth weight (OR=5.603, p>0.01) was a significant risk factor for stunting among children. Vitamin A supplementation, deworming and vaccinations were not significant factors in stunting risk (Table 4.3).

Table 4.3: Factors associated with stunting risk (n=530).

Risk factor	OR	95% CI	p-value
Deworming delayed[a]	1.601	0.766-3.344	0.211
Vitamin A delayed[b]	1.223	0.577-2.593	0.600
Vaccinations delayed[c]	1.081	0.415-2.499	0.969
Low birth weight[d]	5.603	2.987-10.512	>0.01*
Male sex[e]	1.668	0.964-2.867	0.067

a. Reference category deworming up to date
b. Reference category vitamin a up to date
c. Reference category vaccinations up to date
d. Reference category normal birth weight
e. Reference category sex is female

* Statistically significant at $p<0.05$

4.4 Discussion

This study aimed to describe the coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. Approximately a third of children with completed clinic cards had missed vitamin A and deworming treatments, whereas less than 15% of children were not up to date with their vaccination schedules. It was also found that there was a relationship between missed vitamin A and deworming treatment and age category. Most immunisation doses under the EPI schedule take place within the first 18 months of life. It is suggested that the EPI schedule provides an opportunity for vitamin A deworming through routine visits to clinics and mobile clinics. However, Comley *et al*., (2015) suggested that vitamin A distribution needs re-evaluation in South African communities as there is a large discrepancy between vitamin A and vaccination uptake. This is supported by our finding that vitamin A supplementation uptake is poorer when children are older and require less frequent vaccinations.

4.4.1 Nutrition specific interventions and anthropometric measures of nutritional status

A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children. The WHO has made a strong recommendation for providing vitamin A supplementation in communities at risk of deficiency as there is good evidence of effectiveness of vitamin A supplementation in reducing childhood mortality (WHO 2011). However, the evidence for effectiveness in other indicators of child health such as growth are weaker (WHO 2011). No significant differences in anthropometric indicators (WAZ, HAZ and WHZ) were observed for children who had received vitamin A and missed the most recent dose of vitamin A. The findings of this study suggest that children are likely to miss doses of deworming medications, putting them at a higher risk of re-infection and undermining the effectiveness of the intervention. However, in this sample poorer coverage of vaccination and deworming did not affect the nutritional status of participating children. Other researchers suggest that academic achievement is poorer among children infected with soil-transmitted helminths (Gall *et al*., 2017). Stunting is associated with poorer cognitive development (Fink and Rockers 2014). However, regularly treating children with deworming medications does not appear to improve weight, height, stunting prevalence, school performance, iron status or mortality outcomes (Taylor-Robinson *et al*., 2019; Welch*.,* 2017). WaSH strategies including improved sanitation, wearing shoes, washing hands before eating and after defaecating could instead be prioritised as long-term interventions to prevent helminth infestation and associated negative outcomes. This is because frequent re-infection may be undermining chemotherapeutic strategies to address soil-transmitted helminths (Strunz *et al*., 2014).

Basic staple foods have been fortified with vitamin A in South Africa since 2003 (Republic of South Africa 2003). Faber *et al.,* (2015) found that fortified bread and maize products contributed to the majority of vitamin A intake in urban children in South Africa and that while vitamin A supplementation rates were poor, the prevalence of vitamin A deficiency was lower in urban areas compared with national estimates. Therefore, the value of high-dose vitamin A supplementation may be reduced in urban environments in the context of higher intakes of vitamin A-fortified staple foods. This may in part explain why no associations could be demonstrated between poor vitamin

A coverage and a compromised nutritional status. Given the evidence of the emergence of hypervitaminosis A among South African children, Coutsoudis *et al*., (2019) have called for the vitamin A supplementation programme to be withdrawn.

4.4.2 Birth weight and anthropometric measures of nutritional status

Previous research from this community revealed that access to child support grants and household food security are associated with stunting risk until low birth weight is considered as a co-factor (McLaren *et al*., 2018). When low birth weight was considered, food security and access to grants were no longer significantly associated with anthropometric indicators of nutritional status in children. Significant differences in WAZ, HAZ and WHZ were observed for children born LBW compared with those born with a normal birth weight in the current study, and children with LBW were at an increased risk of stunting. Children with a low birth weight were more likely to have a HAZ<-2 in the first 12 months of life, but children with LBW in older age categories were not significantly more at risk of stunting. This suggests that children with low birth weight may eventually experience catch up growth. However, the reasons for this recovery were not accounted for in the present study. The results of the multinomial regression analysis suggest that sex, delayed vitamin A, delayed deworming and delayed vaccinations are not associated with stunting risk, but low birth weight is a significant risk factor for stunting. There was no evidence that delayed vitamin A, deworming and vaccinations contributed to stunting and wasting in this sample, and that low birth weight was likely to be corrected without these interventions. Longitudinal evidence from India suggests that childhood immunisations are associated with recovery from stunting between five and eight years of age (Singh *et al*., 2017). Faye *et al*., (2019) found that timely child immunisation along with age at stunting, household economic status and mother's parity were among the factors associated with recovery from stunting before the fifth birthday in Kenya.

4.4.3 Study strengths

This study made use of gold standard techniques of measuring child anthropometry. It made use of the same techniques for measuring and interpreting childhood nutritional status as is recommended by the South African Department of Health. Clinical record cards were used to collect data on medical history of the children included in the sample. This study made use of gold standard anthropometry methods for data collection.

4.4.4 Study limitations

Data was collected from children attending creches and therefore the results cannot be generalised to the wider population. The study used a cross-sectional design which is not the ideal design for describing the factors associated with the dynamic growth patterns in children. Data on vitamin A, deworming and vaccination history was limited to the last dose and did not account for the full vitamin A, deworming and vaccination history. There was no investigation whether children in this sample with delayed deworming were infected with STH. Data was not collected on potential confounding factors including HIV and other illnesses. Morbidity and mortality were not assessed in this study, limiting the interpretations of the effectiveness of vitamin A supplementation, deworming and vaccinations to their effects on anthropometric status. Birth weight was recorded but not gestational age, so no distinction is made between low birth weight and premature birth children. Data were collected on vitamin A supplementation coverage, but not vitamin A status in this population.

4.5 Conclusion

Coverage of vitamin A supplementation and deworming treatment, but not immunisations was poor among children in this population. One third of children had missed vitamin A or deworming treatment. The Department of Health should invest in strategies to improve coverage of these interventions. History of delayed vitamin A supplements, deworming and vaccinations were not associated with anthropometric status of children. Low birth weight was the only factor significantly associated with stunting risk. Children with low birth weight should be considered for more rigorous follow up as they are at a higher risk of stunting.

CHAPTER 5

ASSOCIATIONS BETWEEN SOCIO-ECONOMIC FACTORS AND INDICATORS OF NUTRITIONAL STATUS AMONG WOMEN OF CHILDBEARING AGE IN SOUTH AFRICA

Overview

Low birth weight has been consistently shown to be a risk factor for stunting. Therefore, maternal nutritional status and socioeconomic factors may play an important role in the development of childhood malnutrition. This study aimed to identify features of the nutritional double burden of disease among women of childbearing age in South Africa, and to determine whether there were associations between indicators of nutritional status and socio-economic factors within this population.

5.1 Introduction

Weight gain during pregnancy includes the weight of the developing foetus, placenta, and amniotic fluid, as well as an increased maternal blood volume, extracellular fluid and fat deposits. Most of the gestational weight gain takes place during the second half of pregnancy (after 20 weeks gestation). The Institute of Medical Classification suggests that normal weight gain during pregnancy should be determined based on pre-pregnancy weight status (Institute of Medicine 2009). A woman with a normal pre-pregnancy BMI could expect to gain between 11.5 and 16 kg over the course of gestation, while a woman with an obese BMI (BMI>30 kg/m2) might gain between 5 and 9 kg. However, in many countries, there is no officially recognised range of healthy weight gain during pregnancy.

Models predicting energy requirements during gestation initially estimated that the total energy cost of pregnancy was approximately 78872 kcal (WHO 1985). This model assumed an average gestational weight gain of 12.5 kg, of which 0.9 kg was protein, 3.8 kg was fat and 7.8 kg was water. It also assumed that efficiency of energy utilisation was 90% (Hytten and Chamberlain 1980). This would result in an increase in energy requirements of 280 kcal per day. However, research indicates that this model does not reflect actual increases in energy intakes during pregnancy. Similarly, recommendations on energy intake during pregnancy by the FAO, WHO and UN

(2004) are higher than intakes typically detected in observational studies with no adverse effect on birth weight outcomes. Data on undernourished Gambian women suggested that metabolic adaptations take place which protect foetal growth (Singh *et al*., 1989). These physiological adaptations are not present in well-nourished women (Prentice *et al*., 1989). Energy intakes of approximately 200 kcal above pre-pregnancy energy intakes during the third trimester only are sufficient to meet the energy costs of pregnancy (Jebeile *et al*., 2016). However, women who are overweight at the start of pregnancy may not require this additional increment. In addition, evidence suggests that a large proportion of women in sub-Saharan Africa do not gain sufficient weight during pregnancy, and that the risk of inadequate gestational weight gain is particularly high among underweight women (Asefa *et al*., 2020).

Both infant birth weight and maternal weight gain during gestation are associated with the risk of complications for mother and baby (WHO 1995). A birth weight between 3.1 and 3.6 kg is associated with the optimal ratio of infant and maternal outcomes (WHO 1995).

There is an important distinction between preterm infants and low birth weight infants. Preterm infants are those which are born before 37 weeks gestation. Low birth weight babies are born at more than 37 weeks gestational age, but have a birth weight of less than 2500 g. Low birth weight is associated with low pre-pregnancy BMI, short maternal stature, poor gestational weight gain, anaemia, infections, smoking and excessive alcohol intake during pregnancy. There is a higher risk of morbidity and mortality for both preterm and LBW infants (Wilcox 2001). There is also an increased risk of chronic diseases in adulthood among infants born preterm or with LBW (Barker 1998).

Maternal nutritional status is an important determinant of the risk of preterm delivery. The risk of preterm delivery is twice as high among women with an obese class II body mass index (BMI) compared with normal weight women (BMI18.5-24.9 kg/m2). This risk triples at a BMI greater than 40 kg/m2 (Cnattingius *et al*., 2013). Obesity increased both the risk of preterm delivery as well as extremely preterm delivery (Cnattingius *et al*., 2013). Common causes of preterm delivery among South African women include hypertension, spontaneous preterm labour and preterm rupture of membranes (Odendaal *et al*., 2013). Obesity, and visceral fat, raise the risk of hypertension through alterations to hormonal, inflammatory and endothelial systems (Seravalle and Grassi 2017).

5.1.1 Iron metabolism and biological markers

Iron deficiency anaemia is one of the most common micronutrient deficiencies across the world. It is estimated that 600 000 women of childbearing age suffer from iron-amenable anaemia globally (WHO). Poorly educated women, women living in urban settlements and women with low incomes, between 25 and 35 years of age are at an increased risk of iron deficiency anaemia in sub-Saharan Africa (Correa-Agudela *et al*., 2021).

Dietary iron is present in two forms- haem iron from animal sources and non-haem iron found in plant foods. Both forms of dietary iron are absorbed in the duodenum in the small intestine. Haem and non-haem iron have different oxidation states. Haem iron is ferrous iron (Fe^{2+}), while non-haem iron is ferric iron (Fe^{3+}). Ferric iron must be reduced to ferrous iron before it can be absorbed. A membrane protein on the duodenal cell known as DcytB reduces ferric iron to ferrous iron before it is absorbed into the duodenal cell via the membrane protein divalent metal transporter-1 (DMT-1). Haem iron is absorbed intact, and the haem group is removed inside the duodenal cell by the enzyme haem oxidase (HO). Free iron in the duodenal cell is known as the labile iron pool. Unbound ferrous iron has a high affinity for oxygen and generates free radicals, which can damage cell membranes and DNA. Therefore, iron is stored safely in ferritin, a storage protein for iron. Iron from the labile iron pool may also be used in enzymatic pathways by the mitochondria. Iron is exported to the blood via ferroportin and transported to target sites by transferrin in the plasma. Transferrin carries ferric iron exclusively, therefore ferrous iron from the duodenal cell is oxidised to ferric iron by a membrane protein attached to ferroportin called hephaestin. There is no excretory pathway for iron, and therefore iron homeostasis is regulated at the site of iron absorption. Hepcidin is produced by the liver when iron stores are adequately full. This protein binds to feroportin and hephaestin, resulting in structural changes in these proteins which causes them to be resorbed into the duodenal cell and dismantled. Hepcidin is also produced in response to inflammation.

Transferrin transports iron to the liver, spleen and bone marrow among other sites, where the majority of the iron is utilised in manufacturing erythrocytes. Iron is lost through sloughing epithelial cells from the skin and gastrointestinal tract. In women, iron is also lost through menstruation. Approximately 1 mg of iron is lost via sloughing epithelial cells per day. Menstruation accounts for an additional loss of iron equivalent to 8 mg per day.

Anaemia is assessed using biomarkers of iron storage. Haemoglobin is a commonly used indicator of anaemia. Haemoglobin is present in the erythrocytes. Anaemia is defined as haemoglobin concentration of less than 13 g/dL in men older than 15 years, less than 12 g/dL in non-pregnant women older than 15 years, and less than 11 g/dL among pregnant women (WHO 2008). However, anaemia is a clinical manifestation of iron deficiency. Anaemia is detectable only after a period of iron depletion. Erythrocytes have a typical lifespan of 120 days before they are recycled.

In cases of inadequate iron intake, haemoglobin continues to be produced while stored iron is still available in ferritin and haemosiderin. Serum ferritin concentrations correspond with total body stores of iron. This indicator is the only marker capable of assessing iron deficiency or excess. Inflammation is known to raise ferritin levels, and therefore mask iron deficiency (Kelly 2017). Additional markers of iron status include ferritin saturation and transferrin saturation.

5.1.2 Anaemia and birth weight outcomes

Evidence from Pakistan found that anaemic women are significantly more likely to deliver a low-birth-weight infant than non-anaemic women (Ahmad *et al*., 2011). Measurements of haemoglobin level took place during labour in this study. Kidanto et a (2009) found that the risk of preterm delivery was associated with maternal anaemia, and that this risk increased with greater anaemia severity. However, it has also been found that anaemia during the first trimester of pregnancy is associated with an increased risk of delivering a low-birth-weight infant, while anaemia in the second and third trimesters is not associated with an increased risk (Hamalainen *et al*., 2003). Therefore, maternal iron status is an important determinant of low birth weight and preterm delivery risk, and pre-pregnancy and early pregnancy iron status is particularly important for determining risk of low birth weight and preterm deliveries.

There is no requirement for additional dietary iron during pregnancy. This is because physiological adaptations take place which assist in meeting additional costs of iron for the developing foetus and increased blood volume. Iron stores assist with meeting the requirements for iron during gestation. If iron stores are low at the beginning of pregnancy, the requirements will need to be met through dietary iron (Fernandez-Ballart 2000).

5.1.3 The nutritional double burden of malnutrition

The nutritional double burden of disease refers to the phenomenon of undernutrition, wasting, stunting, micronutrient deficiency coinciding with overweight, obesity, and diet-related non-communicable diseases, within individuals, households and populations throughout the lifecycle (WHO 2017). Individuals may be simultaneously exposed to underlying risk factors for malnutrition including infection, diet quality and physical activity levels (Tzioumis and Adair 2014).

The prevalence of obesity has been increasing across the world, with prevalence doubling in more than 70 countries since 1980 (The GBD 2015). Anaemia affects one third of women of childbearing age globally and continues to be a major health concern across the developing world (WHO 2020). Anaemia during the first or second trimesters of gestation is associated with significantly increased risks for low birth weight and preterm births (Haider *et al*., 2013).

It is thought that increased consumption of cheap, staple foods and highly processed foods are causing a concurrent problem of overweight and obesity and undernutrition (Popkin, Corvalan, and Grummer-Strawn 2020). Stunting is common among South African children, with approximately 30% of children younger than five years in a sample from KwaZulu Natal stunted (Govender *et al*., 2021). Simultaneously, the prevalence of overweight in the same sample was 15% (Govender *et al*., 2021) and approximately 40% among women between 1 and 35 years of age (Govender 2021). Carbohydrate intake was high in this population, while fibre and micronutrient intakes, including vitamin A intakes were poor (Govender *et al*., 2021). Inadequate dietary intake is a direct cause of malnutrition. However, factors indirectly related to nutrition are recognized in the development of malnutrition. These factors include inadequate care for women and children, insufficient health services and an unhealthy environment, and the distribution of resources. These factors are termed nutrition sensitive areas for intervention (Ruel and Alderman 2013).

This study aimed to determine whether there were differences between anthropometric categories and socio-economic factors in terms of haemoglobin level among women aged 15 to 49 years old in South Africa.

5.2 Methods

Data were taken from the DHS 2016 public access dataset with permission from the DHS Programme (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF 2016). The DHS programme is a health surveillance system which provides data on basic demographic and health indicators for use by policy makers and programme managers to design and evaluate health programmes. Surveys have been conducted in South Africa in 1998, 2003 and 2016. Children between birth and five years old, women between 15 and 49 years old and men between 15 and 59 years old are included in the survey. The DHS uses a stratified, cluster sampling method. The survey is designed to obtain a representative national estimate for South Africa, as well as for each of the nine provinces in the country. There were 15 292 households selected for the sample, of which 11083 were successfully interviewed. Among these, 8514 interviews were completed with women between the ages of 15 and 49 years (Statistics South Africa 2019). Data collection methods are presented elsewhere (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF 2016).

Variables selected for analysis included body mass index (BMI; kg/m^2), haemoglobin (Hb) level (g/dL) adjusted for altitude, wealth index, access to improved water and access to improved sanitation. Underweight was defined as BMI<18.5 kg/m^2, normal weight was defined as a BMI between 18.5 and 24.9 kg/m^2, overweight was defined as a BMI between 25 and 29.9 kg/m^2, obese class I was defined as a BMI between 30 and 34.9 kg/m^2, obese class II was defined as a BMI between 35 and 39.9 kg/m^2 and obese class III was a BMI>40 kg/m^2. Anaemia is defined using haemoglobin levels according to World Health Organization (WHO) classifications. A haemoglobin level below 12 g/dL among non-pregnant women between the ages of 15 and 49 years is defined as anaemic (World Health Organisation 2008). Mild anaemia is defined as haemoglobin concentration between 11 g/dL to 11.9 g/dL, moderate anaemia is defined as 8 g/dL to 10.9 g/dL and severe anaemia is a haemoglobin concentration of less than 8 g/dL (WHO 2011). The DHS household wealth index defines five categories of wealth, ranging from poorest to richest, based on household assets. The definitions and calculations are presented elsewhere (United States Agency for International Development 2002). Improved water sources and improved sanitation facilities were identified according to WHO definitions (WHO and UNICEF 2017).

Data were analysed using SPSS v26 (IBM Corp. Released 2017). Data were analysed using a complex samples design using 26 strata and 455 sampling units to account for sampling weight. Variables were initially tested for normality using Q-Q plots. Frequencies and percentages were reported for categorical data. Normally distributed continuous variables were reported as means and standard deviations. Non-parametric continuous variables were reported as medians and interquartile ranges. As the data were not normally distributed, analysis was conducted using the Kruskall-Wallis test. Bivariate categorical indicators were analysed using the Mann-Whitney U test. The type I error rate was set to $p < .05$. In cases where a significant difference was detected, post hoc Dunn tests were performed to determine the location of the differences.

5.3 Results

A total of 2690 women between 15 and 49 years of age were included in the final analysis after missing data and outliers identified through observing Q-Q plots were removed. The mean age of the women was 30.2 years (±9.8). Of the women in the sample, 4.6 % had moderate anaemia, and 24.3 % had mild anaemia. The mean BMI was 28.12 kg/m^2 (±6.8). Underweight was prevalent among 3.2 % of the women, while 28.7 % of the women were overweight, 19.8 % were in the obese class I category, 9.0 % were in the obese class II category and 5.6 % in the obese class III category. It was found that 16.5 % did not have access to improved water, and 31.1 % did not have access to improved sanitation.

There was evidence of a significant difference between BMI categories as presented in Table 5.1 (Independent Kruskall-Wallis test= 27.014; df=5; p<0.001). Post hoc analysis revealed that haemoglobin level in the normal weight category was significantly different to obese class I, obese class II and obese class III respectively. Haemoglobin levels were higher among women with access to improved sanitation compared to those without access to improved sanitation (p=0.017). Haemoglobin levels were significantly different for wealth index category (Kruskall-Wallis =29.568; df=4; p<0.001). Women from the poorer wealth index category had the lowest haemoglobin levels, while women from the richest wealth index category had the highest haemoglobin levels (p<0.05).

Table 5.1: Differences in haemoglobin levels adjusted for altitude between anthropometric and socio-economic factors.

Factor	Category	N	Haemoglobin Median	Haemoglobin 25^{th} centile	Haemoglobin 75th centile
BMI	Underweight	87	12.8	11.3	13.9
	Normal weight	894	12.7^{abc}	11.5	13.8
	Overweight	779	12.8	11.5	13.8
	Obese class I	536	13.0^{a}	12.0	14.0
	Obese class II	243	13.1^{b}	11.9	14.0
	Obese class III	151	13.2^{c}	12.0	14.2
Kruskall-Wallis =27.014; df=5; p<0.001; n=2690 ^{a,b,c} Denotes statistically significant difference (p<0.05) adjusted by Bonferroni correction for multiple tests					
Access to improved sanitation	Improved sanitation	1853	12.8	11.7	13.9
	Unimproved sanitation	837	12.8	11.6	13.7
Mann-Whitney U test p=0.017; n=2690					
Access to improved water	Improved water	2246	12.9	11.9	13.9
	Unimproved water	444	12.8	11.6	13.9
Mann-Whitney U test p=0.175; n=2690					
Wealth index	Poorest	664	12.8^{af}	11.9	13.8
	Poorer	576	12.6^{abcd}	11.3	13.7
	Middle	624	12.8^{be}	11.6	13.9
	Richer	549	12.8^{c}	11.7	13.9
	Richest	277	13.3^{def}	12.0	14.1
Kruskall-Wallis =29.568; df=4; p<0.001; n=2690 ^{a,b,c,d,e,f} Denotes statistically significant difference (p<0.05) adjusted by Bonferroni correction for multiple tests					

5.4 Discussion

This study found significant differences in haemoglobin level between BMI categories among women 15 to 49 years old in South Africa. While median levels of haemoglobin were similar comparing women with access to improved sanitation and those with no access, there were differences in the distributions of haemoglobin between these groups. Household wealth is also related to haemoglobin levels among South African women.

The results of this study suggest that women with obesity have higher haemoglobin levels than underweight, normal weight and overweight women.

Women with a normal BMI may be at a higher risk of anaemia. This result locates two features of the double burden of disease- a high prevalence of overweight and obesity, as well as micronutrient deficiency, in South African women. Similar findings have been observed in China, where an inverse relationship was found between anaemia and BMI (Qin *et al*., 2013). Obesity and being in the highest wealth category were both factors associated with a lower risk of anaemia among women of childbearing age in Rwanda (Hakizamana *et al*., 2019). While iron intake was not accounted for in the present study, it is possible that iron intake varies between women across all BMI categories. The estimated average requirement (EAR) for iron for women 19–50 years old is 8 mg/day. A study on dietary adequacy among women in KwaZulu-Natal found that underweight women consumed 9.24 mg/day (4.33; 10.63), normal weight women consumed 7.68 mg/day (5.53; 11.97) and overweight women consumed 7.29 mg/day (5.50; 9.34) while those in the obese categories consumed 8.12 mg/day (5.86; 11.41) (Napier and Oldewage-Theron 2015). Basic staple foods have been fortified with iron in South Africa since 2003 (Republic of South Africa [RSA]). However, evidence suggests that foods fortified with iron are not a significant contributor to iron intake in South Africa (Friesen *et al*., 2020). It may be that higher meat consumption, resulting in a higher caloric consumption and BMI (You and Hanneberg 2016), also results in a greater intake of more bioavailable heme iron, while plant protein and carbohydrates are less likely to result in overweight and obesity (Friesen *et al*. 2020) and provide less bioavailable non-heme iron. Among rural South Africans, meat consumption is associated with disposable income (Xazela *et al*. 2017). Significant differences were observed between wealth index groups for haemoglobin. A similar relationship between wealth status and anaemia was found in other sub-Saharan African countries. As an example, the prevalence of anaemia was 25 percentage points higher among the poorest women in Burundi compared with the richest (Jiwani *et al*. 2020). Socio-economic differences also exist across BMI categories in South Africa, with those in poorer socio-economic groups facing an increase in obesity rates (Tzioumis and Adair 2014).

The current study found an association between access to improved sanitation and haemoglobin levels. Schistosomiasis and protozoan infections are common in areas of poor sanitation, causing diarrhoea and blood loss (Hechenbleikner and McQuade 2015). In addition to blood loss, enteric infections can contribute to the development of anaemia as inflammation and infection promote the production of hepcidin. Hepcidin is an iron-regulating hormone which prevents iron absorbed into the duodenal cells from entering circulation.

A positive association has been observed between BMI and haemoglobin levels among pregnant South African women (Madlala *et al*., 2020). Higher BMI was also associated with increasing age and parity (Madlala *et al*., 2020). The risk of high birth weight infants and large for gestational age infants was associated with maternal obesity. It was also found that gestational weight gain was associated with the risk of spontaneous preterm delivery and high birthweight infants (Madlala *et al*., 2020). Traditional black South African diets are high in whole grains, legumes, vegetables and traditional meats, and lower in refined sugar and fat (Wrottelsey *et al*., 2017). Following a traditional diet among black African women in South Africa has been associated with a reduced risk of excessive weight gain during pregnancy (Wrottelsey *et al*., 2017). However, following a typically "Western" diet was associated with an increase in gestational weight gain in both normal weight and obese women during gestation (Wrottelsey *et al*., 2017). Similar results were observed by Madlala *et al*., (2021). As mentioned previously, South African women have a high carbohydrate intake and low fibre intake (Govender *et al*., 2021). Among HIV-negative women, the risk of overweight or obesity was associated with consumption of potatoes, butternut squash or pumpkin 1-3 days a week (OR=1.98) but decreased with egg consumption (OR=0.52). Consuming peanuts or nuts 4-7 days a week reduced the risk of excessive gestational weight gain (OR=0.34) (Madlala *et al*., 2021). Regular consumption of various vegetables including tomatoes, beans and lentils reduced the risk of overweight and obesity and excessive gestational weight gain among HIV-positive South African women (Madlala *et al*., 2021).

Anaemia during the first or second trimesters of gestation is associated with significantly increased risks for low birth weight and preterm births (Haider *et al*. 2013). Infants born with a low birth weight have been found to be at an increased risk of stunting in Rwanda (Nshimyiryo *et al*. 2019). Stunting risk is higher among children from the Eastern Cape, South Africa, who are born with a low birth weight compared with normal birth weight, even when food insecurity and access to social grants is considered (McLaren *et al*. 2018). Therefore, improving the health and nutritional status of women of childbearing age is vital for reducing the burden of childhood malnutrition. While there are many areas in South African antenatal care and healthcare for women of childbearing age that need to be addressed, from the results of this study, improving sanitation should be a priority area. This study reported differences in haemoglobin levels between anthropometric and socio-economic categories. However, reporting haemoglobin on its own may result in overestimations of normal iron status among populations. Obesity is associated with chronic, low-intensity inflammatory processes mediated by the toll-like receptor 4 (TLR4) pathway (Rogero and Calder 2018). Inflammation promotes the production of hepcidin. Inflammatory cytokines including IFN-gamma, TNF-alpha and IL-6 are produced during times of infection. These cytokines down regulate erythropoiesis, the production of new red blood cells. High rates of overweight and obesity is a characteristic of countries facing the double burden of disease. Jordaana et al., showed that transferrin saturation is a better indicator of iron status in double burden high obesity prevalence areas (Jordaana *et al*., 2020).

5.4.1 Study strengths

A strength of this study is the sampling design undertaken by the DHS. The DHS makes use of a two-stage stratified cluster design. Enumeration areas are identified from census data in the first stage, and then a sample of households are drawn from each enumeration area in the second stage. The sample size was large and generally representative at national and regional level.

5.4.2 Limitations

This study is limited in that only haemoglobin was used as a marker of iron status. Future research should include biomarkers including ferritin and transferrin to better understand the relationship between anthropometric status and iron status as well as to differentiate between nutritional iron deficiency and other causes of anaemia. The interpretations of this study are limited by the cross-sectional design. Environmental exposures were measured, but dietary intakes of iron, folate vitamin B12 were not included.

5.5 Conclusion

Features of the nutritional double burden of disease are prevalent in South Africa among women of childbearing age. Overweight and obesity are the primary nutritional concern for this segment of the population, and there is a concurrently high prevalence of anaemia. While those who are overweight or obese may be more likely to have normal haemoglobin levels, women in the normal weight category may be at risk of anaemia. Inequality of wealth is also reflected in haemoglobin status among South African women. Strategies to address economic disparity, access to improved sanitation and improved micronutrient intakes among this population group may be effective strategies to reduce the effects of the double burden of malnutrition in South Africa.

CHAPTER 6

MID-UPPER ARM CIRCUMFERENCE AS A SCREENING TOOL FOR MALNUTRITION IN A SOUTH AFRICAN POPULATION

Overview

Mid-upper arm circumference and weight for height Z-scores are used as independent tools to identify acute malnutrition among children. However, regional differences in the ability of MUAC to identify acute malnutrition have been demonstrated. An assessment of the current MUAC cut-off values recommended by the WHO in the context of the South African population had not been undertaken. The current MUAC cut-off values were assessed, and it was found that they were not sensitive or specific enough to identify children with acute malnutrition in a peri-urban township in the Eastern Cape. New MUAC cut off values were suggested which had a higher sensitivity and specificity.

6.1 Introduction

The global under-five child mortality rate was 39 per 1000 live births in 2017, equivalent to 5.4 million children who died before their fifth birthday (WHO, 2017). It has been estimated that malnutrition is implicated in 45% of under-five child deaths (WHO 2017, WHO 2013). Severe acute malnutrition (SAM) is common among children younger than five years admitted to hospitals in developing regions (Gachau *et al*., 2018). It is estimated that approximately 17 million children younger than five years had SAM in 2018, of which 4.4 million were from sub-Saharan Africa (UNICEF, WHO, World Bank 2019).

Acute malnutrition is caused by insufficient dietary intake or illness. Severe acute malnutrition (SAM) is a condition characterised by severe wasting, anorexia, micronutrient deficiency, electrolyte imbalance and oedema and dehydration.

SAM is defined by two distinct clinical entities. Severe wasting or marasmus is defined as a child between birth to 59 months with a WHZ<-3 Z scores according to the WHO (2006) growth standards. Kwashiorkor presents with bilateral pitting oedema and is differentiated from marasmus by the presence of nutritional oedema. Marasmus and kwashiorkor are now referred to as acute malnutrition and divided into uncomplicated SAM and complicated SAM. Uncomplicated SAM children present without signs of infection and are otherwise clinically well, with no other indication for hospital admission and can pass an appetite test, an indication of the absence of severe metabolic disturbance. In the appetite test, a child will be presented with RUTF and the amount of RUTF consumed in up to half an hour is compared against a predetermined amount for the child's weight as presented in table 6.1.

Table 6.1: Minimum amount of RUTF the client should eat to pass the appetite test.

Client weight (kg)	Amount of RUTF
<4	1/8 – ¼
4.0-6.9	¼ - 1/3
7.0-9.9	1/3 – ½
10.0-14.9	½ - ¾
15.0-29.9	¾-1
>30	1

Children with a WHZ<-3 SD of the median have a greatly elevated risk of death compared to children with a WHZ>-3 SD (WHO, 2006). A mid-upper arm circumference (MUAC) of less than 11.5cm was also recommended to identify SAM in children between six and 59 months of age (WHO, 2013; WHO and UNICEF, 2009). This is because WHZ<-3 and MUAC<11.5cm reveal similar prevalence of acute malnutrition in the field. MUAC is considered appropriate for use as agreement has been observed between the two indicators among children with acute malnutrition (Bari *et al*., 2019).

Children are identified in the community by trained community health workers by assessing mid upper arm circumference and presence of bilateral pitting oedema. Children 6-59 months old with MUAC<12.5 cm and any degree of oedema are referred immediately to a treatment centre for a full assessment for severe acute malnutrition. The full assessment includes plotting and interpreting weight for height, an examination of oedema, a clinical examination for IMCI danger signs and an appetite test. Children with a MUAC<11.5 cm or WFH<-3 or severe bilateral pitting oedema presenting with medical complications or poor appetite are treated as inpatients. Children without medical complications, pass an appetite test and are alert can be treated as outpatients (WHO, 2013).

However, using the WHZ cut-off values may be challenging at community and household level due to practical limitations such as carrying bulky equipment by community health workers who may not always have access to transport. Furthermore, in resource-poor settings, a MUAC tape may offer several advantages such as being non-invasive, cheaper and faster to use when compared with the scales, stadiometers and length boards required for determining WHZ. MUAC may also be more sensitive to identifying children who are at a high mortality risk (Briend *et al*., 2015). Community health workers, parents and guardians of children can be trained to use MUAC to identify acute malnutrition with few errors (Blackwell *et al*., 2015). Mid-upper arm circumference is increasingly being championed as the primary community screening tool for acute malnutrition in both emergency and non-emergency settings (Goossens *et al*., 2012).

Dasgupta *et al*., (2013) identified the low sensitivity (17.5%) of the current MUAC cut-off values for identifying SAM among Indian children. Similarly, Laillou *et al*., (2014) found that MUAC<11.5 cm failed to identify more than 90% of children identified as SAM by WHZ<-3, and that WHZ<-3 missed 80% of children identified by MUAC as having SAM. In a Nigerian study, neither WHZ nor MUAC was able to identify all children with acute malnutrition (John *et al*., 2017). John *et al*., (2017) recommended that the MUAC cut-off value for malnutrition should be redefined. Furthermore, Ahn *et al*., (2020) noted that MUAC-only screening using the current cut-off values would delay the identification of malnourished children. The sensitivity and specificity of MUAC's ability to identify acute malnutrition appears to differ by region (Grellety and Golden, 2016). However, there is little information available on the sensitivity and specificity of MUAC for WHZ for South Africa. One comparison of WHZ against MUAC-for-age Z-score (MAZ) was undertaken by Dukhi, Sartorius and Taylor (2017) among children six to 59 months old. These researchers described a fair level of agreement between MAZ and WHZ but that while 7.7% (n=44) of the sample were identified as malnourished by WHZ, 6.6% (n=38) were identified using MUAC (Dukhi, Sartorius and Taylor 2017).

The aim of this study is to evaluate the diagnostic accuracy of mid-upper arm circumference for identifying children 6-59 months with MAM and SAM, compared with the WHO (2006) growth standard WHZ cut-offs.

6.2 Methods

An observational, cross-sectional study was used to obtain data from a convenience sample of 400 infants and young children from clinics and early childhood development (ECD) centres in Motherwell, Nelson Mandela Bay from October 2015 to February 2016. The weight, length and MUAC of children younger than two years old were measured by trained fieldworkers according to protocols described by the CDC (2007). Ethical approval (H15-HEA-002) was obtained from the Research Ethics Committee (Human), NMMU and the Eastern Cape Department of Health. Inclusion in the study required written informed consent from caregiver of the participant.

Z-scores greater to or less than 5 SD from the mean were removed according to WHO (2006) data cleaning criteria. These Z-scores are biologically implausible and are more likely to be the result of measurement or transcription errors. Data was tested for normality using Shapiro-Wilk tests. Normally distributed data was described using means and standard deviations, while non-normally distributed data was described using medians and interquartile ranges (IQR). Differences in MUAC values between different ages and sexes was assessed using a Scheffe test. Correlations were carried out using the Pearson correlation co-efficient (*r*) was used to measure the strength or degree of the relationship between normally distributed variables. Spearman's rho was used to assess correlations between non-normally distributed variables. Sensitivity and specificity tests were used on the data with the existing recommended MUAC cut-off values as well as new calculated MUAC cut-off values to determine whether the new MUAC cut-off values were more sensitive in the identification of children affected by wasting, without including false negatives (children without SAM or MAM).

6.3 Results

Data was collected from 419 infants and young children. Ten records were removed as the infants and young children had implausible Z-scores for WAZ, HAZ or WHZ. Four records were removed as the children were older than 24.0 months. Five records were removed as they children were not of African ethnicity. The final sample was made up of 400 infants and young children. All of the infants and young children in the final sample were of African ethnicity (100%, n=400). Half (n=199) of the infants and young children in the final sample were male (Table 6.2).

Table 6.2: Demographic characteristics of the sample and summary weight for height (WHZ) and MUAC statistics for age categories (n=400).

	Male				**Female**				**Total**			
Age category Months	**N**	**%**	**MUAC**	**WHZ**	**n**	**%**	**MUAC**	**WHZ**	**n**	**%**	**MUAC (cm) (SD)**	**WHZ (SD)**
0-2	25	12	13.54 (1.48)	0.31 (1.70)	24	12	13.53 (2.30)	0.52 (0.86)	49	12	13.53 (1.91)	0.41 (1.35)
3-5	33	17	14.98 (1.51)	0.70 (1.21)	46	23	14.33 (1.22)	0.71 (1.07)	79	20	14.61 (1.38)	0.71 (1.12)
6-8	40	20	15.44 (1.33)	0.57 (1.50)	31	15	13.52 (1.24)	1.11 (1.01)	71	18	15.38 (1.32)	0.81 (1.33)
9-11	29	15	16.09 (1.68)	0.79 (1.51)	31	15	15.13 (3.19)	1.03 (1.21)	60	15	15.86 (1.61)	0.93 (1.36)
12-14	24	12	16.30 (1.28)	1.15 (0.93)	26	13	15.92 (1.30)	0.96 (1.24)	50	13	16.10 (1.29)	1.07 (1.10)
15-17	20	10	16.51 (1.71)	0.83 (1.53)	13	6	15.99 (1.66)	1.00 (1.36)	33	8	16.30 (1.69)	0.90 (1.44)
18-20	18	9	16.59 (1.26)	1.29 (1.15)	21	10	16.25 (1.58)	1.04 (1.14)	39	10	16.41 (1.43)	1.19 (1.13)
21-23	10	5	16.57 (1.28)	0.73 (1.24)	9	4	15.97 (1.69)	0.63 (1.80)	19	5	16.28 (1.48)	0.68 (1.49)
Total	199	100			201	100			400	100		

Of the total sample, the mean weight-for-age z-score (WAZ) was +0.44 (SD=1.26), the height-for-age z-score (HAZ) was -0.24 (SD=1.34) and the mean WHZ was 0.83 (SD=1.28). One child in the sample (n=1) was classified as severely wasted, according to WHZ (WHZ<-3) with one percent (n=3) moderately wasted (WHZ<-2) and six percent mildly wasted (WHZ<-1) as presented in Table 6.3. A total of seven infants and young children were classified as SAM using the WHO (2013) MUAC cut-off, and eleven were classified as MAM by MUAC.

Table 6.3: WHZ and MUAC categories (n=400).

WHZ Category	MUAC Category							
	SAM (<11.5 cm)		MAM (<12.5 cm)		Normal (>12.5 cm)		Total	
<-3	0	0.0%	1	9.1%	0	0.0%	1	0.3%
<-2	0	0.0%	0	0.0%	3	0.8%	3	0.8%
<-1	3	42.9%	2	18.2%	18	4.7%	23	5.8%
-1 to +3	4	57.1%	5	45.5%	190	50.1%	199	50.1%
>1	0	0.0%	3	27.3%	103	27.2%	106	26.7%
>2	0	0.0%	0	0.0%	44	11.6%	44	11.1%
>3	0	0.0%	0	0.0%	21	5.5%	21	5.3%
Total	7	100.0%	11	100.0%	379	100.0%	397	100.0%

It was found that infants younger than six months had lower MUAC values compared with infant and young children older than six months. No significant differences were observed for MUAC among infants and young children between six and 24 months of age, as presented in Table 6.4.

Table 6.4: Differences in mean absolute MUAC measurements for age categories (n=400).

Effect	Level 1	Level 2	Mean $MUAC_1$	Mean $Muac_2$	p*	Cohen's d
Intercept	-	-	15.39	-	<.0005	8.86
Age Category	0 - 2 months	3 - 5 months	13.50	14.65	.017	0.73
	0 - 2 months	6 - 8 months	13.50	15.38	<.0005	1.19
	0 - 2 months	9 - 11 months	13.50	15.86	<.0005	1.34
	0 - 2 months	12 - 14 months	13.50	16.04	<.0005	1.58
	0 - 2 months	15 - 17 months	13.50	16.30	<.0005	1.53
	0 - 2 months	18 - 20 months	13.50	16.43	<.0005	1.69
	0 - 2 months	21 - 23 months	13.50	16.28	<.0005	1.54
	3 - 5 months	6 - 8 months	14.65	15.38	.246	0.56
	3 - 5 months	9 - 11 months	14.65	15.86	.003	0.83
	3 - 5 months	12 - 14 months	14.65	16.04	.001	1.07
	3 - 5 months	15 - 17 months	14.65	16.30	<.0005	1.14
	3 - 5 months	18 - 20 months	14.65	16.43	<.0005	1.29
	3 - 5 months	21 - 23 months	14.65	16.28	.011	1.20
	6 - 8 months	9 - 11 months	15.38	15.86	.860	0.32
	6 - 8 months	12 - 14 months	15.38	16.04	.574	0.51
	6 - 8 months	15 - 17 months	15.38	16.30	.283	0.64
	6 - 8 months	18 - 20 months	15.38	16.43	.097	0.76
	6 - 8 months	21 - 23 months	15.38	16.28	.598	0.67
	9 - 11 months	12 - 14 months	15.86	16.04	1.000	0.13
	9 - 11 months	15 - 17 months	15.86	16.30	.964	0.27
	9 - 11 months	18 - 20 months	15.86	16.43	.843	0.37
	9 - 11 months	21 - 23 months	15.86	16.28	.991	0.27
	12 - 14 months	15 - 17 months	16.04	16.30	.999	0.18
	12 - 14 months	18 - 20 months	16.04	16.43	.984	0.29
	12 - 14 months	21 - 23 months	16.04	16.28	1.000	0.18
	15 - 17 months	18 - 20 months	16.30	16.43	1.000	0.08
	15 - 17 months	21 - 23 months	16.30	16.28	1.000	0.01
	18 - 20 months	21 - 23 months	16.43	16.28	1.000	0.10
Gender	Male	Female	15.60	15.19	.025	0.23

* Scheffé Test if 3+ Levels, else t-Test

As significant differences were observed between age categories of infants, further analyses were conducted on infants and young children between six and 24 months old. A comparison of infants and young children identified as malnourished by WHZ category and MUAC value is presented in Table 6.4. None of the infants and young children between six and 24 months old were identified as SAM by WHZ. One child was identified as MAM by WHZ. No children were identified as SAM by MUAC<11.5, however one child was identified as MAM by MUAC<12.5 cm. Table 6.5 and 6.6 demonstrates that the two MAM cases were separate individuals.

Table 6.5: MUAC and WHZ category for infants and young children between six and 24 months old (n=267).

WHZ Category	**MUAC (cm)**											
	< 11.0		**11.0 to 11.5**		**11.5 to 12.0**		**12.0 to 12.5**		**13.0 to 24.0**		**Total**	
	n (%)		**n (%)**		**n (%)**		**n (%)**		**n (%)**		**n (%)**	
SAM	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
MAM	0	(0)	0	(0)	0	(0)	0	(0)	1	(0)	1	(0)
Normal	0	(0)	0	(0)	0	(0)	1	(100)	265	(100)	266	(100)
Total	0	(0)	0	(0)	0	(0)	1	(100)	266	(100)	267	(100)

Table 6.6: Test results for WHZ MAM using MUAC < 13. 0 cm criterion

WHZ MAM	**MUAC < 13.0 cm**					
	Yes		**No**		**Total**	
	n (%)		**n (%)**		**n (%)**	
Yes	0	(0.0)	1	(0.4)	1	(0.4)
No	1	(0.4)	265	(99.3)	266	(99.6)
Total	1	(0.4)	266	(99.6)	267	(100.0)

Significant differences in MUAC were observed for male and female infants and young children (p<0.017). Therefore, analyses were conducted on infants and young children six to 24 months old, with separate MUAC cut-off values predicted for male and female infants and young children.

MUAC was strongly correlated with WHZ, for the full sample and or male and female sub-groups (Table 6.7; Figures 6.1 and 6.2). A weak, but statistically significant correlation was observed between MUAC and HAZ.

Table 6.7: Correlations between MUAC and WHZ and HAZ for male and female children (n=259).

Indicator	R	r^2	p-value
WHZ	0.78	0.60	<0.001
HAZ	0.271	0.076	<0.001
Male	N=132		
WHZ	0.728	0.529	<0.001*
HAZ	0.285	0.091	0.001*
Female	N=127		
WHZ	0.790	0.642	<0.01*
HAZ	0.295	0.077	0.01*

*Significant at p<0.05

The r-value (0.78) for the relationship between WHZ and MUAC suggests a dependent relationship between these two indicators. The least squares regression formula (Y=15.409+0.803x (males); Y=15.13+0.83x (females)) was then used to predict where WHZ=-2 is most likely to correspond with a MUAC value in cm. The new predicted MUAC values of 13.8cm (males) and 13.5cm (females) were subsequently tested for sensitivity and specificity.

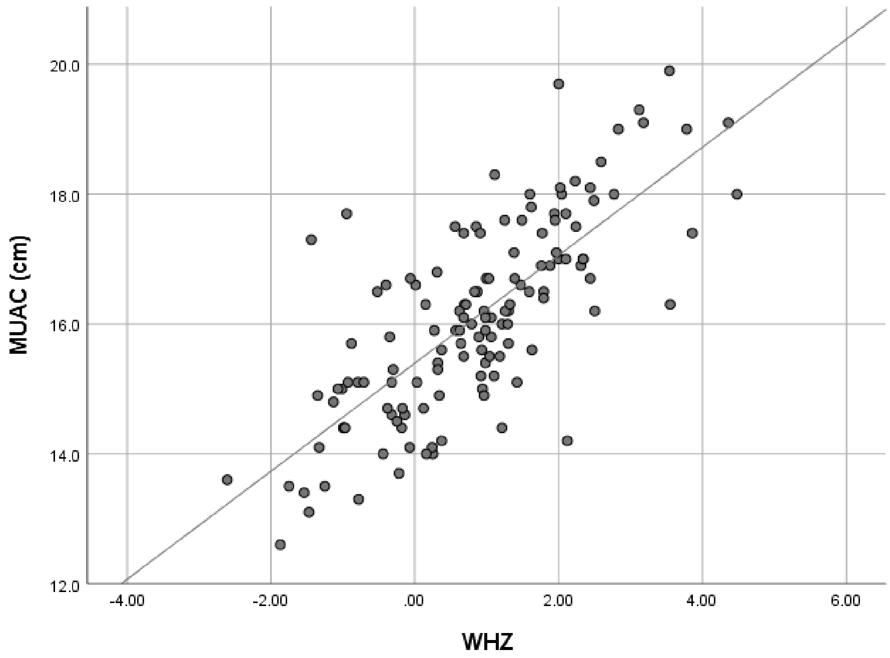


Figure 6.1: The relationship between WHZ and MUAC among male participants, six to 24 months old (n=140).

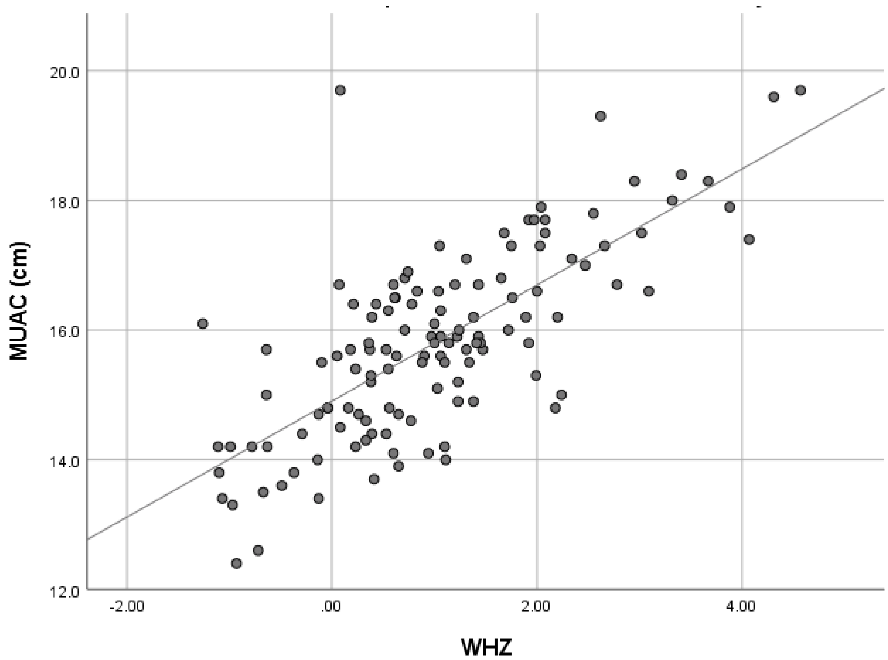


Figure 6.2: The relationship between WHZ and MUAC among female participants between six and 24 months old (n=130).

The sample was too small to calculate sensitivity for both sexes, but 96.4% specificity was achieved for females (Table 6.8). A sensitivity of 100% and specificity of 94.5% was achieved with the male MUAC cut-off. Thus, the proposed cut-offs identified all the wasted children (WHZ<-2), while identifying an acceptably low number of false positives.

Table 6.8 presents the sensitivity and specificity of MUAC for identifying infants and young children aged six to 24 months with MAM in South Africa. The current MUAC cut-off value of <12.5 cm has a sensitivity of 0.0% and specificity of 99.6%.

Table 6.8: Diagnostic test results for moderate wasting (WHZ<-2) using MUAC.

Sex	**WHZ**	**MUAC (cm)**	**TP**	**FP**	**FN**	**TN**	**Sensitivity (%)**	**Specificity (%)**	**PPV**	**NPV**
Male	**MAM**	<12.5	0	0	1	140	0	99.6	0	0.993
	MAM	<13.8	1	7	0	133	100	94.5	1.0	1.0
Female	**MAM**	<12.5	0	1	0	130	#	99.3	#	1.0
	MAM	<13.5	0	5	0	126	#	96.4	#	1.0

Value cannot be calculated- denominator=0

*sample size limitation

6.4 Discussion

It was found that MUAC<12.5cm has a high specificity, but low sensitivity for identifying children 6-24 months old with MAM when compared with WHZ. Increasing the MUAC cut-off value to 13.8 cm for males and 13.5 cm for females increases its level of agreement with WHZ, but at a cost of reduced specificity. The cut-off value at 12.5 cm for MAM were not sensitive enough to identify all the children with MAM. Increasing the MUAC cut-off for MAM to 13.8 cm for males and to 13.5 cm for females substantially improves the accuracy of the number of true positives, while maintaining a low number of false negatives. Laillou *et al*., (2014) found that the current MUAC cut-off value at 12.5 cm has a sensitivity of 13.4% and specificity of 98.1% for WHZ<-2 in a large sample of Cambodian children. The same study found that the sensitivity was 6.1% and specificity 99.7% for MUAC<11.5 cm for WHZ<-3. Sougaijam *et al*.,

(2019) found a sensitivity of 23.6% and specificity of 98.5% for MUAC in identifying SAM. A study from Nigeria found that the sensitivity of MUAC<11.5 cm for WHZ<-3 was 0%, while the specificity was 98.5% (John *et al*., 2017). A large international study (n=34937) using nutrition surveillance data showed a sensitivity of 25% and specificity of 99.7% for MUAC<11.5 cm vs WHZ<-3 (Fernandes *et al*., 2010). If the MUAC cut-off value was increased to 12.5 cm to identify SAM for this large international sample, the resulting sensitivity would be 55% and specificity 93.6%. Results similar to those in the current study have been found in other populations, with a consistently low sensitivity demonstrated for the current MUAC cut-off values.

Concerns have been raised that the current MUAC cut-off values for identifying infants and young children with acute malnutrition mean that identification is delayed until children are extremely malnourished (Joseph *et al*., 2002). There is enough evidence for using WHZ z-scores and MUAC as independent criteria for identifying acutely malnourished children and both indicators can identify children at a high risk of mortality (Grellety and Golden, 2018). However, research has also demonstrated that MUAC and WHZ identify different groups of children as wasted within the same population (Laillou *et al*., 2014). Therefore, either of the indicators on its own will not represent the true prevalence of acute malnutrition in a population. There is an apparent lack of agreement between MUAC and WHZ within populations, with Laillou *et al*., (2014) finding that the level of agreement was 16.7% (kappa). The size of this disagreement varies between countries (Grellety and Golden 2016). It does not appear that this disagreement can be explained by variation in relative body lengths between groups (Grellety and Golden 2016). However, age (Bern *et al*., 1995) and hydration status (Modi *et al*., 2015) may play a role. Younger children are more vulnerable to changes in weight status. Weight for height may be influenced by loss of body water caused by diarrhoea (Modi *et al*., 2015), or rendered inaccurate by the presence of oedema. MUAC does not appear to significantly affected by changes in hydration status (Modi *et al*., 2015). Despite the lack of overlap, researchers have suggested that MUAC alone is an acceptable indicator of malnutrition (Ali *et al*., 2013). Raising the MUAC cut-off value has been suggested as a way of increasing the number of children at a high risk of malnutrition included in interventions (Ali *et al*., 2013).

In addition, there is a question over whether a single MUAC cut-off value is appropriate in regions with a high prevalence of stunting, as MUAC increases with height and age (Mei *et al*., 1997). It was found that HAZ has a weak, but statistically significant correlation with MUAC, suggesting that MUAC and HAZ are not independent.

Briend *et al*., (2016) have suggested that raising the MUAC cut-off in an attempt to encompass all children with acute malnutrition is not a viable option as it would overburden the health system with children who are not acutely malnourished or at a high risk of death. However, this should not be the case if the cut-off value selected has an acceptably high specificity. Raising the recommended MUAC cut-off value for identifying SAM from 11.5cm to 13.3cm as suggested by Laillou, *et al*., (2014), or even as high as 15.5cm, as recommended by Dairo, Fatokun & Kuti (2012), results in a higher sensitivity of the tool. However, the raised sensitivity results in a lower specificity. When the cut-off value is raised, the number of false positives increases, resulting in an overestimation of the prevalence of malnutrition. However, raising the cut-off value also reduces the number of false negatives (Fernandez *et al*., 2010). In the current study, raising the MUAC cut-off value had this effect. There was a small change in the specificity of the MUAC cut-offs when raised to 13.5 cm and 13.8 cm for MAM. Given a population of 5817 children, and assuming that 50% of the population is male, it could be estimated that 29 male children will be acutely malnourished at a 1% prevalence of acute malnutrition. Using the current MUAC cut-off values, none of these children would be identified as acutely malnourished, and all 29 would be falsely identified as not acutely malnourished. Twelve healthy children would be incorrectly referred for assessment (false positives) and 2968 would be correctly identified as not acutely malnourished. If the new MUAC cut-off of 13.8 cm were adopted in this population, the 29 acutely malnourished children would be correctly identified with no false negatives. However, 158 children would be incorrectly identified as acutely malnourished and referred for treatment. The result is that children potentially mis-diagnosed as not acutely malnourished will be less likely to receive inappropriate referral and treatment.

MUAC is age-dependent, and older children within the 6-59 months age group tend to have greater mid-upper arm circumferences than younger children (De Onis, Yip and Mei 1997). This creates a bias which has been accepted as beneficial, as more infants and younger children who are at a higher risk of deterioration are diagnosed compared with older children (De Onis, Yip and Mei, 1997). Raising the MUAC cut-off value may have the effect of losing this advantage.

The practical advantages of using MUAC as a community screening tool has led to the abandonment of WHZ in favour of a MUAC-only intervention criterion and by aid agencies. Moving towards using the MUAC-only criteria is not appropriate in all countries, as there is a large deficit in the number of children identified by MUAC in some populations (Grellety and Golden, 2016). In this South African context, it appears that MUAC has a low sensitivity for identifying acute malnutrition. Therefore, infants and young children who are malnourished may not be receiving timely referrals for appropriate treatment if screened by MUAC. It may be likely that these children represent uncomplicated cases without oedema or severe metabolic disturbance, however, evidence suggests that both marasmus and kwashiorkor result in developmental delay (Van den Heuval *et al*., 2017). The results of this study suggest that raising the MUAC cut-off values for MAM and SAM will increase the number of children correctly identified as being acutely malnourished in the community, while maintaining a reasonably low number of false positive cases. Southern Africa has a relatively low prevalence of acute malnutrition compared with other countries in the continent and South Asia (Ssentongo *et al*., 2021), making these children more difficult to detect. However, it has a higher case mortality rate (Massyn *et al*., 2019). The South African health system is relatively well-resourced, with an effective intervention in place for treating acute malnutrition in the community (Brits *et al*., 2017). The decision to raise the MUAC cut-off value will depend on the priorities of the health system. If identifying only the most malnourished and those at the highest risk of death is the priority, then a high specificity should be prioritised over sensitivity. If, however, identifying as many malnourished children as possible is the priority, then raising the MUAC threshold and prioritising sensitivity at the expense of specificity is acceptable. The risk of sacrificing specificity is that false negatives may go through unnecessary referral and assessment, undermining faith in the health system (John *et al*., 2017). The South African supplemental feeding programme already suffers from high patient dropout, with an important reason cited as long distances to travel to clinics (Brits *et al*., 2017).

6.4.1 Strengths and limitations

This study made use of gold standard methods of measuring weight, height and MUAC for infants and young children. This study made use of a cross-sectional design, therefore the incidence of acute malnutrition could not be determined for this population. This study made use of a convenience sample. This study was conducted at primary health centres and creches and therefore the results will not be generalisable to the wider population which does not make use of these services. Therefore it is possible that at-risk children may not have been included in the study. The low number of children with SAM is a limitation to this study.

6.5 Conclusion

WHZ and MUAC are strongly correlated. Current MUAC cut-off values recommended by the WHO have a poor sensitivity for acute malnutrition. Increasing the MAM MUAC cut-off to 13.8 cm for males and 13.5 cm for females results in a high sensitivity and acceptable specificity for MAM in this population.

CHAPTER 7

MID-UPPER ARM CIRCUMFERENCE AS A SCREENING TOOL FOR OVERWEIGHT AND OBESITY

Overview

Mid-upper arm circumference is a simple tool for assessing anthropometry. It has been used to identify children with acute malnutrition with recommendations for specific cut-offs produced by the WHO. The measuring tape measures the circumference of all of the tissues in the upper arm, including bone, skeletal muscle, adipose tissue and skin. Therefore, MUAC could be used as a proxy measure for adiposity. This study aimed to determine MUAC cut-off values which could be used to classify children as overweight or obese. Mid-upper arm circumference measurements were analysed to determine cut-off values for identifying overweight and obesity among children six to 24 months old. The prevalence of overweight (WLZ > +2) and obesity (WLZ > +3) was 11% (n = 44) and 5% (21) respectively. A MUAC cut-off value for identifying male children 6 to 24 months old with overweight was determined at 16.5 cm (85% sensitivity, 71.4% specificity, AUC = 0.821) and female children at 16.5 cm (100% sensitivity, 76.6% specificity, AUC = 0.938).

7.1 Introduction

According to the WHO (2020), 42 million children under the age of five years are overweight or obese. The prevalence of stunting and wasting is reducing in low- and middle-income countries (LMIC), while overweight and obesity is becoming more prevalent among children (NCD Risk Factor Collaboration 2017). Accelerated weight gain in early life may be related to non-communicable disease risk in later life (Kim, Lee and Sangwon 2017). Overweight at one year old may greatly increase the risk of type 2 diabetes and premature death from cardiovascular disease (Barker 2004). High rates of glucose intolerance and pre-hypertension have been observed among rural South African adolescents (Pedro *et al*., 2014), indicative of the epidemiological transition taking place.

Major changes to the diet as a result of the nutrition transition include increased consumption of refined carbohydrates, added sweeteners, edible oils and animal source foods. These dietary patterns can result in higher rates in overweight and obesity in both children and adults. In Southern African countries, it has been estimated that 72% of people are not meeting the recommendations for vegetable and fruit consumption (Nnyepi *et al*., 2015). Furthermore, while the rate of initiation of breastfeeding is high in South Africa, the exclusive breastfeeding rate declines rapidly (Sayed and Schonfeld 2018). Early introduction of foods and liquids other than breastmilk before the age of six months is common (Sayed and Schonfeld 2018) and may be associated with overweight and obesity later in life (Wang *et al*., 2016). High-sugar fruit juices are being introduced to infants from six months of age (Budree *et al*., 2017). A large proportion of South African infants are consuming foods such as processed meats (56%) and crisps (32%) on a daily basis by the time they are twelve months old (Budree *et al*., 2017). These less healthy foods are rapidly becoming more affordable, accessible, and acceptable to all populations in South Africa, including rural and informal settlements (Igumbor *et al*., 2012). The effects of these shifts in dietary patterns are already being observed, with as many as 10% of infants overweight at six months of age (Matsungo *et al*., 2017).

The emerging double burden of disease poses significant practical challenges for targeting nutrition interventions, particularly in resource-poor settings. Current anthropometric indicators to identify overweight in children as recommended by the WHO and the World Obesity Federation (WOF) (Cole and Lobstein 2012), include weight for length (WLZ) or weight for height (WHZ) and BMI for age. Evidence suggests that WHZ and BMI for age yield similar prevalence of overweight and obesity and therefore there is no need to monitor both indicators (De Onis *et al*., 2012). However, using the WHZ or BMI for age cut-off values may be challenging at community and household level. BMI is frequently used to assess nutritional status among adults, however, interpreting this index requires the use of smoothed growth curves for children. Children display dynamic growth trajectories for weight and height. Mid-upper arm circumference has been shown to differ little among children between six and 59 months of age. Therefore, a single MUAC cut-off value is possible for children, simplifying the measurement and interpretation of anthropometry among children when using this tool. It has been demonstrated that mothers, caregivers and community health workers can measure and interpret MUAC measurements in the community with a high level of accuracy (Goosens *et al*., 2012).

Research has begun to establish that MUAC can be effective in identifying overweight and obese children (Talma *et al*., 2019). The rate of increase in arm circumference has also been reported parallel to the rate of weight gain in children (Goossens *et al*., 2012) (Talma *et al*., 2019). There is currently no formal recommendation for a single cut-off value for MUAC to identify overweight and obese infants and children in the same way that cut-off values are available for identifying acute malnutrition. The WHO MUAC field tables available can be cumbersome to use; rely on the age of the child and undermine the simplicity of MUAC as a screening tool. There is also a lack of data relating to children younger than two years as many of the studies available, which assess the ability of MUAC to identify obese children, focus on children older than two years (Talma *et al*., 2019; Jaiswal *et al*., 2017).

Therefore, the aim of this study was to predict MUAC cut-off values to identify overweight and obesity risk infants and children between birth and twenty four months of age within a per-urban South African population.

7.2 Methods

This descriptive study was undertaken using a cross sectional design. Ethical approval was obtained from the Research Ethics Committee (Human), Nelson Mandela University, as well as the Eastern Cape Department of Health (ref. no H15-HEA-002). Inclusion in the study required written informed consent from the primary caregiver of the participant. Data on weight, height or length and MUAC was collected from infants and young children between birth and 24 months of age, living in a South African resource-poor peri-urban settlement, aged from birth to two years (n=400) between October 2015 and February 2016. Only black African children were included in order to create a homogenous sample and prevent bias in interpreting the results. Children from ethnicities other than black African were excluded from the study. Both male and female infants and young children were included. Children who were older than 24 months at the time of the measurement were excluded from the study. Children with foetal alcohol syndrome, cerebral palsy or history of tuberculosis (TB) were excluded from the study as these conditions affect growth and anthropometry.

Date of birth and date of measurement were recorded and participant age calculated as an age in decimals. Procedures for obtaining anthropometric data followed protocols described by the Centres for Disease Control and Prevention (2007). Anthropometric data were used to calculate Z-scores for weight for age (WAZ), height for age (HAZ), weight for height (WHZ) and body mass index for age (BMIZ) using

WHO Anthro software (WHO, Switzerland). Data cleaning criteria were applied according to WHO guidelines (WHO 2006). Children with a weight for height, weight for age or height for age Z-score more than five standard deviations from the median were excluded from the analysis, as these Z-scores are physiologically unlikely and are more likely to represent errors in data collection or capture.

Descriptive statistics were used to describe the outcomes. As absolute MUAC was expected to increase from younger to older age groups; tests for significance in MUAC between age groups was performed using a Scheffe test. A p-value of < 0.05 was considered significant. A receiver operating characteristic (ROC) curve was generated using SPSS software (v. 25; IBM Corp, Armonk, NY, USA) and used to calculate the area under the curve (AUC) to assess the performance of MUAC as a diagnostic test when using WLZ as the criterion for overweight and obesity. WLZ was used as the standard criterion as it is the recommended indicator of overweight and obesity (WHO 2006). An AUC value of > 0.8 was considered an accurate test (Kumar and Indrayan 2011). The Youden index (J) is the difference between the true positive rate (sensitivity) and the false positive rate with 1 indicating a perfect test, and 0 a useless test. It signifies the optimal sensitivity and specificity values yielding the maximum sums from the ROC curves. The J-value was used to inform the optimal MUAC cut-off values.

7.3 Results

Nineteen records were removed from the sample as they had implausible Z-scores. The final sample (n=400) was homogenously (100%) of black African ethnicity. The sample was made up of 50% (n=199) male participants, and 50% (n=200) female participants. There was no significant difference between the ages of male and female participants (p=0.53).

The mean WHZ was 0,83 (SD=1,28). The prevalence of overweight (WHZ>+2) and obesity (WHZ>+3) was 11% (n=44) and 5% (21) respectively. There were no significant differences observed between genders for WHZ category (p=0.094), as shown in Table 7.1.

Table 7.1: Demographic and anthropometric data for the sample (n=399).

Anthropometric indicator	Sex	n	Mean (SD)	p-value	Cohen's D
Weight (kg)	Male	199	9.19 (2.59)	0.018*	0.24
	Female	200	8.58 (2.49)		
Height (cm)	Male	197	70.83 (8.86)	0.049*	0.20
	Female	200	69.04 (9.12)		
WHZ	Male	197	0.77 (1.40)	0.367	0.09
	Female	200	0.88 (1.15)		
MUAC (cm)	Male	199	15.59 (1.74)	0.017*	0.24
	Female	200	15.17 (1.75)		
MUAC (cm) 0-6 months	Male	58	14.36 (1.65)	0.31	
	Female	70	14.05 (1.7)		
MUAC (cm) 6-24 months	Male	130	15.88 (1.32)	0.014*	0.07
	Female	130	15.78 (1.46)		

Differences in MUAC across age categories were assessed using a Scheffe test. It was found that infants younger than six months had lower MUAC measurements compared with infants and young children older than six months. There were no significant differences in MUAC due to age among children six to 24 months old. This resulted in the decision to test a single MUAC for children six to 24 months old as these children were found to be comparable.

Male and female children were shown to have significantly different MUAC measurements. Therefore, it appeared appropriate to test separate cut off values for male and female children. The absolute MUAC mean for males (15.59cm) was statistically higher than the absolute MUAC mean value for females (15.17cm) (p=0.017). This difference was also observed when excluding children younger than six months old (p=0.014), indicating that male and female children between six and 24 months old would benefit from separate MUAC cut-off values.

The AUC for identifying overweight males 0-6 months old (n=58) was 0.766. The MUAC cut-off value at 14.5 cm had a sensitivity of 88.9% and specificity of 63.3% (J=0.542). Female children 0-6 months old had an AUC of 0.788 for overweight. The MUAC cut-off with the highest J-value (J=0.585) was 14.2 cm (100% sensitivity, and 58.5% specificity).

Data obtained from males aged six to 24 months (n=139) generated ROC curves with AUC of 0.821 for overweight (+2<WLZ<+3) and 0.905 for obesity (WLZ>+3), presented in Table 7.2. The MUAC cut-off value of 16.5 cm had the highest J-value (0.589) and a sensitivity of 85% and specificity of 71.4% for identifying overweight. The optimum MUAC cut-off value for identifying obesity among males six to 24 months old was 17.2 cm (88.9% sensitivity, 80.8% specificity, J=0.697). As presented in Table 7.3, a MUAC cut-off for identifying overweight female children aged six to 24 months (n=130) was determined at 16.5 cm (AUC=0.938). This cut-off value had a sensitivity of 100% and specificity of 76.7% (J=0.767). The optimum MUAC cut-off value for identifying obesity was 17.0 cm (J=0.758).

Table 7.2: Potential MUAC cut-off values for identifying overweight and obesity in males six to 24 months old, compared with WLZ (n=139).

+2<WLZ<+3 Male 6-24 months		**AUC=0.821**	**N=139**	**WLZ>+3 Male 6-24 months**		**AUC=0.905**	**N=139**
MUAC (cm)	**Sensitivity**	**Specificity**	**Youden Index**	**MUAC (cm)**	**Sensitivity**	**Specificity**	**Youden Index**
16.3	0.850	0.664	0.522	16.8	0.889	0.731	0.620
16.4	0.850	0.672	0.564	16.9	0.889	0.738	0.627
16.5	**0.850**	**0.714**	**0.589**	**17.0**	**0.889**	**0.762**	**0.650**
16.6	0.850	0.739	0.573	17.1	0.889	0.792	0.681
16.7	0.800	0.773	0.582	17.2	0.889	0.808	0.697

Table 7.3: Potential MUAC cut-off values for identifying overweight and obesity in females six to 24 months old, compared with WLZ (n=130).

+2<WLZ<+3 Female 6-24 months		**AUC=0.938**	**N=130**	**WLZ>+3 Female 6-24 months**		**AUC=0.938**	**N=130**
MUAC (cm)	**Sensitivity**	**Specificity**	**Youden Index**	**MUAC (cm)**	**Sensitivity**	**Specificity**	**Youden Index**
16.3	1.000	0.717	0.717	16.8	0.900	0.833	0.733
16.4	1.000	0.742	0.742	16.9	0.900	0.850	0.750
16.5	**1.000**	**0.767**	**0.767**	**17.0**	**0.900**	**0.858**	**0.758**
16.6	0.900	0.792	0.692	17.1	0.800	0.867	0.667
16.7	0.900	0.833	0.733	17.2	0.800	0.883	0.683

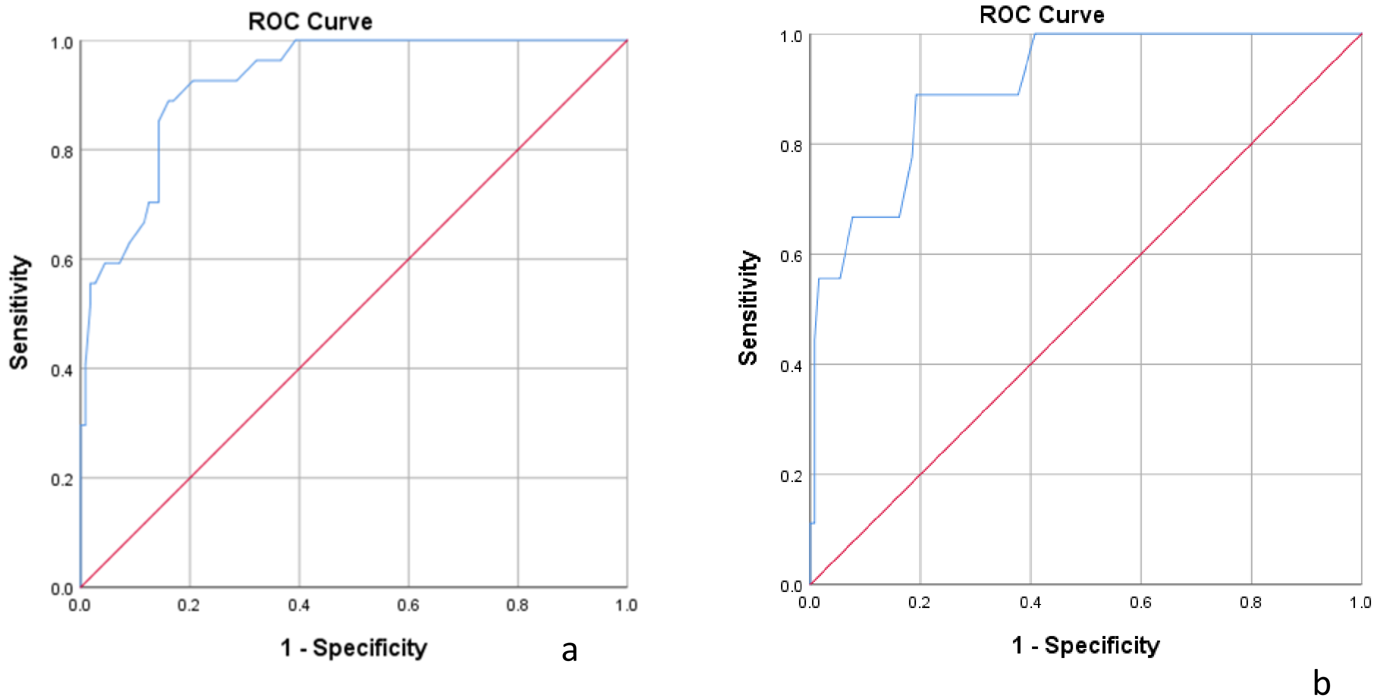


Figure 7.1: ROC curve for overweight males (a) and obese males (b) six to 24 months old (n=139).

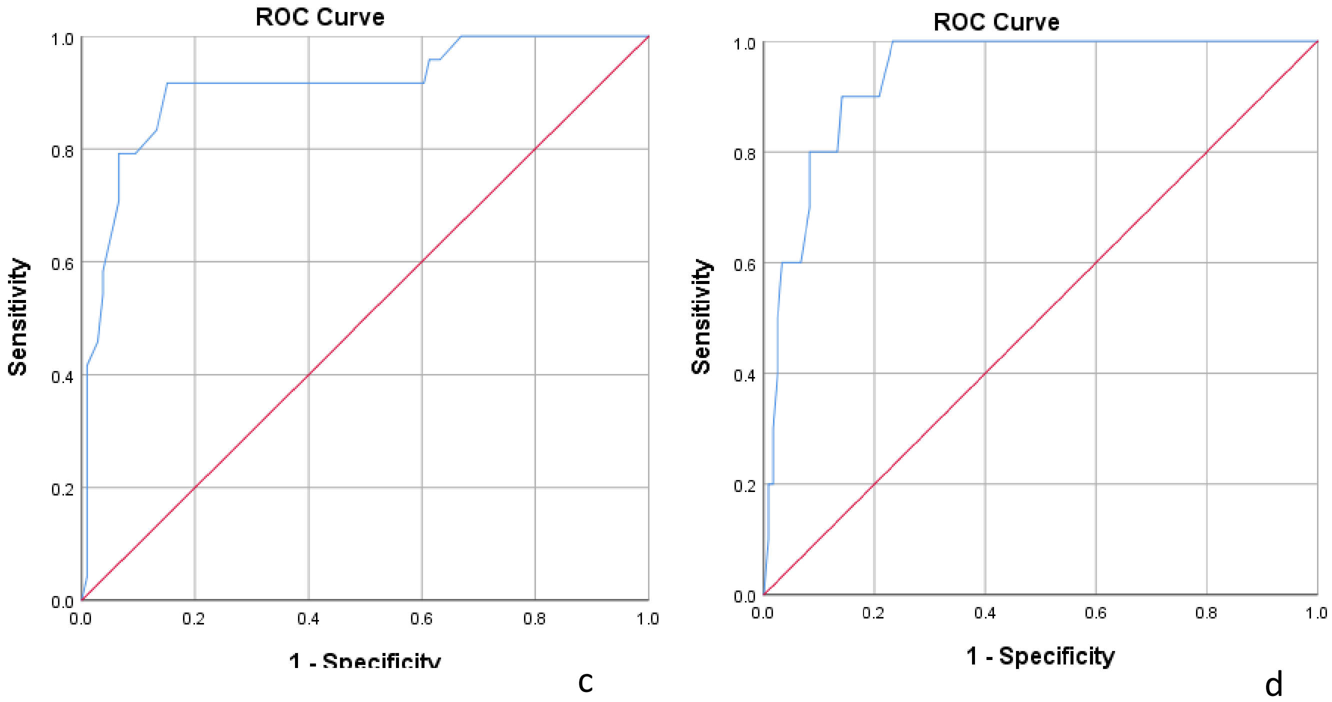


Figure 7.2: ROC curve for overweight females (c) and obese females (d) six to 24 months old (n=130).

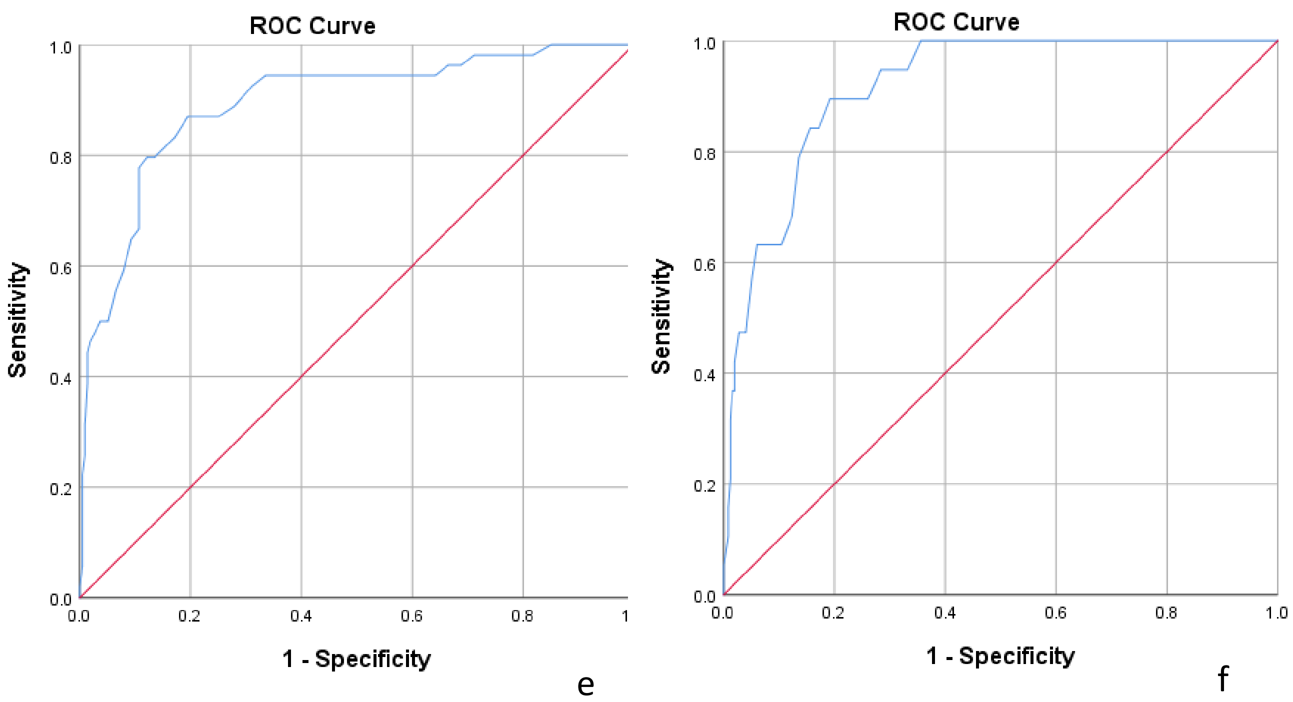


Figure 7.3: ROC curve for overweight (e) and obese (f) children six to 24 months old (n=269).

7.4 Discussion

The proposed MUAC cut-off values of 16.5 cm for overweight (+2<WLZ<+3) males and females, and 17.2 cm for identifying obesity risk in males and 17.0 cm for females correctly classified an acceptably high number of children. The simplicity of MUAC measurements could assist with identifying infants and young children who are clinically overweight or obese early on in community and household settings. MUAC is simple to use. It also could potentially allow for screening for over and under nutrition with a single tool reflecting different cut-off values.

7.4.1 Prevalence of overweight and obesity

The prevalence of overweight was 11% and obesity 5% in this cohort of children from the Eastern Cape, which was higher than expected when compared with a similar cohort of infants residing in a peri-urban environment in the North West Province, where the combined prevalence of overweight and obesity (WFH>+2) was 10.1% (Rothman *et al*., 2018). The relative proximity of these communities to urban environments could explain some of the discrepancy; the risk of obesity increases closer to the city (Vorster *et al*., 2005). However, it is thought that household income, total energy and total fat intake, and level of physical activity are the major determinants of obesity in nutrition-transition sub-Saharan African communities (Hawkes *et al*., 2020). Furthermore, the prevalence of overweight and obesity is increasing in low- and middle-income countries, often at a far higher rate than in high-income countries (Peng and Berry 2018), highlighting the growing importance of early-intervention strategies.

7.4.2 Use of MUAC for identifying overweight and obesity

The results of this study demonstrate that MUAC may be an appropriate tool for identifying children younger than two years old as at risk of overweight and obesity in South Africa. MUAC has been shown to be an effective screening tool for overweight and obesity among adolescents in Ethiopia (Sisay *et al*., 2020). In this Ethiopian sample, MUAC achieved an area under the curve of 96% for males, and 96% for females for identifying overweight or obesity (Sisay *et al*., 2020). MUAC performed well as an indicator of overweight and obesity among Thai children between six and 13 years old (Rerksuppaphol and Rerksuppaphol 2017). The suggested MUAC cut-off values for this population were age and sex-specific. Predicted MUAC cut-off values had high areas under the curve for both male and female children (Rerksuppaphol and Rerksuppaphol 2017). The area under the curve for all groups tested in the current study was found to have a very good diagnostic value. Research so far has not addressed the need for a suitable MUAC cut-off value for identifying overweight risk among children younger than two years. Investigations into the use of MUAC as a screening tool for overweight and obesity risk have largely focused on children of school-going age. Chaput *et al.,* (2017) demonstrated a high level of sensitivity and specificity for identifying overweight and obesity among nine-to eleven-year-olds using novel MUAC cut-offs. A recent systematic review and meta-analysis showed that MUAC has an excellent ability to identify overweight and obesity compared with BMI among children (Sisay *et al*., 2022). However, the authors noted that there is a lack of evidence on the performance of MUAC against gold standard measures of adiposity (Sisay *et al*., 2022). Craig *et al.,* (2014) conducted a study that showed similar results using MUAC in South Africa, but again this research focused on children and adolescents older than five years. The areas under the curve for the current study for females and males were both greater than 0.8, considered the threshold for an acceptably accurate test (Kumar and Indrayan 2011).

It is recognised that there is no accepted definition of obesity in infants (Ogden *et al.,* 2014), therefore there is some controversy surrounding classifying infants younger than two years of age as overweight or obese. Recommendations from the Expert Committee on the Assessment, Prevention, and Treatment of Child and Adolescent Overweight and Obesity include annual nutritional assessment to identify overweight after the age of 24 months, but lack recommendations before this age (Barlow 2007). Reid (2009) identified that parents are uncomfortable with a classification of overweight and obesity in their infants and young children, preferring the terms "unhealthy weight" and "outside of the healthy weight range" to describe overweight and obese infants. However, McCormick *et al.,* (2010) found that children who are obese at 24 months of age were likely to have been obese at six months old. Given the long-term importance of early feeding, including breastfeeding and formula feeding and complementary feeding practices for later risk of childhood overweight and obesity (Gunther, Buyken and Kroke 2007), early identification is an important aspect of prevention. Therefore the importance of these classifications is related to intervention, and not in labelling infants and children.

There is some discordance between BMI for age and WHZ among infants younger than six months (Roy *et al.,* 2016). BMI among 0-6 month olds is a better predictor of overweight and obesity at two years (Roy *et al.,* 2016). BMI does not differentiate fat mass from fat free mass. It is known that fat mass, and specifically, visceral adipose tissue, is a predictor of risk for chronic diseases of lifestyle in adults. The waist to height ratio has been shown to be a better predictor of cardiovascular disease risk than BMI among adults (Lee *et al*., 2008). Mazicioglu *et al*., (2010) assessed the performance of MUAC against waist circumference to identify obesity among children six to 17 years old. It was found that the areas under the curve for MUAC and waist circumference were not significantly different, and therefore both indicators are useful predictors of obesity (Mazicioglu *et al*., 2010). According to Chomtho, Fewtrell and Jaffe (2006), MUAC is reflective of total body adipose tissue in children.

Evidence suggests that cut-off values for anthropometric indicators of nutritional status need to be specific to the population in which they are deployed. BMI must be interpreted using smoothed growth curves for infants, children and adolescents, due to the dynamic growth trajectories present during these stages of the lifecycle. There are several definitions for overweight and obesity among children. These include the WHO criterion and international obesity task force (IOTF) criterion. The prevalence of obesity identified by using either of these definitions in a given population is similar, and there is no need to use both indicators. However, the IOTF definition is more sensitive for identifying metabolic syndrome risk among adolescents (60-85%) than the WHO definition (Goncalves de Oliveira and Guedes 2017). There are currently no smoothed waist circumference centiles used for the South African childhood population. Motswagole *et al*., (2019) have developed population-specific waist circumference centiles for black South African children between the ages of ten and 14 years. It was found that children aged 11 years and older met the adult cut-off for metabolic syndrome risk if they had a waist circumference above the 95th centile in the South African population (Motswagole *et al*., 2019). The current study demonstrated that MUAC is a useful predictor of overweight and obesity among infants and young children. However, the relationship between body morphology and risk of detrimental clinical outcomes such as metabolic syndrome is less clear in this population. In addition, the relationship between MUAC and waist circumference has not been investigated among infants and young children in South Africa.

7.4.3 MUAC in the context of the double-burden of malnutrition

Kim, Lee and Sungwon (2017) report that overweight and obesity between ages two and six years is significantly associated with developing adult metabolic syndrome, while the association between overweight and obesity before the second birthday and development of metabolic syndrome in adulthood exists but is not significant. This may suggest that a window for intervention exists before the second birthday that might have a significant impact on future chronic disease risk. Given that the first 1000 days is such a crucial time for development, identifying overweight and obesity in this age group could potentially prevent future problems associated with the global double-burden of disease. Hawkes *et al*. (2020) have recently suggested that as all forms of malnutrition have common drivers, health workers should aim to simultaneously prevent under and overnutrition, under the term "double-duty actions". Potential double-duty actions include redesigning the existing growth monitoring programmes including weight for height in primary care settings and interpreting overweight where feasible (Hawkes *et al*., 2020). A MUAC cut-off value for overweight and obesity could aid in expanding this action to community and household screening for referral.

Some of the challenges in nutrition screening such as accurately estimating a child's age (Hall *et al*., 2011) are avoided using MUAC and weight for height indicators. Weight for height still requires trained fieldworkers and equipment (WHO 2006), and time available to spend on training fieldworkers may be limited due to overloading roles with tasks and large geographic coverage diluting trained fieldworkers (Hall *et al*., 2011). Additionally, health workers are capable of measuring and interpreting weight but can be uncomfortable with weight and length measurements in combination, therefore weight for height interpretations may not be performed routinely in the field (Cloete *et al*., 2013). According to the results of this study, MUAC is capable of accurately identifying overweight and obese infants and young children. The simplicity of MUAC may also be advantageous in the emerging problem of childhood overweight and obesity as it should help to minimise resource allocation to growth charts, anthropometric equipment, training materials and workshops (WHO 2006) in community settings.

7.4.4 Limitations

This study is limited as the mean age of the participants was 9.78 months, creating a bias toward younger children. The study was conducted in primary care facilities and crèches, therefore excluding children who do not attend these facilities. A further limitation of the study was the cross-sectional approach. A longitudinal study would have yielded more information in relation to the dynamic growth of children, however longitudinal data can be impractical to collect. This study must be repeated with a larger sample size in urban, peri-urban and rural South African communities in order to validate the use of the tool.

7.5 Conclusion

MUAC has the potential to identify children with overweight and obesity in South African communities, where community health workers lack adequate access to growth monitoring equipment. Referrals to health services made during the crucial stage of childhood development before the second birthday can potentially reduce the later risks of overweight and associated chronic diseases of lifestyle in adolescence and adulthood. To the best of the authors' knowledge, this is the first work to address a MUAC cut-off value for overweight and obesity among children younger than two years based on the WHO (2006) criteria. Further research is needed, using larger samples from different South African contexts as well as different definitions of overweight and obesity, to provide better insights into its standardised use.

CHAPTER 8

THE VALIDATION AND DESIGN OF A NUTRITIONAL DOUBLE-BURDEN MUAC TAPE

Overview

Population-specific, adapted mid-upper arm circumference cut-off values have been suggested in countries across the world. It is suggested that adapting the MUAC cut-off values can improve the sensitivity and specificity of the current MUAC cut-off values for identifying acute malnutrition. Simultaneously, evidence is growing that MUAC can be used to identify overweight and obesity among children. Both under- and over-nourished children share the same resources in low- and middle-income countries, including trained personnel and screening equipment. Therefore, the aim of this study was to design an adapted MUAC tape which could identify both under- and over-nutrition among children.

8.1 Introduction

The nutritional double burden of disease refers to a concurrently high prevalence of under- and overnutrition affecting many parts of the developing world. Approximately 45 million children are wasted, 150 million are stunted and 39 million are overweight across the world (UNICEF, World Health Organisation, World Bank Group 2021).

South Africa has a high rate of stunting, with approximately a quarter of children younger than five years stunted (Shisana *et al*., 2013). The prevalence of acute malnutrition is lower in South Africa than the Southern African region, at 1.2% and 3.2% respectively (UNICEF, World Health Organisation, World Bank Group 2021). However, the case mortality rate for severe acute malnutrition (SAM) is high in South Africa, at 30.9% (Massyn *et al*., 2019). Simultaneously, South Africa faces an increase in the prevalence of childhood overweight and obesity, with a projected prevalence of 22.1% in 2025 according to the World Obesity Federation (2020). South African adolescents are already displaying features of the metabolic syndrome associated with higher adiposity (Sekokotla *et al*., 2017).

8.1.1 Measuring nutritional status among children

Anthropometry is an important aspect of nutritional assessment. Anthropometric measurements are considered to be the most universally applicable, non-invasive method of assessing growth in children (De Onis, 2015).

A commonly used method for estimating body composition based on body density was suggested by Siri (1961). These predictions were based on compartmentalising the human body into water, adipose tissue, protein and minerals. Importantly, the sum of the weights of all these compartments is equal to the total weight of the body being measured. In addition, the total density of the body being measured is equal to the sum of the densities of the compartments. Density is given by the equation Density (kg/L) = mass (kg)/volume (L), where pressure and temperature are constant. The density of fat is 0.9 g/cm^{-3}, the density of water is 0.993 g/cm^{-3}, the density of protein is 1.34 g/cm^{-3} and the density of the mineral compartment is 3.0 g/cm^{-3} at physiological temperatures and pressures (37 degrees Celsius) (Siri 1961). Keys and Brezek (1953) established the consistency in density of human adipose tissue regardless of its source. A two-compartment model of body composition is postulated comprised of fat mass, and fat free mass. Therefore, a simplified equation for estimating fat mass and fat free mass is made possible as fat free mass has a constant water content of approximately 73%. This equation assumes a fat mass density of 0.9 g/mL, fat free mass density of 1.1 g/mL, constant hydration, and a constant proportion of fat free mass to bone or mineral content. Total body density can be measured using hydrodensitometry or underwater weighing, or air displacement plethysmography. As there is a constant, inverse linear relationship between body density and percentage fat mass, the Siri (1961) equation can be applied to estimate body composition. This equation is given as $\%FM = \frac{495}{D}$ -450 where D is total body density.

Body mass index is commonly used among adults to identify overweight and obesity. BMI is an index of weight for height, calculated using the equation BMI (kg/m^2) = $\frac{Weight\ (kg)}{Height2\ (m)}$. Including height in the index accounts for variations in weight due to differences in body size. The utility of BMI for this purpose has been demonstrated as the correlation between BMI and height is non-significant. BMI has also been shown to be comparable for adults at different ages as they do not grow linearly after adolescence. Therefore, a single set of BMI cut-off values can be used for all adults.

This is useful as the same measures can be used to interpret individual weight status as well as population overweight and obesity prevalence. However, the length or height of infants and children is not static. The weight, height and BMI of infants and children needs to be interpreted against a reference for age.

Initially the index weight-for-age (WFA) was introduced to quantify growth retardation and had important consequences for health and policy planning (Gopolan and Rao 1984). Subsequently, Waterlow introduced the terms “wasting” and “stunting” to assist in differentiating types of growth retardation (Gopolan and Rao 1984). These terms have been adopted by the World Health Organisation. Stunting is assessed using the index height for age. A BMI for age reference was only suggested in subsequent decades.

While the prevalence of undernutrition remains high across the globe, the prevalence of overweight and obesity is increasing among children at a rapid pace. Measures of overweight and obesity among children are essential to understanding the prevalence and aetiology of childhood overweight and obesity, to facilitate nutrition surveillance and identify individuals for treatment and intervention. A number of indices are available for infants and children which quantify overweight and obesity. Body mass index curves were developed in the United Kingdom in 1990 (Cole *et al.,* 1995; Freeman *et al*., 1995). These reference curves identified the distribution of BMI for children at different ages, and the smoothed reference curves could be used to determine where a child’s BMI is positioned in relation to other children of the same age. These curves make use of centiles, where particularly useful centiles are found at the 50th centile, corresponding with the median, the 2nd centile corresponding with the point two standard deviations below the median, and the 98th centile, corresponding to two standard deviations above the median. The 98th and 99.2nd centiles are used to identify children with overweight and obesity respectively in clinical settings, however, in the United Kingdom and United States of America, the 85th centile identifies overweight and 98th centile identifies obesity in public health surveillance. Cole *et al*., (2000) expanded these centile curves to include an internationally representative sample to define childhood overweight and obesity, with centile curves corresponding to adult BMI of 25 and 30 kg/m^2. This was intended to reduce the arbitrary nature of the differences in interpreting different centile lines as cut-offs in different contexts (Cole *et al*., 2000).

The dangers of overweight and obesity are related to the physiological effects of higher adiposity. Higher adiposity, but not necessarily weight, is associated with metabolic disturbances. Therefore, a useful indicator of overweight and obesity should be capable of differentiating infants, children and adults who have a high degree of adipose tissue as part of their body composition from those who do not. In addition, it is known that the site of adipose tissue deposition is an important indicator of metabolic disease risk. A limitation of BMI is that it does not differentiate fat mass from fat free mass, nor is it capable of differentiating an android obesity phenotype from a gynoid obesity phenotype. Therefore, establishing the utility of BMI as an indicator of body composition and clinical outcomes in children is important.

Widhalm *et al*., (2001) assessed the correlation of BMI and percentage body fat among children. It was found that BMI was positively ($r=0.65$, $p<0.00$) correlated with percentage body fat among children, with a slight difference in correlation between boys and girls ($r=0.63$ for boys vs $r=0.68$ for girls). The r^2 values for BMI explaining variability in percentage body fat were high among children younger than 10 years, from both sexes, however, this was poor for both sexes for children older than 10 years (Widhalm *et al*., 2001). The r^2 value was also lower among obese children and adolescents, indicating that there is greater variability in body fat percentage at the upper end of the BMI scale (Widhalm *et al*., 2001). However, skinfold thickness measurements are better predictors of body fat percentage than BMI among children (Sarria *et al*., 1998).

Skeletal muscle is metabolically active, and is the site of insulin receptors. Adipose tissue is less metabolically active. The BMI can be further divided into the fat mass index (FMI=fat mass/height^2) and fat-free mass index (FFMI=fat free mass/height^2). The sum of the FMI and FFMI is equal to the BMI. Importantly, fat-free mass does not differentiate between skeletal muscle and smooth muscle, organ and mineral content of the body. Research on long-term survivors of acute lymphoblastic leukaemia in childhood has revealed important patterns in fat free mass and fat mass distribution across the body (Marriott *et al*., 2017). It was found that approximately three quarters of skeletal muscle mass is located in the limbs. Sarcopenic obesity refers to the concurrent presence of high body fat mass and low skeletal muscle mass. Mid upper arm circumference (MUAC) measures the circumference of all tissues in the upper arm including skin, skeletal muscle, adipose tissue and bone. Acute malnutrition presents with an initial rapid depletion of adipose tissue, protecting protein stores in skeletal muscle and organs as an adaptation to starvation. It has been shown that children with acute malnutrition display increased rates of lipolysis and reduced rates of proteolysis, with increased concentrations of the products of fat metabolism observed in the serum (Freemark, 2015; Bartz *et al.,* 2014).

Hand grip strength and endurance may be used as a proxy measure for body composition. Muscle mass, strength and fitness are associated with metabolic disease risk and insulin sensitivity, even among children (McCarthy *et al*., 2013). Both overweight and underweight children have lower handgrip strength than normal weight children, and an inverse relationship exists between body fat percentage and handgrip endurance among adolescents (Lad *et al*., 2013). These relationships were more marked among male compared with female adolescents (Lad *et al*., 2013). McCarthy *et al*., (2013) produced normalised growth curves for fat free mass percentage, absolute skeletal muscle mass and skeletal muscle mass percentage. It was found that relative fat free mass (%FFM) was different for male and female children, but that absolute and relative skeletal muscle mass were similar across sexes (McCarthy *et al*., 2013).

Anthropometric measurements such as BMI and body fat percentage may be useful in predicting the risk of metabolic disease. Bohn *et al*., (2015) found that both BMI and body fat percentage were capable of predicting cardiovascular disease risk factors among children and adolescents. Body fat percentage was capable of predicting risk of hypertension, elevated LDL cholesterol and low HDL cholesterol but not impaired glucose metabolism (Bohn *et al*., 2015). The correlation between BMI and hypertension was stronger than the correlation between hypertension and body fat percentage (Bohn *et al*., 2015).

Despite the existence of more advanced and sensitive measures of childhood body composition, practical limitations make these difficult to implement. Measuring fat mass and fat free mass requires expensive and bulky equipment, limiting its use in population surveys and nutrition surveillance. In addition, these measures require a high level of technical expertise and competence. The use of measures of skeletal muscle mass in infants and children has also been limited by a lack of smoothed centile charts for interpreting measurements (McCarthy *et al*., 2013). Due to large differences in body composition across different populations, population-specific reference curves are required for accurate interpretations (Kohli, Gao and Lear 2009). It has been demonstrated that people of South Asian, African, and white European ethnicity have different body compositions. These differences are apparent from infancy. Differences have been attributed to ethnicity, as well as maternal body fat percentage and gestational diabetes (Anand *et al*., 2016).

8.1.2 MUAC as a measure of both under- and overnutrition

MUAC has been found to have a strong correlation with BMI among adolescents (Dasgupta *et al*., 2010). The high co-efficient of correlation (74%) suggests that variance for MUAC vs BMI has a strong explanatory ability (Dasgupta *et al*., 2010). MUAC has a high sensitivity (94.6%) and specificity (71.2%) for malnutrition in this population (Dasgupta *et al*., 2010). The strong association between arm anthropometry and BMI has also been observed among South African adolescents. Both MUAC (r=0.926) and tricep skinfold thickness (r=0.643) had a strong, positive and statistically significant association with BMI among South African adolescents (Otitoola *et al*., 2021). Both MUAC and tricep skinfold thickness could accurately classify these adolescents as overweight or obese as defined by BMI categories (Otitoola *et al*., 2021).

MUAC and BMI for age Z-scores have been shown to have a strong, positive correlation (r=0.81) among adolescents (Sisay *et al*., 2020). These researchers identified optimum absolute cut-off values for MUAC among adolescents between 15 and 19 years of age. Separate cut-off values were recommended for male and female adolescents. Due to the high accuracy of MUAC for identifying overweight and obesity, it has been suggested that MUAC may be a viable alternative tool for nutrition surveillance, as well as individual nutrition screening activities (Sisay *et al*., 2020).

8.1.3 Targeting nutrition interventions in the context of double-burden South Africa

Evidence suggests that drivers of both under- and overnutrition include poor education and poverty, the built environment and access to health services (Hawkes *et al*., 2020). Addressing the double burden of disease therefore will need to consider competition for resources including screening equipment and healthcare personnel between children who are under- and over-nourished. South Africa uses community health workers (CHWs), trained to use MUAC as a screening tool for acute malnutrition, in the community setting. The tool is simple to use compared with complicated growth charts and bulky scales and length boards, making it a useful tool in resource-poor settings. However, the current MUAC cut-off values endorsed by the WHO have shown a poor sensitivity and specificity among South African children (McLaren, Steenkamp and Venter 2017). Therefore, alternative MUAC cut-off values have been proposed, which achieve higher sensitivity and specificity. In addition, research has shown that MUAC can be used to identify overweight and obesity with a high sensitivity and specificity in this population (McLaren *et al*., 2020).

Therefore, the aim of this study is to validate alternative MUAC cut-off values for South African children between six and 24 months old. It aims to design a new double-burden MUAC tape as a single piece of equipment for community screening across the spectrum of malnutrition in this population.

8.2 Methods

8.2.1 Studies used to generate MUAC cut-off values

Data was collected using a cross-sectional design. Ethics approval was obtained from the Research Ethics Committee (Human), Nelson Mandela University, as well as the Eastern Cape Department of Health (ref. no H15-HEA-002). Data was collected on weight, height and MUAC from children from birth to two years old at primary health care centres and creches between October 2015 and February 2016. The Pearson correlation co-efficient was used to predict MUAC values for given WHZ values in order to identify MUAC cut-off values for wasting. Definitions for wasting were used according to WHO protocol. A receiver's operating characteristic (ROC) curve was used to evaluate the area under the curve for MUAC and overweight and obesity. Optimum MUAC values for overweight and obesity were identified using Youden's J.

8.2.2 Validation study

A cross-sectional, descriptive study was undertaken between September 2015 and February 2016. Weight, height and MUAC were collected from children enrolled in pre-Schools. Ethics approval (H15-HEA-DIET-003) was obtained from Nelson Mandela University (NMU) Research Ethics Committee (Human).

Anthropometric data was collected following CDC protocols for both samples. WHO (2005) data cleaning criteria were applied to both samples prior to data analysis.

8.2.3 Statistical analysis

Sensitivity, specificity, positive predictive value, negative predictive values were calculated by applying the MUAC cut-off values published previously to the validation dataset. The association between MUAC category and WHZ category allocation defined by the proposed MUAC cut-off values was assessed using a chi-square test, with Cramer's V used to determine the strength of the association and a Kappa test to determine the level of agreement between the two indicators. Analyses were conducted using SPSS v25.

8.3 Results

8.3.1 Validation dataset

The mean age was 13.57 months (SD, 5.34) and 49.8% of the sample was male. Mean MUAC=15.32 cm (SD, 1.04) and mean WHZ=0.50 (SD, 0.99). WHZ ranged from -3.2 to 4.57. Descriptive statistics for male participants are given in Table 8.1, and descriptive statistics for female participants are given in Table 8.2.

Table 8.1: Descriptive statistics for male participants (n=247).

Age group (months)	Male n (%)	Age Mean (SD)	WAZ Mean (SD)	HAZ Mean (SD)	WHZ Mean (SD)	MUAC Mean (SD)
0-3	37 (14.9)	2.35 (0.85)	-0.09 (1.48)	-0.44 (1.52)	0.53 (1.56)	14.04 (1.80)
4-6	40 (16.2)	5.36 (0.98)	0.29 (1.32)	-0.03 (1.21)	0.48 (1.48)	15.03 (1.39)
7-9	34 (13.7)	8.25 (0.88)	-0.04 (1.50)	-0.84 (1.54)	0.65 (1.59)	15.57 (1.58)
10-12	33 (13.3)	11.43 (0.88)	0.71 (1.10)	-0.10 (1.02)	0.99 (1.17)	16.15 (1.34)
13-15	24 (9.7)	14.27 (0.64)	0.81 (1.33)	-0.26 (2.09)	1.17 (1.29)	16.35 (1.46)
16-18	32 (12.9)	17.29 (0.90)	0.31 (1.26)	-0.95 (1.48)	1.04 (1.21)	16.38 (1.34)
19-21	27 (10.9)	20.57 (0.98)	0.60 (1.25)	-0.34 (1.48)	1.01 (1.34)	16.17 (1.24)
22-24	20 (8.0)	23.68 (0.78)	0.13 (1.19)	-1.24 (1.47)	1.03 (1.14)	16.67 (1.25)

Table 8.2: Descriptive statistics for female participants (n=245).

Age group (months)	Female n (%)	Age Mean (SD)	WAZ Mean (SD)	HAZ Mean (SD)	WHZ Mean (SD)	MUAC Mean (SD)
0-3	39 (15.9)	2.38 (0.81)	0.01 (1.16)	-0.36 (1.54)	0.50 (1.03)	13.54 (1.96)
4-6	47 (19.1)	5.15 (0.88)	0.48 (1.26)	-0.14 (1.56)	0.88 (0.98)	14.82 (1.17)
7-9	29 (11.8)	8.31 (0.99)	0.72 (0.96)	-0.06 (1.13)	1.06 (0.87)	15.50 (1.30)
10-12	35 (14.2)	11.26 (0.91)	0.78 (1.03)	-0.09 (1.07)	1.14 (1.24)	15.81 (1.31)
13-15	23 (9.3)	14.14 (0.71)	0.97 (1.16)	0.26 (1.26)	1.18 (1.35)	16.03 (1.52)
16-18	25 (10.2)	17.65 (0.82)	0.39 (1.27)	-0.69 (1.23)	0.95 (1.27)	15.95 (1.76)
19-21	25 (10.2)	20.27 (0.74)	0.37 (0.86)	-0.27 (1.27)	0.64 (1.12)	16.05 (1.28)
22-24	22 (8.9)	23.49 (0.84)	0.50 (1.21)	-0.30 (1.82)	0.88 (1.28)	16.24 (1.63)

MUAC<13.0 cm had a sensitivity of 100% and specificity of 99.1% (PPV=0.25, NPV=1.0) for WHZ<-3. MUAC between 13.1 and 13.8 cm had a sensitivity of 100% and specificity of 95.6% (PPV=0.117, NVP=1.0) for WHZ<-2. MUAC between 16.5 and 16.9 cm had a sensitivity of 11.1% and specificity of 86.8% (PPV=0.111, NPV=0.868) for WHZ>+2. MUAC>17.0 cm had sensitivity of 90.9%, specificity of 80.1% (PPV=0.235, NPV=0.992) for WHZ>+3. The performance of the new MUAC cut-off values is presented in Table 8.3.

Table 8.3: Performance of the double burden MUAC tape for identifying malnutrition (n=248).

WLZ	MUAC (cm)	TP	FP	FN	TN	Sensitivity (%)	Specificity (%)	PPV	NPV
WLZ<-3	<13.0	1	3	0	344	100	99.1	0.25	1.0
-3<WLZ<-2	13.1-13.8	2	15	0	331	100	95.6	0.117	1.0
+2<WLZ<+3	16.5-16.9	5	40	40	263	11.1	86.8	0.111	0.868
WLZ>+3	>17.0	20	65	2	261	90.9	80.1	0.235	0.992

There was a significant agreement between MUAC and WHZ (Kappa= 0.255; p<0.001). There was a significant association between the proposed MUAC cut-off values and WHZ categories (Pearson Chi square = 233.52; df=16; n=348; p<0.001). This association is strong (Cramer's V= 0.410; p<0.001). The level of agreement between MUAC and WHZ is presented in Table 8.4.

Table 8.4: Agreement between double burden MUAC tape and WHZ (n=248).

Category		**SAM**	**MAM**	**Normal**	**Overweight**	**Obese**	**Total**
	MUAC (cm)	**WHZ<-3**	**-2>WHZ>-3**	**-2<WHZ<2**	**2>WHZ<3**	**WHZ>3**	
SAM	**<13.0**	1	0	4	0	0	5
MAM	**13.1-13.8**	0	2	18	0	0	20
Normal	**13.9-16.4**	0	0	184	8	1	193
Overweight	**16.5-16.9**	0	0	39	5	1	45
Obese	**>17.0**	0	0	33	32	20	85
Total		1	2	278	45	22	348

Results of the studies were used to design a double burden MUAC tape (figure 8.2), based on the design of the WHO (2013) acute malnutrition MUAC tape (figure 8.1).

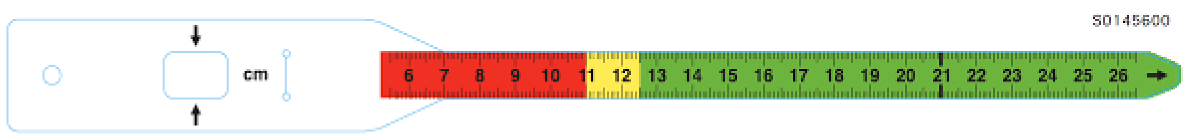


Figure 8.1: WHO (2013) MUAC tape.

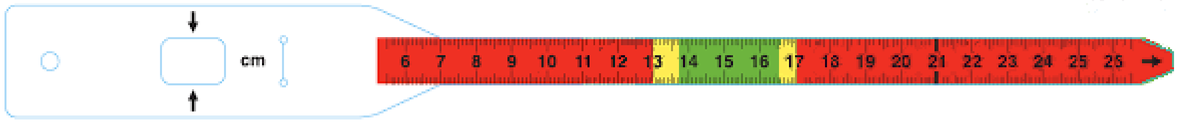


Figure 8.2: Adapted double-burden MUAC tape for assessing acute malnutrition and overnutrition among South African children aged six to 24 months.

8.4 Discussion

The proposed cut-off values for the double burden MUAC tape present a high sensitivity and specificity for SAM, MAM and obesity among South African children between six and 24 months old. The sensitivity of the adapted MUAC tape for identifying overweight children is poor, with most children identified as overweight by the tape having a normal weight-for-height. Results of the chi square test show an association between MUAC category and WHZ category. Further analysis shows this association be of moderate strength, with a fair level of agreement between the two indicators.

It has been argued that the current MUAC cut-off values of 11.5 cm for SAM and 12.5 cm for MAM endorsed by the WHO are appropriate as they have an accepted bias toward younger children who are at a higher risk of mortality (Briend *et al*., 2016). The MUAC cut-off values proposed for acute malnutrition in the present study are designed based on a sample of younger children at a higher risk of mortality. In addition, the lower WHO MAUC cut-offs delay identification of acutely malnourished children (Joseph *et al*., 2002). This is of particular importance in South Africa where the mortality rate among children with SAM is high, in spite of the low prevalence in the community. While raising the cut-off values may increase the number of false positives, potentially overburdening the health system with assessing non-acutely malnourished children, the specificity and negative predictive values of the cut-off values proposed suggest that few children will be erroneously sent to primary health centres for assessment.

Simultaneously, South Africa has a growing problem of childhood overweight and obesity. Targeting interventions is an important aspect of management of childhood overweight and obesity, especially as the evidence of effectiveness of interventions is poor. Barriers to success of childhood overweight interventions in the African context is closely related to resource allocation and access. One aspect of this is ensuring that interventions are designed in a way in which outcomes can be effectively evaluated. Common approaches include behavioural and anthropometric outcomes. However, research suggests that facilitators are inhibited by lack of training, resources, buy-in, and fear of being criticised for incorrect implementation (Klingberg *et al*., 2019). A simplified MUAC tape may assist in measuring effectiveness of interventions.

8.4.1 MUAC as a screening tool across the spectrum of malnutrition

MUAC has been shown to have a strong, positive correlation with BMI for age in adolescents (Chaput *et al*., 2017; Sisay *et al*., 2020). The potential use of MUAC to identify malnourished children across the spectrum of nutritional status as been investigated in a population of Sri Lankan children. In this sample of children between the ages of five and ten years, MUAC was found to be capable of identifying underweight, stunting and overweight with an acceptably high level of accuracy (Shinsugi, Gunesekara and Takimoto 2020). The cut-off values obtained in this Sri Lankan study were higher than those obtained in a sub-Saharan African study. The authors speculated that this may be as a result of differences in ethnicity, as well as the result of differences in the rates of preterm birth and subsequent effects on growth trajectory, which were excessive in the Sri Lankan population (Shinsugi, Gunesekara and Takimoto 2020).

MUAC is not capable of more detailed descriptions of body composition possible for methods of assessment which make use of the two-compartment method, and therefore has the same limitations as BMI. However, MUAC may be a useful single tool for screening for both under- and overnutrition. In cases of undernutrition or wasting, adipose tissue is depleted rapidly, followed by skeletal muscle and finally vital organ proteins to supply glucose and ketones for the brain. In overweight and obesity, there may be an expected amount of muscle mass in the upper arm, in combination with additional adipose tissue. In addition, in obesity, there may be a higher ratio of adipose tissue to skeletal muscle, which can be exacerbated in cases of sarcopenic obesity.

8.4.2 Addressing the double burden of malnutrition

The problem of the nutritional double burden of malnutrition has been discussed in the literature since at least 2001 (Rutengwe *et al*., 2001). However, the two main features of the double burden of malnutrition - under- and overnutrition, largely continue to be investigated separately. Policies and programmes aim to address either stunting and underweight, or overweight, but rarely aim to address both simultaneously. Therefore, there is a lack of evidence on effective "double duty actions" - policies and interventions which are capable of simultaneously addressing under- and overnutrition (Nugent *et al*., 2020).

Intervention strategies for the double burden of malnutrition focus on either addressing underweight or overweight, with few examples of effective "double duty actions" available in the literature (Menon and Penalvo 2019). Interventions addressing undernutrition typically focus on poverty reduction, while interventions addressing overweight and obesity tend to focus on nutrition education and physical activity (Menon and Penalvo 2019). One area of overlap is school feeding schemes. Sekiyama *et al*., (2017) investigated a school lunch intervention which focused on sustainable foods. The intervention resulted in improvements in iron status and anthropometry among children who were undernourished at the start of the intervention, but no changes were observed among overweight children (Sekiyama *et al*., 2017). A study in Burkino Faso aimed to address the double burden of malnutrition through an innovative school feeding scheme (Edde *et al*., 2019). It was found that thinness was positively impacted by the intervention, but there was no effect on overweight and obesity (Edde *et al*., 2019). Nutrition-sensitive interventions including cash transfers have been proposed to address the underlying causes of the double burden of malnutrition. Conkin *et al*., (2018) modelled the effects of increasing minimum wages in 24 low and middle income countries on the nutritional status of women. The model showed a positive correlation between earnings and weight gain among malnourished women, but increasing incomes did not have a protective effect against overweight and obesity (Conkin *et al*., 2018). Given that there is a lack of evidence for "double-duty" interventions, a plausible approach is to identify under- or overnutrition in communities for referral to an appropriate intervention for either under- or overnutrition.

8.4.3 Study strengths

This study made use of gold standard growth charts for interpreting anthropometric indices of child growth. This study made use of accurate methods for measuring weight, height and MUAC for infants and young children.

8.4.4 Limitations

The studies took place in community health centres and creches, therefore limiting the generalisability of the findings. This study should be repeated with a larger sample. In addition, this should take place in a diverse set of settings to improve the generalisability of the findings. MUAC should be compared with other measures of adiposity such as DEXA, bioelectrical impedance analysis or body density plethysmography to gain a more detailed understanding of the relationship between MUAC and body composition.

8.5 Conclusion

The double-burden MUAC tape proposed has potential for reducing resource requirements for screening for both under- and overnutrition in a South African context. Despite the poor performance of the tool for identifying overweight, it has a high sensitivity and specificity for acute malnutrition and obesity. Further research is warranted using a larger independent sample with a range of states of nutrition as well as against clinical outcomes.

CHAPTER 9

GENERAL DISCUSSION

Research priorities in childhood malnutrition identified by the United Nations in the Global Action Plan on Child Wasting include the identification of nutrition-sensitive and nutrition specific interventions which are cost effective and achieve sustained nutritional recovery for children suffering from moderate acute malnutrition (WHO 2020). Priorities include identifying the effect of pre-pregnancy and pregnancy maternal health interventions on the prevention of low birth weight and subsequent childhood malnutrition risk (WHO 2020). Priorities include identifying the impact of interventions on managing growth failure among infants and young children between birth and 24 months of age (WHO 2020).

The distribution of resources is an important ethical consideration in public health system delivery (Roberts and Reich 2002). This is of particular importance in resource-poor environments, where there are limitations on finance, expertise and time.

9.1 Summary of findings

This portfolio of published work explores underlying risk factors for undernutrition and over-nutrition in the context of double-burden South Africa. The aim of this work is to assess the ability of mid upper-arm circumference (MUAC) as a screening tool across the spectrum of malnutrition in children, and to adapt this tool for optimal screening of both under and overnutrition in South Africa.

A large proportion of children in Nelson Mandela Bay are food insecure or at risk of food insecurity. The results suggested that low birth weight is associated with HAZ and WAZ Z-scores, but not with WHZ Z-scores among infants and children younger than 24 months. Approximately two thirds of infants and young children participating in this study were beneficiaries of the child support grant programme. WAZ and WHZ were not different between infants and young children receiving the CSG and those not receiving the CSG, however, the prevalence of stunting was higher among CSG recipients. HAZ scores were significantly different between CSG recipients and non-recipients, with a small practical significance also observed. However, when further analyses were undertaken with birth weight as a covariate, it was found that only birth weight and not food security or accessing CSGs was significantly associated with indicators of nutritional status. This suggests that birth weight is an important aetiological determinant of undernutrition risk among infants and young children in this peri-urban community, and the effects of birth weight are not moderated by later food security or social safety nets.

It has been established that South Africa is net food secure (Du Toit *et al*., 2011). However, evidence (Statistics South Africa 2019) including the current study, demonstrates that food insecurity is present at the household level. South Africa is at a high risk of drought, and this risk affects the risk of water and food insecurity in the population (Baudoin *et al*., 2017). Future predictions of rising global temperatures in the coming decades will present a new challenge to ensuring adequate dietary intake among South Africans, particularly among the most vulnerable segments of society. Childhood malnutrition is exacerbated by undesirable birth outcomes. Strategies will be needed which address low birth weight risk. Accelerated weight gain in early life could potentially lead to adverse health outcomes. Evidence from Nepal suggests that improving access to antenatal services and provision of iron supplementation during pregnancy may be effective strategies for reducing the low-birth-weight rate (Khanal *et al*., 2014). Presently, three quarters of South African women are estimated to attend at least four antenatal care visits (WHO 2021), however, the rate of anaemia in pregnancy is estimated to be 30.8% (WHO 2019).

Approximately a tenth of children younger than five years had missed their vaccinations, while over a third had missed the most recent dose of vitamin A or deworming treatment in this population. It was found that there was no relationship between vaccination history and age of the child, however, older children were more likely to have missed a vitamin A or deworming dose compared with younger children and infants. A relationship between history of missed vitamin A or deworming and age was observed. The results of this study suggested that anthropometric indicators of nutritional status and growth were no different between infants and children with a history of missed vaccination, vitamin A or deworming and those that were up to date with treatments. However, WAZ, HAZ and WHZ were significantly different between infants and children with a history of low birth weight compared with normal birth weight infants and children. It was found that stunting risk is highest among low-birth-weight children in the first year of life, but that the risk of remaining stunted is no longer significant at five years of age. This suggests that there is a potential for catch-up growth among children who are stunted and have a history of low birth weight.

The vitamin A coverage rate for children 6-59 months of age in South Africa is 50% (World Bank, UNICEF 2018). However, the present study has demonstrated that vitamin A supplementation is not a significant factor in child growth. Evidence from the Northern Cape suggests that South African children are at risk of hypervitaminosis A (Sheftel *et al*., 2022, van Stuijvenberg *et al*., 2019), leading to calls to revoke the vitamin A supplementation programme (Coutsoudis *et al*., 2019).

The results of this research suggest that South African women of childbearing age have high rates of overweight and obesity and a high prevalence of anaemia. It was found that haemoglobin levels were different between women in different BMI categories. Women with an overweight or obese BMI have significantly different haemoglobin levels compared with women with a normal BMI. These results suggest that the double burden of malnutrition affects women of childbearing age in South Africa. It was found that haemoglobin levels are higher among women with access to improved sanitation, compared with women without access to improved sanitation. No significant differences in haemoglobin levels were observed between women with access to improved water compared with women without access to improved water. Women in the poorest wealth category had lower haemoglobin levels compared with other wealth categories.

Overall, this population appears to suffer from high levels of childhood stunting and overweight, and a large proportion of the population is affected by food insecurity or at risk of food insecurity. In addition, there is a large proportion of this population who require child support grants. Vaccination coverage is good, however vitamin A and deworming coverage is poorer, particularly among older children. In spite of these problems, the overriding risk factor for stunting and underweight is a history of low birth weight in this population. Maternal nutritional status is an important determinant of risk of adverse birth outcomes such as preterm and small for gestational age infants. South African women of childbearing age display high rates of overweight, obesity and anaemia. Factors which are associated with anaemia among South African women of childbearing age include BMI, access to improved sanitation and poverty.

The results indicate that current MUAC cut-off values have a poor sensitivity and specificity for identifying acute malnutrition among South African children younger than 24 months of age in a peri-urban environment. Male and female infants and young children display different growth trajectories reflected in their MUAC measurements, which is a rationale for using sex-specific cut-off values. No differences in MUAC measurements were observed for infants and young children between the ages of six and 24 months, therefore a single MUAC cut-off value is feasible to use for each sex in this age group. Adapting the MUAC cut-off values from the current WHO recommended values to a population-specific set of cut-offs improves the sensitivity and specificity of MUAC for identifying acute malnutrition.

The results also indicate that MUAC may be an appropriate tool for identifying overweight and obesity among infants and young children. As with MUAC for identifying acute malnutrition, MUAC measurements were significantly different between male and female infants and young children, and therefore separate, sex-specific cut-off values were developed. In addition, MUAC was significantly different for infants younger than six months of age, but no differences were detected for infants and young children between the ages of six and 24 months. Therefore, a single, sex specific MUAC cut off value for overweight and obesity was feasible for all children between the ages of six and 24 months. The practical advantage of this is that one cut off can be used, independent of age in this group, which is not possible when interpreting weight, height, weight for height or BMI among children. The suggested MUAC cut-off values correctly identified a high proportion of children as overweight or obese compared with WHZ>2 and WHZ>3 respectively.

The newly proposed MUAC cut-off values specific to South African children between the ages of six and 24 months were validated using a separate dataset of children from the same community. It was found that the new MUAC cut-off values for acute malnutrition had a high sensitivity and specificity. Therefore, the new cut-off values could identify children presenting with acute malnutrition with a high level of accuracy, while maintaining an acceptably low level of false positives. The proposed MUAC cut offs for obesity performed similarly well, however, the MUAC cut off for overweight displayed a poor sensitivity. Nonetheless, there was a good level of agreement between MUAC and WHZ, as well as between children's classification as under- or overnutrition as categorised by WHZ and MUAC.

9.2 Implications of findings and recommendations

Low birth weight was consistently found to be associated with indicators of nutritional status among infants and young children in this peri-urban population. Low birth weight could be used as a predictor of anthropometric deficit in early childhood. Triaging infants born with a low birth weight for regular follow ups with nutritional, health and social support services may help to mitigate the risk of malnutrition. Nutrition sensitive interventions which may help to prevent low birth weight among South African infants could include improving access to improved sanitation for households, with an emphasis on those occupied by women of childbearing age. In addition, poverty alleviation schemes may assist in improving micronutrient status among women of childbearing age. Investigations into nutritional risk factors for low birth weight among South African infants should be undertaken.

Health services could aim to improve vitamin A supplementation and deworming strategies for young children. Improved targeting of these interventions and combination with WaSH strategies could improve their effectiveness in individuals and populations where they are required. Further research might investigate the relationship between vitamin A status and malnutrition risk among infants and young children in various South African settings.

Although the sensitivity and specificity of the current MUAC cut-off values was found to be poor compared to WHZ, further investigation is warranted into the sensitivity and specificity of the tool compared with other clinical outcomes. This would further increase the accuracy of the tool in identifying infants and young children at high risk of the serious consequences of acute malnutrition, namely increased risk of mortality, morbidity and developmental delay.

MUAC cut-off values for overweight and obesity were developed based on WHZ indices. However, while WHZ and BMI for age give an indication of future chronic disease risk in adolescents, they are imperfect indicators of body composition. It is known that body composition varies between ethnicities. Further research should investigate the relationship between MUAC and fat mass and fat free mass in infants and young children.

While the newly developed MUAC cut-off values for under- and overnutrition improved the sensitivity of the tool, this was achieved at a cost of lower specificity. This can potentially over-burden the health system with inappropriate referrals or result in a larger caseload of potentially malnourished infants and children. Further research should aim to assess the effects of alternative MUAC cut-off values on health service use.

9.3 Study critique

The study which generated data for articles I, IV, V and VI was conducted at primary health centres and creches and therefore the results will not be generalisable to the wider population which does not make use of these services. The low number of children with SAM is a limitation to this study.

Data for chapter 4 were collected from children attending creches and therefore the results cannot be generalised to the wider population. The study used a cross-sectional design which is not the ideal design for describing the factors associated with the dynamic growth patterns in children. Data on vitamin A, deworming and vaccination history was limited to the last dose and did not account for the full vitamin A, deworming and vaccination history. There was no investigation whether children in this sample with delayed deworming were infected with STH. Data was not collected on potential confounding factors including HIV and other illnesses. Morbidity and mortality were not assessed in this study, limiting the interpretations of the effectiveness of vitamin A, deworming and vaccinations to their effects on anthropometric status. Birth weight was recorded but not gestational age, so no distinction is made between low birth weight and premature birth children. This study made use of gold standard anthropometry methods for data collection.

The results of chapter 5 are limited in that only haemoglobin was used as a marker of iron status. Future research should include biomarkers including ferritin and transferrin to better understand the relationship between anthropometric status and iron status as well as to differentiate between nutritional iron deficiency and other causes of anaemia. A strength of this study is the sampling design undertaken by the DHS.

The results of chapter 7 are limited as the mean age of the participants was 9.78 months, creating a bias toward younger children. The study was conducted in primary care facilities and crèches, therefore excluding children who do not attend these facilities. A further limitation of the study was the cross-sectional approach. A longitudinal study would have yielded more information in relation to the dynamic growth of children, however longitudinal data can be impractical to collect. This study must be repeated with a larger sample size in urban, peri-urban and rural South African communities in order to validate the use of the tool.

Cross-sectional studies are not the study design of choice to determine growth patterns in children and this should be considered a limitation. Measuring infants and young children in clinics and crèches inherently excludes children who do not attend clinics and crèches and thus the results cannot be generalised. This study does not differentiate low birth weight as a consequence of small for gestational age or preterm birth.

9.4 Study strengths

A strength of this research is that it made use of large samples of infants and young children. Inclusion and exclusion criteria were applied to produce a homogenous sample which improves the generalisability of the findings to the population group studied. This work made use of gold standard methods of measuring the weight, height and mid-upper arm circumference of infants and young children. The sampling design used by the DHS is a strength; the stratified sampling method employed allows for inferences to be draw about the South African population. Data on medical histories including birth weight history were obtained from clinical record cards, improving the validity and reliability of the work. Data on food security was obtained using a validated tool and results were standardised. Data cleaning exercises were carried out using recommendations from the World Health Organisation to improve the quality of the data, and to reduce the risk of type 2 errors arising from inaccuracies in measurements or data capturing.

9.5 Contribution to knowledge

The results of these studies have been published in peer-reviewed, scientific journals. There has been wide interest in the literature with regards to food security and its relationship to nutritional status among South African children While evidence has been emerging with regards to social welfare and its relationship with childhood malnutrition status, this work made a unique contribution to the literature by accounting for birth weight as a co-factor in the development of malnutrition among South African children, in the context of food security and social welfare. This work has also contributed to the literature on the uptake of vitamin A supplementation and deworming medications among South African children. Limited data was available on these patterns, and this work described relationships between the age of the child and likelihood of using these health services. This work has contributed to the understanding of the performance of MUAC as an indicator of wasting among South African children. This work has been the first to address a MUAC cut-off value for overweight and obesity among South African children. To the best of the researcher's knowledge, this is the first work to investigate MUAC cut-off values for overweight and obesity among infants and children younger than 24 months of age and their performance against WHO (2006) definitions of overweight and obesity.

9.6 Impact on community or potential impact

The findings of these studies have already been shared with the scientific community through publication in peer-reviewed scientific journals. Parts of this research have been incorporated into nutrition skills training for community health workers across the Eastern Cape in South Africa. At present, the South African Department of Health does not discriminate between children with a WFH>-2 as normal weight, overweight or obese, but classifies all of these children as "not acutely malnourished". Therefore, it is hoped that this research will be a useful starting point for addressing childhood overweight and obesity in the Eastern Cape province and recognition of the importance of these distinctions.

9.7 Future directions of the researcher's work

Further work currently under peer-review investigates the overlap between underlying causes of stunting and overweight among South African children. Results of this study suggest that birth weight is the only factor associated with the development of both stunting and overweight in the South African context, while poor maternal educational attainment, poverty and short maternal stature place children at a higher risk of stunting but not overweight.

Work is also currently underway to investigate the ability of community health workers and nutrition advisors to accurately identify nutritional status of infants and young children in Nelson Mandela Bay using anthropometry. This work makes use of a mixed qualitative and quantitative approach to provide additional insights into interpretations of nutritional status by health workers in the field.

This research is also supporting work under way in the KwaZulu-Natal province in South Africa, where telomere length among malnourished children is being investigated as an early molecular indicator of cellular aging resulting in higher risk of chronic diseases of lifestyle, in the context of the double burden on malnutrition.

The researcher also intends to develop this work in the context of the United Kingdom, by exploring anthropometric indicators of nutritional status among different ethnic groups in London. The researcher aims to develop research on the prevalence and risk factors for food insecurity in London. In addition, this research and the expertise developed through its execution will support research being undertaken in Uganda which focuses on maternal health. The researcher will support this work as part of the supervisory team.

Conclusion

This research aimed to identify contextual factors surrounding childhood malnutrition in a South African per-urban community. The results of this work suggest that initiatives under the Integrated Nutrition Programme and IMCI including vitamin A and deworming are insufficient to impact nutritional status of children in the context of low birth weight. The results of this work suggest that improved sanitation, women's health and reducing poverty would have some impact on nutritional status in this population. This research aimed to assess the sensitivity and specificity of MUAC in identifying malnutrition among infants and young children. These results do not support the current WHO MUAC cut-off values in this South African context. It has been suggested that the current cut-off values are adapted to the local population.

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Appendices

Appendix A: Research ethics committee (Nelson Mandela University) letter for “Use of Mid Upper- Arm Circumference (MUAC) as screening tool in an urban township in the Eastern Cape: rationale for testing changed cut-off values to identify malnutrition”, “Screening for overweight using mid-upper arm circumference (MUAC) among children younger than two years in the Eastern Cape, South Africa” and “Food insecurity, social welfare and low birth weight: Implications for childhood malnutrition in an urban Eastern Cape Province township”

Nelson Mandela Metropolitan University

for tomorrow

• PO Box 77000 • Nelson Mandela Metropolitan University
• Port Elizabeth • 6031 • South Africa • www.nmmu.ac.za

Chairperson: Research Ethics Committee (Human)
Tel: +27 (0)41 504-2235

Ref: [H15-HEA-DIET-002 /Approval]

Contact person: Mrs U Spies

21 July 2015

Dr L Steenkamp
Faculty: Health Sciences
Department: Dietetics
M & P Building, Room 01-15
South Campus

Dear Dr Steenkamp

ANTHROPOMETRIC INDICATORS IN IDENTIFYING MALNUTRITION RISK AMONG CHILDREN YOUNGER THAN TWO YEARS IN MOTHERWELL, NELSON MANDELA METROPOLITAN MUNICIPALITY

PRP: Dr L Steenkamp
PI: Mr S McLaren

Your above-entitled application served at Research Ethics Committee (Human) for extension.

We take pleasure in informing you that the extension was approved by the Committee.

The ethics clearance reference number is **H15-HEA-DIET-002** and is valid for three years. Please inform the REC-H, via your faculty representative, if any changes (particularly in the methodology) occur during this time. An annual affirmation to the effect that the protocols in use are still those for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

CB Cilliers

Prof C Cilliers
Chairperson: Research Ethics Committee (Human)

cc: Department of Research Capacity Development
Faculty Officer: Health Sciences

Appendix B: Approval letter from the Eastern Cape Department of Health

Province of the
EASTERN CAPE
HEALTH

Nelson Mandela Bay Health District
Private Bag X 28000
Greenacres
Port Elizabeth
6057
REPUBLIC OF SOUTH AFRICA

Enquiries : Dr L F MAYEKISO
Telephone : 041-391-8173
Facsimile : 041-391-8155
E-mail : Mfusa.mayekiso@gmail.com

Our Reference: RESEARCH/2015
Your Reference:
Date: 16 OCTOBER 2015

Ms S Mclaren

REQUEST FOR PERMISSION TO CONDUCT "ANTROPOMETRIC INDICATORS IN IDENTIFYING MALNUTRITION AMONG CHILDREN YOUNGER THAN TWO YEARS IN MOTHERWELL, NELSON MANDELA BAY HEALTH DISTRICT"

In response to your application for permission to conduct the above research study at facilities within the Nelson Mandela Bay Health District (NMBHD), permission is hereby granted with the following proviso:

There should be no negative impact on existing health service delivery operations. All required data should be collected by the Researcher or a designated fieldworker (whose name should be forwarded to the relevant Sub District Coordinator prior to data collection). The Sub District Coordinator, Mrs Siphokazi Mautu - 083 378 1942 and Mrs P Njalo, Facility Manager, Motherwell CHC 060 583 6676 should be contacted before your visit and this letter is to be presented when visiting the Motherwell Community Health Centre.

The Nelson Mandela Bay Health District, as the research site, will expect a copy of the final research report when the study is completed. If the duration of the research period is required to be extended, the NMBHD should be informed accordingly.

We would like to take this opportunity to wish you well for your research study.

DR L F MAYEKISO
CLINICAL GOVERNANCE MANAGER - NMBHD

Appendix C: Authorisation letter to use secondary data for “The relationship between haemoglobin level and socio-economic indicators among women of childbearing age in South Africa: A secondary analysis of DHS data”

ICF

Nov 02, 2020

Shawn McLaren
London Metropolitan University
United Kingdom
Phone: 07848170172
Email: mclarens@staff.londonmet.ac.uk
Request Date: 11/02/2020

Dear Shawn McLaren:

This is to confirm that you are approved to use the following Survey Datasets for your registered research paper titled: "The relationship between iron status and body mass index among women of childbearing age in South Africa: An analysis of DHS data":

South Africa

To access the datasets, please login at: https://www.dhsprogram.com/data/dataset_admin/login_main.cfm. The user name is the registered email address, and the password is the one selected during registration.

The IRB-approved procedures for DHS public-use datasets do not in any way allow respondents, households, or sample communities to be identified. There are no names of individuals or household addresses in the data files. The geographic identifiers only go down to the regional level (where regions are typically very large geographical areas encompassing several states/provinces). Each enumeration area (Primary Sampling Unit) has a PSU number in the data file, but the PSU numbers do not have any labels to indicate their names or locations. In surveys that collect GIS coordinates in the field, the coordinates are only for the enumeration area (EA) as a whole, and not for individual households, and the measured coordinates are randomly displaced within a large geographic area so that specific enumeration areas cannot be identified.

The DHS Data may be used only for the purpose of statistical reporting and analysis, and only for your registered research. To use the data for another purpose, a new research project must be registered. All DHS data should be treated as confidential, and no effort should be made to identify any household or individual respondent interviewed in the survey. Please reference the complete terms of use at: https://dhsprogram.com/Data/terms-of-use.cfm.

The data must not be passed on to other researchers without the written consent of DHS. However, if you have coresearchers registered in your account for this research paper, you are authorized to share the data with them. All data users are required to submit an electronic copy (pdf) of any reports/publications resulting from using the DHS data files to: references@dhsprogram.com.

Sincerely,

Bridgette Wellington

Bridgette Wellington
Data Archivist
The Demographic and Health Surveys (DHS) Program

Appendix D: Registration with the National Health Research Database

RESEARCH PROPOSAL DETAILS: EC_2015RP34_978

APPLICATION DETAILS

Title of Research Project

ANTHROPOMETRIC INDICATORS IN IDENTIFYING MALNUTRITION RISK AMONG CHILDREN YOUNGER THAN TWO YEARS IN MOTHERWELL, NELSON MANDELA METROPOLITAN MUNICIPALITY

Status of Project

On-Going

Application State

Approved

Propsal Submission Date

2015/07/22

Research Staff assigned to Project/Proposal

Title	Name	Surname	Role	Institution
MR	Shawn	Mclaren	Lead Investigator	Nelson Mandela Metropolitan University

Aim and Objectives

This study aims to synthesise a profile of actual growth among children younger than two years old in Motherwell, Nelson Mandela Metropolitan Municipality (NMMM) to determine associations between anthropometric indicators for possible use as predictors for malnutrition risk.

Study Area(s)/Field(s)

Description
Child Health

Study Design(s)

Description
Cross-Sectional Study

Data Collection Method(s)

Method Category	Method Description
QUALITATIVE	Direct Observations
QUANTITATIVE	Questionnaire

Sample

A sample will be drawn from the community of Motherwell in the Eastern Cape using a cluster sampling method. A minimum of 30 study participants will be required per cluster, as suggested by the Unit of Statistical Consultation (NMMU).

Data Analysis Tool(s)

Tool Description
Statistician (If Available)
Microsoft Excel

Locations(s) where study will be conducted

Appendix E: Food insecurity, social welfare and low birth weight: Implications for childhood malnutrition in an urban Eastern Cape township.

Food insecurity, social welfare and low birth weight: Implications for childhood malnutrition in an urban Eastern Cape Province township

S McLaren,[1] MSc Dietetics; **L Steenkamp**,[2] MSc, MSc PHN, PhD (Dietetics); **A Feeley**,[3] MSc PHN, PhD; **J Nyarko**,[4] B Cur, MBA, MPA; **D Venter**,[5] PhD

[1] *Department of Dietetics, Faculty of Health Sciences, Nelson Mandela University, Port Elizabeth, South Africa*
[2] *HIV/AIDS Research Unit, Nelson Mandela University, Port Elizabeth, South Africa*
[3] *UNICEF, Pretoria, South Africa and MRC/WITS Developmental Pathways for Health Research Unit, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa*
[4] *Maternal Child and Women's Health, Nelson Mandela Bay Health District, Port Elizabeth, South Africa*
[5] *Nelson Mandela University, Port Elizabeth, South Africa*

Corresponding author: *L Steenkamp (liana.steenkamp@nmmu.ac.za)*

Background. Limited information is available regarding the impact of food insecurity, low birth weight (LBW) and the protective effect of the child support grant (CSG) on malnutrition in South Africa (SA).
Objectives. To describe malnutrition in the context of food insecurity, CSG and LBW history among children younger than 24 months from an underprivileged urban settlement in the Eastern Cape Province of SA.
Methods. A descriptive study using a cross-sectional design was used to collect data from a non-probability sample of 400 young children from October 2015 to February 2016. Inferential statistics included *t*-tests to compare anthropometric data from different birth weight categories and analysis of covariance (ANCOVA) to allow for the effect of covariates.
Results. Of the sample, 9% were stunted, 1% were wasted, 16% were overweight, 23% were food secure, 47% were at risk of hunger, and 31% were classified as hungry. LBW history was significantly associated with stunting but not with wasting. CSG holders and 'hungry' households' children had significantly lower mean height-for-age *z*-scores (HAZ) than non-CSG holders and food-secure households. Despite these apparent associations, when LBW is considered as a covariate, it becomes apparent that neither the CSG nor CCHIP category is significantly related to any of the anthropometric indicators.
Conclusion. The Department of Health has to recognise the significant impact of LBW on the prevalence of stunting and thus the need to prioritise antenatal care. Policymakers could aim to make the CSG available to mothers as close after birth as possible, or during pregnancy, in order to be more effective in reducing the long-term effects of LBW.

S Afr J Child Health 2018;12(3):95-99. DOI:10.7196/SAJCH.2018.v12i3.1468

South Africa (SA) is one of the most unequal societies in the world, with a Gini coefficient of 63.4.[1] One of the direct results of inequality is insufficient access to food, which is also one of the underlying causes of malnutrition.[2] According to the results of the 2016 General Household Survey, 22.3% of SA households had inadequate or severely inadequate access to food.[3] In the Eastern Cape Province, 26.4% had inadequate access to food and 5.9% suffered severe inadequate access to food, indicating a high level of vulnerability.[3] Shisana *et al.*[4] reported that the national prevalence of hunger was the highest in informal urban settings with an estimated 32.4% of people experiencing food insecurity.

Initiated in 1998, the SA Child Support Grant (CSG) provided a safety net to 2.5 million children from vulnerable households.[5] In 2015, 11 792 900 children were registered as CSG beneficiaries,[6] and this figure was projected to rise to 12.3 million by 2017.[7] While social grants have made some impact on SA household food security,[8] others argue that the effect of the CSG on nutritional status 'may have been eroded by food price inflation and limited progress in the provision of other important interventions and social services.'[9]

Koornhoff[10] stated that CSG-receiving households in the Western Cape Province reported significantly lower household income and more child stunting than households in the same area not receiving CSGs. In a study in urban townships in the Eastern Cape,[11] CSG-receiving households reported a higher monthly income than non-CSG-receiving ones. However, Steenkamp *et al.*[11] showed that significantly more households with people receiving the CSG spent less than ZAR8 a day on food, compared with those not receiving the CSG. Households with children who received the CSG spent more money on non-food items, which may have contributed to the fact that they also experienced hunger more often, indicating that the CSG grant does not necessarily act as a safety net against hunger.

Apart from food insecurity contributing to malnutrition in children, women's health during the antenatal period may also impact fetal growth and development. A meta-analysis of 19 longitudinal birth cohorts from low- and middle-income countries revealed that children who were small for gestational age (birth weight less than 10th percentile for gestational age) were 2.4 times more likely to be stunted later in life, while preterm (less than 37 weeks' gestation) children had 1.9 times increased odds of stunting.[12] Children who were both small for gestational age (SGA) and preterm had a 4.5 times increased risk of stunting when compared with normal birth weight and term children.[12] Maternal health and nutrition are therefore both important factors in the development of chronic child undernutrition.

In SA, LBW was prevalent among 9.9% and preterm birth occurred in 11.4% of participants.[12] The LBW rate in Nelson Mandela Bay health district (NMBHD) was 16% during the 2016 calendar year (District Health Information Software, Eastern Cape Department of Health).

Despite the available data on maternal and child outcomes, limited information is available regarding the impact of food insecurity, LBW, the protective effect of CSGs on malnutrition risk during the first 1 000 days and the complex associations between these variables. The aim of the present study was to describe malnutrition risk among children younger than 2 years age residing in Motherwell, NMBHD, in the context of food insecurity, CSG and LBW history.

Methods

This was a descriptive study using a cross-sectional design. It involved measuring the weight, length or height and mid-upper arm circumference (MUAC) of children younger than 2 years residing in Motherwell. Motherwell is an area of ~25.86 km^2 and with a population of 140 351 people,[13] with 5 817 children younger than 2 years in 2016. This community comprises lower-income residents with 6 clinics providing primary healthcare services. Procedures for obtaining anthropometric data followed protocols described by the Centers for Disease Control and Prevention (CDC).[14] Measurements were carried out by trained fieldworkers. Weight was measured using a Nagata BW-2010 infant scale. A Seca infantometer with a movable foot piece was used for measuring length. Non-stretch MUAC tapes were used in the study. The study also involved the use of structured questionnaires including demographic information and the household food security (HHFS) by means of the Community Childhood Hunger Identification Project (CCHIP) questionnaire.[15] This questionnaire is composed of 8 questions, with each affirmative answer adding one point to a household's score. A CCHIP score of 0 indicates food security, a score of 1 to 4 indicates that a household is at risk of hunger, and a score of >5 indicates hunger.[15] Where needed, the CCHIP questions were translated into isiXhosa and captured by a trained fieldworker. A non-probability sampling method was employed (convenience sampling) resulting in a sample of 400 infants and young children. This sample was obtained from 5 clinics and 15 Early Childhood Development (ECD) centres over the period October 2015 to February 2016. Ethical approval was obtained from the Research Ethics Committee (Human) (ref. no. H15-HEA-002), Nelson Mandela University and the Eastern Cape Department of Health. Inclusion in the study required written informed consent from the primary caregiver of the participant. Although the primary caregivers had to provide consent, not all were available at the ECD centres at the time of data collection to complete the CCHIP questionnaire or provide grant information. Anthropometric data were used to calculate *z*-scores for weight-for-height (WHZ), weight-for-age (WAZ) and height-for-age (HAZ) using World Health Organization (WHO) Anthro software (WHO, Switzerland). For the purpose of this study, data cleaning criteria according to WHO[16] were applied. Descriptive statistics i.e. frequencies and percentages, were used to describe outcomes of categorical data. Inferential statistics included *t*-tests to compare anthropometric data from different birth weight categories and ANCOVA to allow for the effect of covariates.

Results

Nine records were removed from the sample as they had implausible *z*-scores. A further 10 records were removed due to incomplete data or not meeting the inclusion criteria.

All of the children included in this study were of black ethnicity and younger than 2 years of age. Half of the sample were male (n=199). The mean (standard deviation (SD)) participant age was 9.78 (6.13) months (median 9 months).

Of the sample, 9% were stunted, 1% were wasted and 16% were overweight. The mean (SD) WAZ was 0.44 (1.26), the mean (SD) WHZ was 0.83 (1.28) and the mean (SD) HAZ was −0.24 (1.26). The mean WAZ, HAZ and WHZ did not differ significantly between males and females in the sample or between age categories when using 3-month age intervals. Furthermore, there were no significant differences between the age of stunted compared with non-stunted children.

Food security

Responses to the CCHIP questionnaire were obtained from 76% (n=305) of the participants' caregivers. These (Table 1) were collated and revealed that 23% of the sample were food-secure, 47% were at risk of hunger, while 31% were classified as hungry. As illustrated in Table 1, more caregivers reported food insecurity at household level (45 - 60%) than child hunger (15 - 34%).

Children in the 'food-secure' category had a mean (SD) WHZ of +1.0 (1.4) compared with children in the 'hungry' category who had a mean (SD) WHZ of +0.7 (1.2). Similarly, children in the 'food-secure' category had a mean (SD) HAZ of −0.2 (1.3) compared with a mean (SD) HAZ of −0.5 (1.4) in the 'hungry' category.

Birth weight

As illustrated in Table 2, 5.7% (n=22) of the sample with birth weight information available (n=386) reported a LBW (<2 500 g). The mean values for the various anthropometric indicators of nutritional status per birth weight category are presented in Table 2.

Table 1. Results of the CCHIP questionnaire by question (N=305)

	Answer	
	No, n (%)	Yes, n (%)
Household-level food insecurity		
Does your household ever run out of money for food?	122 (40)	183 (60)
Do you ever rely on a limited number of foods to feed your children because you are running out of money to buy food for a meal?	132 (43)	173 (57)
Do you ever cut the size of meals or skip meals because there is not enough money for food?	169 (55)	136 (45)
Individual-level food insecurity		
Do you ever eat less than you should because there is not enough money for food?	165 (54)	140 (46)
Child hunger		
Do your children ever eat less than you feel they should because there is not enough money?	206 (68)	99 (32)
Do your children ever say they are hungry because there is not enough food in the house?	226 (74)	79 (26)
Do you ever cut the size of your children's meals or do they ever skip meals because there is not enough money to buy food?	201 (66)	104 (34)
Do any of your children ever go to bed because there is not enough money to buy food?	260 (85)	45 (15)

CCHIP = Community Childhood Hunger Identification Project.

As expected, LBW participants had a significantly lower WAZ ($p<0.0005$) and HAZ ($p<0.0005$) score than normal birth weight (NBW) participants (Table 2). However, no significant differences could be observed between LBW and NBW participants for WHZ and MUAC. Therefore, during the first 1 000 days, LBW seems to be significantly associated with lower HAZ scores but not with lower WHZ scores. Interestingly, only 3% (n=12) of the NBW children deteriorated later into being stunted from birth till the survey date. These children represented 35% of the total number of stunted children (n=34) in our sample.

Child support grants

CSG data were available from 327 of the 400 participants and 67% (n=221) of participants with available CSG information were grantholders. CSG holders showed a significant ($p<0.05$) lower mean HAZ score than non-CSG holders (Table 3). There were no significant differences between grant recipients and non-recipients for mean WAZ and WHZ. Of the CSG holders, 10% (n=22) were classified as stunted while only 5.6% (n=6) of the non-CSG holders were classified as stunted.

To appropriately account for all variables related to the nutritional indicators (WAZ, HAZ, WHZ), univariate ANCOVAs were conducted with CSG and CCHIP category (the independent variables), as well as birth weight (the covariate). The results are shown in Table 4 and it is clear that birth weight was the only variable significantly related to the nutritional indicators. This shows that the effect of being born LBW results in a much larger negative effect on nutritional risk than the potential impact of food insecurity or the effect of being a CSG holder.

Discussion

Stunting affected almost 10% of the participants of this study, which was lower than expected when compared with other SA studies.[4] The WHO Conceptual Framework on Childhood Stunting suggests that poor micronutrient quality, low dietary diversity and inadequate intake of animal foods as well as the low energy content of complementary foods contribute to stunting.[17] However, in this sample, only a minority of children deteriorated into stunting after being born NBW. The majority of the stunted children had a history of LBW. Since LBW may be caused by intrauterine growth restriction secondary to hypertension,[18] anaemia, teenage pregnancy,[19] smoking and snuff use, as well as alcohol abuse during gestation, optimal antenatal care during pregnancy may have a much larger impact in reversing the high stunting prevalence among children than any of the available nutrition-specific interventions, i.e. supplementation programmes to address stunting after birth.

Catch-up growth in LBW infants is important and associated with an increase in the number of years of education that children received.[20] This emphasises the importance of early identification and treatment of children who fit into high-risk categories. Community health workers or caregivers who are part of the screening process by ward-based outreach teams have a limited capacity to measure and plot the growth of children accurately. It is easier to identify food-insecure infants as well as LBW infants as potential high-risk cases and refer those cases for health facility assessments, than to screen for stunting in the community. Even though hunger affected more than half of the households in our sample, findings suggest that LBW plays a more important role than food insecurity in lower mean height-for-age z-scores observed in infants and young children and therefore strategies and actions to prevent LBW in infants in this health district should be prioritised by healthcare professionals. Low birth weight has also been associated with low maternal body mass index (BMI),[21] underlining the need for nutritional intervention for underweight women of childbearing age. Unfortunately, maternal nutritional status history was not available for this sample and longitudinal data in this district are necessary to provide adequate data to assess the impact of maternal nutritional status on birth outcomes.

As mentioned previously, a high percentage of caregivers in our sample reported hunger and risk of hunger in the households, with

Table 2. *T*-tests by birth weight category for anthropometric indicators of nutritional status

Nutrition variable	Birth weight category	*n*	Mean (SD)	Difference	*t*	*df*	*p*-value	Cohen's *d*
WAZ	LBW	22	–0.64 (1.64)	–1.13	–4.17	382	<0.0005	0.91 (large)*
	Normal	362	0.50 (1.21)					
HAZ	LBW	22	–1.81 (1.81)	–1.65	–5.90	380	<0.0005	1.30 (large)*
	Normal	360	–0.16 (1.24)					
WHZ	LBW	22	0.67 (1.34)	–0.17	–0.59	384	0.555	n/a
	Normal	364	0.84 (1.29)					
MUAC	LBW	22	15.39 (1.70)	0.02	0.05	386	0.964	n/a
	Normal	366	15.37 (1.76)					

WAZ = weight-for-age z-score; LBW = low birth weight; SD = standard devation; HAZ = height-for-age z-score ; WHZ = weight-for-height z-score; n/a = not applicable, MUAC = mid-upper arm circumference.
*Large practical significance.

Table 3. *T*-tests by grantholder category for anthropometric indicators of nutritional status

Nutritional indicator	Grantholder	*n*	Mean (SD)	Difference	*t*	*df*	*p*-value	Cohen's *d*
WAZ	Yes	220	0.30 (1.18)	–0.25	–1.66	322	0.099	n/a
	No	104	0.55 (1.48)					
HAZ	Yes	219	–0.38 (1.27)	–0.36	–2.23	321	0.026	0.27 (small)*
	No	104	–0.03 (1.47)					
WHZ	Yes	221	0.73 (1.23)	–0.16	–1.05	325	0.296	n/a
	No	106	0.89 (1.48)					

SD = standard deviation; df = degrees of freedom.
*Small practical significance.

Table 4. Univariate ANCOVA results for WAZ, HAZ and WHZ related to CSG and CCHIP category when controlling for birthweight (n=298)

Factor	Category	Descriptive statistics		ANCOVA results		
		n	Mean (SD)	*F*-value	*df*	*p*-value
WAZ						
Total		298	0.38 (1.29)			
CSG	No	96	0.60 (1.46)	1.31	1; 293	0.253
	Yes	202	0.28 (1.19)			
CCHIP category	Hungry	91	0.22 (1.32)			
	At risk	138	0.36 (1.31)	0.78	2; 293	0.462
	Food secure	69	0.63 (1.17)			
Birth weight (covariate)				58.72	1; 293	<0.0005
HAZ						
Total		298	–0.27 (1.34)			
CSG	No	96	–0.03 (1.46)	1.90	1; 293	0.170
	Yes	202	–0.39 (1.27)			
CCHIP category	Hungry	91	–0.50 (1.36)			
	At risk	138	–0.16 (1.34)	1.80	2; 293	0.167
	Food secure	69	–0.19 (1.30)			
Birth weight (covariate)				63.22	1; 293	<0.0005
WHZ						
Total		298	0.78 (1.34)			
CSG	No	96	0.95 (1.48)	0.95	1; 293	0.331
	Yes	202	0.70 (1.27)			
CCHIP category						
	Hungry	91	0.74 (1.23)			
	At risk	138	0.68 (1.33)	1.10	2; 293	0.335
	Food secure	69	1.04 (1.48)			
Birth weight (covariate)				8.77	1; 293	0.003

ANCOVA = Analysis of covariance; WAZ = weight-for-age Z-score; HAZ = weight-for-age Z-score; WHZ = weight-for-height Z-score; CSG = Child Support Grant; CCHIP = Community Childhood Hunger Identification Project.

less than a quarter of the households being food secure. However, interestingly, the caregivers reported less children to be at risk of hunger than the number that reported households to be at risk. As stated previously, household food insecurity puts children at a high risk of malnutrition. Qualitative research to explore reasons for the lower prevalence of children at risk should be conducted since it may be related to children still receiving breastmilk during the first 1 000 days, or a reluctance to acknowledge inadequate care on the caregivers' side. However, the food insecurity situation indicates that these children will experience continued problems and that any catch-up growth among LBW children will be highly unlikely, making it almost impossible to undo the long-term effects of LBW.

Since the CSG was implemented to protect poor households against the effects of unemployment and poverty, one would expect CSG holders to be protected against hunger. In our sample, CSG holders were significantly more stunted than non-CSG holders, but when LBW covariate is controlled for, the relationship was attenuated and became non-significant. However, the CSG alone could not undo the negative impact of IUGR, and was not sufficient to allow for catch-up growth in the first 1 000 days in the older age categories in this sample. Recent economic developments may result in higher food, education and transport costs for South Africans. The resulting increase in buying power among beneficiaries may therefore be disrupted. CSG recipients were far more likely to be hungry or at risk of hunger while non-recipients were more likely to be food-secure. Zembe-Mbakile *et al.*[9] concluded that provision of the CSG has not provided any protection against stunting in SA. Children younger than two years have lower take-up rates for the CSG than older children,[22] the stage of the life cycle where most of the irreversible damage to cognitive development caused by stunting occurs. In this otherwise homogenous sample, the CSG was not enough to level the variances in income with regard to food security. The results also leave us with the question whether the CSG, which can only be applied for once the child is born and registered, is not needed much earlier during gestation as suggested in a recent systematic review from programmes in 27 countries.[23] This will ensure that the pregnant mother has sufficient funds to prevent hunger and support regular clinic visits to reduce the risk of preterm deliveries associated with SGA/LBW infants.

Study limitations

Cross-sectional studies are not the study design of choice to determine growth patterns in children and this should be considered a limitation. Measuring infants and young children in clinics and crèches inherently excludes children who do not attend clinics and crèches and thus the results cannot be generalised.

Conclusion

Maternal health is important to prevent LBW and later malnourished children. Reducing the burden of childhood malnutrition will require the Department of Health to recognise the large impact of LBW and thus the need for improvements in antenatal care and healthcare for women of childbearing age. Policymakers could aim to make CSGs available to mothers as close to the time of birth as possible, or during pregnancy, to be effective during the first 1 000 days of growth and development.

Acknowledgements. None.

Author contributions. SMcL was the principal researcher and wrote the initial draft of the manuscript. LS contributed to the design of the study, intepretation of results and final preparation of the manuscript. AF contributed to content, interpretation of results and final preparation of the manuscript. JN provided local context, statistics and contributions to the final manuscript. DV did the statistical analysis and contributed to the lay-out of the results presented.

Funding. Fieldwork was funded by Nelson Mandela University.

Conflicts of interest. None.

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Accepted 23 April 2018.

Appendix F: Coverage of vitamin A supplementation, deworming and immunisations: Associations with nutritional status among urban children younger than five years in Nelson Mandela Bay, Eastern Cape (in press)

Coverage of vitamin A supplementation, deworming and immunisations: Associations with nutritional status among urban children younger than five years in Nelson Mandela Bay, Eastern Cape

SW McLaren: MSc, School of Human Sciences, London Metropolitan University, London, United Kingdom. Email: s.mclaren@londonmet.ac.uk

L Steenkamp: PhD, HIV and AIDS Research Unit, Nelson Mandela University, Gqeberha, South Africa. Email: liana.steenkamp@mandela.ac.za

Abstract

Background: Even though immunisation coverage is tracked through the district health system in South Africa, limited information is available regarding interventions linked to the Expanded Programme on Immunisation (EPI) and the impact on the nutritional status of children younger than five years of age.

Objectives: To describe coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children.

Methods: A descriptive study was conducted between September 2015 and February 2016 where cross-sectional anthropometrical data was collected from 1513 children in 32 pre-schools together with a retrospective analysis on the participants' Road to Health/clinic cards to collect data on immunisation, vitamin A and deworming. Ethics approval (H15-HEA-DIET-003) was obtained from the Nelson Mandela University (NMU) Research Ethics Committee (Human).

Results: Data from 1496 children were included in this analysis. The prevalence of underweight was 2.5% (n=37), 11.2% (n=167) were stunted, and 1.1% (n=16) were wasted. There were associations between the age category and delayed vitamin A (X^2=32.105, df=19, n=836,

p=0.03) and deworming (X^2=45.257, df=17, n=558, p=0.00), but no association between delayed vaccinations and age category. There were no significant differences in anthropometric indicators for children with delayed vitamin A, deworming and vaccinations compared with children who were up to date in this sample of children. However, weight for age, height for age and weight for height Z-scores, and stunting risk were associated with low birth weight (OR= 4.658, p=0.000).

Conclusion: Coverage of vitamin A and deworming but not immunisations was poorer among children in older age categories. History of delayed vitamin A, deworming and vaccinations were not associated with anthropometric status of children. Children with low birth weight should be considered for more rigorous follow up as they are at a higher risk of stunting.

Introduction

The Expanded Programme on Immunization (EPI), begun in 1974 and is considered one of the world's most successful public health programmes[1]. Since the EPI is a platform from which it is possible to deliver additional health interventions, other primary healthcare services like deworming as well as vitamin A supplementation and growth monitoring were integrated to coincide with immunization where possible, as a strategy to increase coverage of these maternal and child health (MCH) interventions. Sub Saharan Africa accounts for one third of all undernourished children globally with approximately 39% stunted, 10% wasted and 25% underweight children under-five years of age[2]. Despite the decline in the global prevalence of stunting, the absolute number of stunted children in the African region has increased from 46.3 million children in 1990 to 57.4 million children in 2020[2]. Therefore, undernutrition and especially stunting is still a public health concern.

As argued by Raiten & Bremer[3], stunting is generally being perceived to be the result of chronic undernutrition. However, evidence suggest that poor maternal education, poverty, low birth weight, using an unimproved water source, low maternal BMI, recurrent diarrhoeal episodes and living in a rural area are all amongst the risk factors for stunting[3,4]. In countries like South Africa, unimproved water sources are mostly limited to rural areas. However, even in urban areas, in poorer communities safe piped water is often only available in the yard, and not necessarily in the house or dwelling[5], which makes optimal implementation of Water, Sanitation and Hygiene (WASH) practices challenging. Therefore, soil transmitted helminth infestation, which may cause anaemia, diarrhoea and reduced appetite, can negatively affect the nutritional intake and growth and development of children even in urban areas[6,7]. According to a randomised controlled trial, deworming with a single dose of 500mg mebendazole at 12 months of age had no effect on the growth of children at follow up[8]. Previous evidence however, suggests that the low efficacy associated with a single dose *Albendazole* may be due to a high rate of re-infection post treatment in developing countries[9]. Therefore, the WHO and South African guidelines still recommend periodic treatment with antihelminthic protocols without previous individual diagnosis, to all at-risk preschool children living in endemic areas.

Apart from helminth infestation impacting growth, micronutrient deficiency, or 'hidden hunger' may also result in a decreased immune function, and inadequate growth leading to stunting[10]. Vitamin A deficiency (VAD) has been identified as a global public health concern affecting about 30% of all children[11]. Therefore, national programmes have implemented high-dose vitamin A supplementation to children younger than five years at 6-month intervals, to reduce morbidity and mortality[12]. Despite inconclusive country-level evidence on the efficacy of vitamin A supplementation to reduce morbidity and mortality[11], the WHO still recommends high dose vitamin A supplementation for infants and children between six and 59 months of age in areas with a high prevalence of vitamin A deficiency[13]. Despite this being a priority, a recent assessment of 82 countries revealed that two thirds either had no data about vitamin A coverage or VAD or data was older than 10 years at the time of assessment[11].

Although vitamin A supplementation according to recent evidence may have yield inconsistent results in relation to childhood mortality and morbidity[14], many countries still support evidence that VAD may contribute to diarrhoea in children. Apart from VAD, rotavirus infection is considered one of the leading causes of diarrhoea in children[15]. The rotavirus vaccine was included as part of the EPI in South Africa in 2009. Apart from the vaccine being associated with significant reductions in severe gastro enteritis in the first 2 years of life[16], immunisation has been associated with improved height-for-age Z-scores (HAZ) among children[17]. Recovery from stunting in childhood has been associated with timely child immunisation[18], suggesting that prevention of childhood illnesses is an important component of preventing childhood malnutrition. South African research suggests that immunisation coverage is not comprehensive, and that poorer and more rural communities may be at a higher risk of late or incomplete vaccination[19]. Visits to primary health care services for routine vaccinations are also often an opportunity for vitamin A and deworming provision, which would improve any country's public health system[20]. Thus the WHO still recommends vitamin A supplementation and deworming at consistent four to six month intervals to prevent childhood malnutrition in children under five years of age. As children require less frequent vaccinations as they get older, visits to primary health care services may decline. Countries with constraint health resources therefore have to consider strategies like outreach visits to community pre-schools and creches, to ensure adequate coverage of these interventions. Although, vaccination rates in Nelson Mandela Bay have been improving[21], the rate of childhood morbidity and mortality remains high[22]. Limited information was available at the time of the study with regards to coverage of vitamin A supplementation and deworming.

The objective of the study was to describe coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children. Since the authors in a previous article[23] presented evidence of stunting being associated with LBW, the authors will try to establish if a similar relationship can be observed from this larger sample, and if a significant relationship exists, control for LBW when doing the analysis.

Methods

A cross-sectional study was conducted between September 2015 and February 2016 in classes from 32 pre-schools or creches. Ethics approval (H15-HEA-DIET-003) was obtained from the Nelson Mandela University (NMU) Research Ethics Committee (Human) and institutional permission was obtained from the Eastern Cape, Department of Education as well as principals and teachers from all the schools. Parents of all the children in the classes of the ECD practitioners received a letter explaining the purpose of the research and inviting them to provide informed, written consent for their children to participate in the study. Parents were requested to send their children's clinic cards to the pre-school. A convenience sample was obtained including all children who possessed signed informed consent letters, clinic cards, and agreed to undergo the anthropometric measurements on the day of data collection. All schools included in the sample fell under the no-fee paying school category.

Weight and height were measured using standardised techniques[24] by trained fieldworkers, under supervision, using calibrated equipment. Weight was measured in kilograms (kg) to the nearest 0.01 kg using a calibrated Seca electronic scale (Model 874) and height was measured in centimetres (cm) to the nearest 0.1 cm using a Seca (Model 217) stadiometer. Date of birth, date of visit, sex of the child, last date of vitamin A supplementation, last date of deworming and vaccination records were collected from participants' clinic cards. Data collection tools were piloted prior to the study, and data was recorded onto an electronic database.

Weight-for-age z-scores, height-for-age z-scores (HAZ), weight-for-height z-scores (for children below 60 months of age) and BMI-for-age z-scores (BAZ) were subsequently generated using the National Center for Health Statistics/WHO reference with the WHO Anthro- and WHO Anthro plus programmes (version 1.0.4)[25], to determine stunting (HAZ < -2 SD), wasting (WHZ < -2 SD) and overweight (WHZ > +2 SD for children up to 60 months or BAZ > +1 SD for children older than 60 months. Data was cleaned according to WHO[26] criteria. Deworming and vitamin A supplementation that was given more than seven months before the assessment date, were considered to be delayed. An immunisation that was due at the appropriate age at the time of assessment, but more than 30 days late according to the clinic card, was considered to be a missed vaccination. For the purpose of data analysis, the participants were split into age categories in three-month intervals.

Data was analysed using SPSS v26[27]. Descriptive statistics including frequencies and percentages were used to describe outcomes of categorical data. Inferential statistics included t-tests to compare anthropometric data from different vitamin A, deworming, vaccination, and birth weight categories. Associations between delayed vaccination, vitamin A and deworming and age categories were analysed using chi squares. Significance was set at $\alpha=0.05$. Binomial regression analysis was used to assess stunting risk associated with birth weight for age categories and multinomial regression analysis was used to explore risk factors for stunting. The odds ratio (OR), 95% confidence interval (CI) and *p*-values were calculated using the model. The significance level was set to $\alpha <0.05$

Results

Data was collected on 1513 children. There were 1496 children included in the analysis, as 17 children had implausible z-scores. The mean age of participants (n=1496) was 34.4 months (SD=17.93) and 50.0% of the sample was male (n=748). The mean birth weight was 3062 g

(SD=577 g) and 14.0% of the children, according to the clinic cards, had a low birth weight (n=170). The mean WAZ was 0.12 (SD=1.16) with 2.5% (n=37) being underweight. The mean HAZ was -0.63 (SD=1.23) and 8.3% (n=126) were moderately stunted with a further 2.7% (n=41) severely stunted. The mean WHZ was 0.69 (SD=1.17). According to the WHO (2006) definitions, 0.3% (n=4) were severely wasted and 0.8% (n=12) were moderately wasted. Due to missing clinic cards or cards that were re-issued, vaccination data was only available for 840 participants, of which 13.8% (n=116) were not up to date with their vaccinations. Deworming data was available for 558 children, and 39.6% (n=221) of these children were not up to date with their deworming treatment. Data on vitamin A was available on 836 children, and 38.5% (n=322) had missed their last vitamin A dose.

Trends in vaccination, vitamin A and deworming coverage

There was no relationship between the age category of children and vaccinations being up to date (X^2=23.79, df=19, n=840, p=0.204). However, a significant relationship was observed between delayed vitamin A supplementation and age category (X^2=32.105, df=19, n=836, p=0.03) as well as between delayed deworming and age category (X^2=45.257, df=17, n=558, p=0.00).

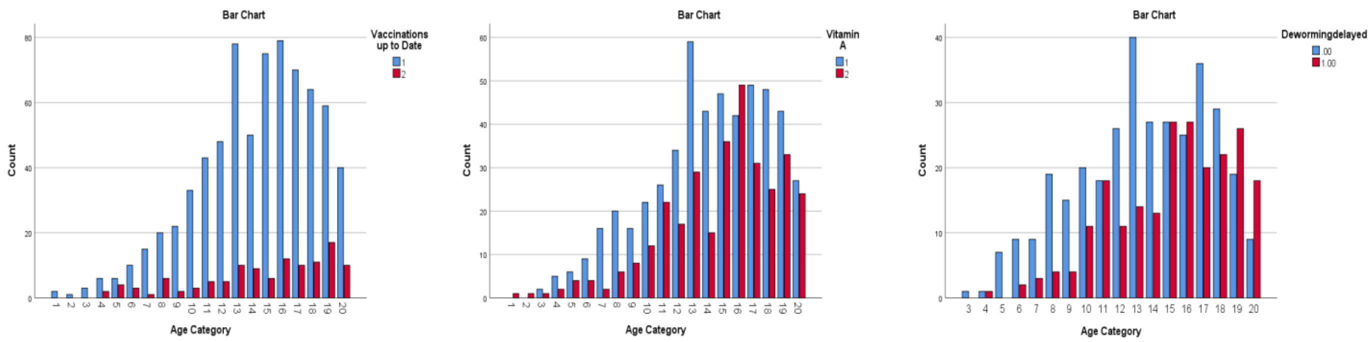

Figure 1: Delayed vs up-to-date vaccination, vitamin A and deworming by age category (n=840).

Relationship between nutritional status and coverage

No significant differences in anthropometric indicators (WAZ, HAZ and WHZ) were observed for children who had received vitamin A and missed the most recent dose of vitamin A (Table 1). Similar trends were observed for up-to-date vaccinations and up-to date deworming, versus interventions that were late. Significant differences in WAZ, HAZ and WHZ were observed for children born LBW compared with those born with a normal birth weight.

Table 1: T-tests by vitamin A category, vaccinations, deworming category and birth weight category for anthropometric indicators of nutritional status

Nutrition variable	**Vitamin A**	**n**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	Up to date	513	-0.01 (1.12)	0.036	0.458	833	0.647
	Delayed	322	-0.05 (1.075)				
HAZ	Up to date	514	-0.815 (1.14)	0.019	0.244	834	0.807
	Delayed	322	-0.834 (1.041)				
WHZ	Up to date	513	0.652 (1.17)	0.025	0.313	833	0.754
	Delayed	322	0.625 (1.16)				
Nutrition variable	**Deworming**	**N**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	Up to date	337	0.16 (1.09)	0.119	1.242	556	0.215
	Delayed	221	0.04 (1.13)				
HAZ	Up to date	337	-0.743 (1.17)	0.033	-0.341	556	0.733
	Delayed	221	-0.77 (1.11)				
WHZ	Up to date	337	0.843 (1.11)	0.119	1.2	556	0.231
	Delayed	221	0.723 (1.21)				
Nutrition variable	**Vaccinations**	**n**	**Mean (SD)**	**Difference**	**t**	**df**	**P**
WAZ	Up to date	723	-0.0427 (1.11)	-0.065	-0.588	837	0.557
	Delayed	116	0.0227 (1.11)				
HAZ	Up to date	724	-0.826 (1.11)	0.0265	0.240	838	0.810
	Delayed	116	-0.852 (0.99)				
WHZ	Up to date	723	0.6284 (1.16)	-0.0938	-0.799	837	0.424
	Delayed	116	0.722 (1.24)				
Nutrition variable	**Birth weight**	**n**	**Mean (SD)**	**Difference**	**T**	**df**	**P**
WAZ	LBW	170	-0.635 (1.13)	-0.857	-9.150	1207	0.000
	NBW	1039	0.222 (1.13)				
HAZ	LBW	170	-1.44 (1.19)	-0.917	-9.582	1208	0.000
	NBW	1040	-0.535 (1.16)				
WHZ	LBW	170	0.325 (1.29)	-0.424	-4.301	1207	0.000
	LBW	1039	0.749 (1.17)				

LBW and nutritional status

Children with LBW were at an increased risk of stunting (OR= 4.658, p=0.000) (Table 2). Among children younger than 12 months, there was an increased risk of being stunted given LBW history (OR=29.318, p=0.000), however, among children with a history of LBW above the age of 48 months, the odds of being stunted were not significant (OR=0.911. p=0.885).

Table 2: Binomial regression analysis of risk of stunting for low-birth-weight children at any age, 12 months and 48 months.

Stunted at follow up (any age) (n=1223)			
Risk factor	**OR**	**95% CI**	**p-value**
Low birth weight[a]	4.658	3.132-6.927	0.000*
Stunted at <12 months (n=261)			
Low birth weight[a]	29.318	10.542-81.534	0.000*
Stunted at >48 months (n=299)			
Low birth weight[a]	0.911	0.257-3.226	0.885
* Statistically significant at p<0.05 a. Reference category is normal birth weight			

Low birth weight (OR=5.603, p=0.000) was a significant risk factor for stunting among children. Vitamin A, deworming and vaccinations were not significant factors in stunting risk (Table 3).

Table 3: Multinomial regression analysis for stunting risk (n=530).

Risk factor	OR	95% CI	p-value
Deworming delayed[a]	1.601	0.766-3.344	0.211
Vitamin A delayed[b]	1.223	0.577-2.593	0.600
Vaccinations delayed[c]	1.081	0.415-2.499	0.969
Low birth weight[d]	5.603	2.987-10.512	0.000*
Male sex[e]	1.668	0.964-2.867	0.067
f. Reference category deworming up to date g. Reference category vitamin a up to date h. Reference category vaccinations up to date i. Reference category normal birth weight j. Reference category sex is female * Statistically significant at p<0.05			

Discussion

This study aimed to describe the coverage of immunisations, vitamin A supplementation and deworming amongst children younger than five in an urban area of Nelson Mandela Bay. Approximately a third of children had missed vitamin A and deworming treatments, whereas less than 15% of children were not up to date with their vaccination schedules. It was also found that there was a relationship between missed vitamin A and deworming treatment and age category. Most immunisation doses under the EPI schedule take place within the first 18 months of life. It is suggested that the EPI schedule provides an opportunity for vitamin A deworming through routine visits to clinics and mobile clinics. However, Comley et al[28] suggested that vitamin A distribution needs re-evaluation in South African communities as there is a large discrepancy between vitamin A and vaccination uptake. This is supported by our finding that vitamin A supplementation uptake is poorer when children are older and require less frequent vaccinations.

A secondary objective was to investigate whether a history of missed immunisations, vitamin A supplementation or deworming were associated with wasting or stunting in children. The WHO has made a strong recommendation for providing vitamin A supplementation in communities at risk of deficiency as there is good evidence of effectiveness of vitamin A supplementation in reducing childhood mortality[13]. However, the evidence for effectiveness in other indicators of child health such as growth are weaker[13]. No significant differences in anthropometric indicators (WAZ, HAZ and WHZ) were observed for children who had received vitamin A and missed the most recent dose of vitamin A. The findings of this study suggest that children are likely to miss doses of deworming medications, putting them at a higher risk of re-infection and undermining the effectiveness of the intervention. However, in this sample poorer coverage of vaccination and deworming did not affect the nutritional status of participating children. Other researchers suggest that academic achievement is poorer among children infected with soil-transmitted helminths[29]. Stunting is associated with poorer cognitive development[30]. However, regularly treating children with deworming medications does not appear to improve weight, height, stunting prevalence, school performance, iron status or mortality outcomes[31,32]. WaSH strategies including improved sanitation, wearing shoes, washing hands before eating and after defaecating could instead be prioritised as long-term interventions to prevent helminth infestation and associated negative outcomes. This is because frequent re-infection may be undermining chemotherapeutic strategies to address soil-transmitted helminths[33].

Basic staple foods have been fortified with vitamin A in South Africa since 2003[34]. Faber et al[35] found that fortified bread and maize products contributed to the majority of vitamin A intake in urban children in South Africa and that while vitamin A supplementation rates were poor, the prevalence of vitamin A deficiency was lower in urban areas compared with national estimates. Therefore, the value of high-dose vitamin A supplementation may be reduced in urban environments in the context of higher intakes of vitamin A-fortified staple foods. This may in part explain why no associations could be demonstrated between poor vitamin A coverage and a compromised nutritional status.

Previous research from this community revealed that access to child support grants and household food security are associated with stunting risk until low birth weight is considered as a co-factor[23]. When low birth weight was considered, food security and access to grants were no longer significantly associated with anthropometric indicators of nutritional status in children. Significant differences in WAZ, HAZ and WHZ were observed for children born LBW compared with those born with a normal birth weight in the current study, and children with LBW were at an increased risk of stunting. Children with a low birth weight were more likely to have a HAZ<-2 in the first 12 months of life, but children with LBW in older age categories were not significantly more at risk of stunting. This suggests that children with low birth weight may eventually experience catch up growth. However, the reasons for this recovery were not accounted for in the present study. The results of the multinomial regression analysis suggest that sex, delayed vitamin A, delayed deworming and delayed vaccinations are not associated with stunting risk, but low birth weight is a significant risk factor for stunting. There was no evidence that delayed vitamin A, deworming and vaccinations contributed to stunting and wasting in this sample, and that low birth weight was likely to be corrected without these interventions. Longitudinal evidence from India suggests that childhood immunisations are associated with recovery from stunting between five and eight years of age[36]. Similarly, Faye et al[18] found that timely child immunisation along with age at stunting, household economic status and mother's parity were among the factors associated with recovery from stunting before the fifth birthday in Kenya.

Limitations

Data was collected from children attending creches and therefore the results cannot be generalised to the wider population. The study used a cross-sectional design which is not the ideal design for describing the factors associated with the dynamic growth patterns in children. Data on vitamin A, deworming and vaccination history was limited to the last dose and did not account for the full vitamin A, deworming and vaccination history. There was no investigation whether children in this sample with delayed deworming were infected with STH. Data was not collected on potential confounding factors including HIV and other illnesses. Morbidity and mortality were not assessed in this study, limiting the interpretations of the effectiveness of vitamin A, deworming and vaccinations to their effects on anthropometric status.

Conclusion

Coverage of vitamin A and deworming but not immunisations was poorer among children in older age categories. History of delayed vitamin A, deworming and vaccinations were not associated with anthropometric status of children. Children with low birth weight should be considered for more rigorous follow up as they are at a higher risk of stunting.

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Appendix G: The relationship between haemoglobin level and socio-economic indicators among women of childbearing age in South Africa: A secondary analysis of DHS data.

ECOLOGY OF FOOD AND NUTRITION
https://doi.org/10.1080/03670244.2021.1954510

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The Relationship between Hemoglobin Level and Socio-economic Indicators among Women of Childbearing Age in South Africa: A Secondary Analysis of DHS Data

S. W. McLaren

School of Human Sciences, London Metropolitan University, London, UK

ABSTRACT

The nutritional double burden of disease refers to the phenomenon of undernutrition, wasting, stunting, micronutrient deficiency coinciding with overweight, obesity, and diet-related non-communicable diseases, within individuals, households and populations throughout the lifecycle. This study aimed to determine whether there were differences in hemoglobin levels between anthropometric categories and socio-economic factors among women aged 15 to 49 years old in South Africa. Data were obtained from the Demographic and Health Survey (DHS) South Africa survey 2016. There were 2690 women between 15 and 49 years old included in the sample. Variables selected for analysis included height and weight, hemoglobin (adjusted for altitude), wealth index, access to improved water and sanitation. Variables were tested for normality using Q-Q plots. Missing data was removed. Frequencies and percentages were reported for categorical data. Non-parametric continuous variables were reported as medians and interquartile ranges. As data were not normally distributed, analysis was conducted using the Kruskall-Wallis test and Mann-Whitney U test. The type I error rate was set to $p < .05$. Where it was found that a significant difference exists, post hoc Dunn tests were performed to determine the location of the differences. Anemia was prevalent among 28.9% of the sample and 63.5% were either overweight or obese. Hemoglobin levels were significantly different between normal weight women and women with a body mass index in the obese class I and obese class II respectively (Kruskall-Wallis = 27.014; df = 5; $p = .000$; n = 2690). There were significant differences in hemoglobin levels between women with access to improved sanitation and those without access (Mann-Whitney U test $p = .017$), but hemoglobin levels were similar between women with access to improved water and those without (Mann-Whitney U test $p = .175$). Poorer women had significantly different hemoglobin levels to the wealthiest women in the sample (Kruskall-Wallis = 29.568; df = 4; $p = .000$). The nutritional double burden of disease is prevalent in South Africa among women of childbearing age. A wealth disparity exists among South African women in terms of hemoglobin levels.

KEYWORDS
Anaemia; haemoglobin; reproductive age women; South Africa; Water sanitation; hygiene

CONTACT S. W. McLaren s.mclaren@londonmet.ac.uk School of Human Sciences, London Metropolitan University, London, UK

Introduction

The nutritional double burden of disease refers to the phenomenon of undernutrition, wasting, stunting, micronutrient deficiency coinciding with overweight, obesity, and diet-related non-communicable diseases, within individuals, households and populations throughout the lifecycle (WHO 2017). Individuals may be simultaneously exposed to underlying risk factors for malnutrition including infection, diet quality and physical activity levels (Tzioumis and Adair 2014).

The prevalence of obesity has been increasing across the world, with prevalence doubling in more than 70 countries since 1980(The GBD 2015). Anemia affects one third of women of childbearing age globally and continues to be a major health concern across the developing world (WHO 2020). Anemia during the first or second trimesters of gestation is associated with significantly increased risks for low birth weight and preterm births (Haider et al. 2013).

It is thought that increased consumption of cheap, staple foods and highly processed foods are causing a concurrent problem of overweight and obesity and undernutrition (Popkin, Corvalan, and Grummer-Strawn 2020). Inadequate dietary intake is a direct cause of malnutrition. However, factors indirectly related to nutrition are recognized in the development of malnutrition. These factors include inadequate care for women and children, insufficient health services and an unhealthy environment, and the distribution of resources. These factors are termed nutrition sensitive areas for intervention (Ruel and Alderman 2013).

This study aimed to determine whether there were differences between anthropometric categories and socio-economic factors in terms of hemoglobin level among women aged 15 to 49 years old in South Africa.

Methods

Data were taken from the DHS 2016 public access dataset with permission from the DHS Programme (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF 2016). The DHS programme is a health surveillance system which provides data on basic demographic and health indicators for use by policy makers and programme managers to design and evaluate health programmes. Surveys have been conducted in South Africa in 1998, 2003 and 2016. Children between birth and five years old, women between 15 and 49 years old and men between 15 and 59 years old are included in the survey. The DHS uses a stratified, cluster sampling method. The survey is designed to obtain a representative national estimate for South Africa, as well as for each of the nine provinces in the country. There were 15 292 households selected for the sample, of which 11

083 were successfully interviewed. Among these, 8514 interviews were completed with women between the ages of 15 and 49 years (Statistics South Africa 2019). Data collection methods are presented elsewhere (National Department of Health, Statistics South Africa, South African Medical Research Council and ICF 2016).

Variables selected for analysis included body mass index (BMI; kg/m^2), hemoglobin (Hb) level (g/dL) adjusted for altitude, wealth index, access to improved water and access to improved sanitation. Underweight was defined as BMI<18.5 kg/m^2, normal weight was defined as a BMI between 18.5 and 24.9 kg/m^2, overweight was defined as a BMI between 25 and 29.9 kg/m^2, obese class I was defined as a BMI between 30 and 34.9 kg/m^2, obese class II was defined as a BMI between 35 and 39.9 kg/m^2 and obese class III was a BMI>40 kg/m^2. Anemia is defined using hemoglobin levels according to World Health Organization (WHO) classifications. A hemoglobin level below 12 g/dL among non-pregnant women between the ages of 15 and 49 years is defined as anemic (World Health Organisation 2008). The DHS household wealth index defines five categories of wealth, ranging from poorest to richest, based on household assets. The definitions and calculations are presented elsewhere (United States Agency for International Development 2002). Improved water sources and improved sanitation facilities were identified according to WHO definitions (WHO and UNICEF 2017).

Data were analyzed using SPSS v26 (IBM Corp. Released 2017). Data were analyzed using a complex samples design using 26 strata and 455 sampling units to account for sampling weight. Variables were initially tested for normality using Q-Q plots. Frequencies and percentages were reported for categorical data. Normally distributed continuous variables were reported as means and standard deviations. Non-parametric continuous variables were reported as medians and interquartile ranges. As the data were not normally distributed, analysis was conducted using the Kruskall-Wallis test. Bivariate categorical indicators were analyzed using the Mann-Whitney U test. The type I error rate was set to $p < .05$. In cases where a significant difference was detected, post hoc Dunn tests were performed to determine the location of the differences.

Results

A total of 2690 women between 15 and 49 years of age were included in the final analysis after missing data and outliers were removed. The mean age of the women was 30.2 years (±9.8). Of the women in the sample, 4.6% had moderate anemia, and 24.3% had mild anemia. The mean BMI was 28.12 kg/m^2 (±6.8). Underweight was prevalent among 3.2% of the women, while 28.7% of the women were overweight, 19.8% were in the obese class I category, 9.0% were in the obese class II category and 5.6% in the obese class III category. It

Table 1. Differences in hemoglobin levels adjusted for altitude between anthropometric and socio-economic factors.

Factor	Category	N	Median	25th	75th
BMI	Underweight	87	12.8	11.3	13.9
	Normal weight	894	12.7[abc]	11.5	13.8
	Overweight	779	12.8	11.5	13.8
	Obese class I	536	13.0[a]	12.0	14.0
	Obese class II	243	13.1[b]	11.9	14.0
	Obese class III	151	13.2[c]	12.0	14.2
Kruskall-Wallis = 27.014; df = 5; p = .000; n = 2690					
[a,b,c] Denotes statistically significant difference (p < .05) adjusted by Bonferroni correction for multiple tests					
Access to improved sanitation	Improved sanitation	1853	12.8	11.7	13.9
	Unimproved sanitation	837	12.8	11.6	13.7
Mann-Whitney U test p = .017; n = 2690					
Access to improved water	Improved water	2246	12.9	11.9	13.9
	Unimproved water	444	12.8	11.6	13.9
Mann-Whitney U test p = .175; n = 2690					
Wealth index	Poorest	664	12.8[af]	11.9	13.8
	Poorer	576	12.6[abcd]	11.3	13.7
	Middle	624	12.8[be]	11.6	13.9
	Richer	549	12.8[c]	11.7	13.9
	Richest	277	13.3[def]	12.0	14.1
Kruskall-Wallis = 29.568; df = 4; p = .000; n = 2690					
[a,b,c,d,e] Denotes statistically significant difference (p < .05) adjusted by Bonferroni correction for multiple tests					

was found that 16.5% did not have access to improved water, and 31.1% did not have access to improved sanitation.

There was evidence of a significant difference between BMI categories as presented in Table 1 (Independent Kruskall-Wallis test = 27.014; df = 5; p = .000). Post hoc analysis revealed that hemoglobin level in the normal weight category was significantly different to obese class I, obese class II and obese class III respectively. Hemoglobin levels were significantly different between women with access to improved sanitation and those without access to improved sanitation (p = .017). Hemoglobin levels were significantly different for wealth index category (Kruskall-Wallis = 29.568; df = 4; p = .000) and Dunn's pairwise tests showed evidence of significant differences between women from the poorest and richest and poorer and richer wealth index categories (p < .05). Women in the middle wealth index category had significantly different hemoglobin levels compared to the richest.

Discussion

This study found significant differences in hemoglobin level between BMI categories among women 15 to 49 years old in South Africa. It was also found that hemoglobin levels were significantly different between women with access to improved sanitation compared to those with no access. Household wealth is also related to hemoglobin levels among South African women.

The results of this study suggest that women with obesity have higher hemoglobin levels than underweight, normal weight and overweight women.

Women with a normal BMI may be at a higher risk of anemia. This result locates two features of the double burden of disease- a high prevalence of overweight and obesity, as well as micronutrient deficiency, in South African women. Similar findings have been observed in China, where an inverse relationship was found between anemia and BMI (Qin et al. 2013). Obesity and being in the highest wealth category were both factors associated with a lower risk of anemia among women of childbearing age in Rwanda (Hakizamana et al. 2019). While iron intake was not accounted for in the present study, it is possible that iron intake varies between women across all BMI categories. The estimated average requirement (EAR) for iron for women 19–50 years old is 8 mg/day. A study on dietary adequacy among women in KwaZulu-Natal found that underweight women consumed 9.24 mg/day (4.33; 10.63), normal weight women consumed 7.68 mg/day (5.53; 11.97) and overweight women consumed 7.29 mg/day (5.50; 9.34) while those in the obese categories consumed 8.12 mg/day (5.86; 11.41) (Napier and Oldewage-Theron 2015). Basic staple foods have been fortified with iron in South Africa since 2003 (Republic of South Africa [RSA]). However, evidence suggests that foods fortified with iron are not a significant contributor to iron intake in South Africa (Friesen et al. 2020). It may be that higher meat consumption, resulting in a higher caloric consumption and BMI (You and Hanneberg 2016), also results in a greater intake of more bioavailable heme iron, while plant protein and carbohydrates are less likely to result in overweight and obesity (Friesen et al. 2020) and provide less bioavailable non-heme iron. Among rural South Africans, meat consumption is associated with disposable income (Xazela et al. 2017).

Significant differences were observed between wealth index groups for hemoglobin. A similar relationship between wealth status and anemia was found in other sub-Saharan African countries. As an example, the prevalence of anemia was 25 pp higher among the poorest women in Burundi compared with the richest (Jiwani et al. 2020). Socio-economic differences also exist across BMI categories in South Africa, with those in poorer socio-economic groups facing an increase in obesity rates (Tzioumis and Adair 2014).

The current study found an association between access to improved sanitation and hemoglobin levels. Schistosomiasis and protozoan infections are common in areas of poor sanitation, causing diarrhea and blood loss (Hechenbleikner and McQuade 2015). In addition to blood loss, enteric infections can contribute to the development of anemia as inflammation and infection promote the production of hepcidin. Hepcidin is an iron-regulating hormone which prevents iron absorbed into the duodenal cells from entering circulation.

Anemia during the first or second trimesters of gestation is associated with significantly increased risks for low birth weight and preterm births (Haider et al. 2013). Infants born with a low birth weight have been found to be at an increased risk of stunting in Rwanda (Nshimyiryo et al. 2019). Stunting risk is higher among children from the Eastern Cape, South Africa, who are born with a low birth weight, even when food insecurity and access to social grants is considered (McLaren et al. 2018). Therefore, improving the health and nutritional status of women of childbearing age is vital for reducing the burden of childhood malnutrition. Improvements in antenatal care and healthcare for women of childbearing age should be prioritized by the South African Department of Health.

This study reported differences in hemoglobin levels between anthropometric and socio-economic categories. However, reporting hemoglobin on its own may result in overestimations of normal iron status among populations. Obesity is associated with chronic, low-intensity inflammatory processes mediated by the toll-like receptor 4 (TLR4) pathway (Rogero and Calder 2018). Inflammation promotes the production of hepcidin. Inflammatory cytokines including IFN-gamma, TNF-alpha and IL-6 are produced during times of infection. These cytokines down regulate erythropoiesis, the production of new red blood cells. High rates of overweight and obesity is a characteristic of countries facing the double burden of disease. Jordaana *et al.*, showed that transferrin saturation is a better indicator of iron status in double burden high obesity prevalence areas (Jordaana et al. 2020). Therefore, this study is limited in that only hemoglobin was used as a marker of iron status. Future research should include biomarkers including ferritin and transferrin to better understand the relationship between anthropometric status and iron status as well as to differentiate between nutritional iron deficiency and other causes of anemia. A strength of this study is the sampling design undertaken by the DHS.

Conclusion

Features of the nutritional double burden of disease are prevalent in South Africa among women of childbearing age. Overweight and obesity are the primary nutritional concern for this segment of the population, and there is a concurrently high prevalence of anemia. While those who are overweight or obese may be more likely to have normal hemoglobin levels, women in the normal weight category may be at risk of anemia. Inequality of wealth is also reflected in hemoglobin status among South African women. Strategies to address economic disparity, access to improved sanitation and improved micronutrient intakes among this population group may be effective strategies to reduce the effects of the double burden of malnutrition in South Africa.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

S. W. McLaren http://orcid.org/0000-0003-3357-7909

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Appendix H: Use of mid-upper arm circumference as a screening tool in an urban township in the Eastern Cape

South African Journal of Clinical Nutrition 2017; 30(4):118–119
https://doi.org/10.1080/16070658.2017.1376859

SAJCN
ISSN 1607-0658 EISSN 2221-1268

SCIENTIFIC LETTER

Use of Mid Upper-Arm Circumference (MUAC) as screening tool in an urban township in the Eastern Cape: rationale for testing changed cut-off values to identify malnutrition

Shawn McLaren[a], Liana Steenkamp[b*] and Danie Venter[a]

[a]*Department of Dietetics, Nelson Mandela University, Port Elizabeth, South Africa*
[b]*HIV & AIDS Research Unit, Nelson Mandela University, Port Elizabeth, South Africa*
**Corresponding author, email: liana.steenkamp@mandela.ac.za*

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Sir

Severe acute malnutrition (SAM) is still a public health concern in South Africa illustrated by the increase in the number of SAM cases from 21 598 in 2012/2013 to 23 743 in 2013/2014.[1] To decrease SAM, early identification of children with moderate acute malnutrition (MAM) is needed.

Children with a weight-for-height *z*-score (WHZ) < -3 standard deviations (SD) of the World Health Organisation (WHO) standard for children less than 60 months of age have a higher mortality compared to children with a WHZ > -3 SD of this standard. The WHO therefore recommends the use of a WHZ of below -3 SD to identify children with SAM.[2,3] The mid-upper arm circumference (MUAC) cut-off values of 11.5 cm and 12.5 cm are used globally as screening tools to identify SAM and MAM, respectively, in children between six and 60 months of age.[2,3] According to the WHO and UNICEF,[3] the WHZ and MUAC may be used interchangeably as a screening tool to identify malnourished infants and children, as they reveal a very similar prevalence of SAM in the field. However, more recent data indicate that there may be little overlap between the children identified with SAM and MAM by WHZ and those identified using the MUAC cut-offs.[4] Therefore, more recently the recommendation is to use WHZ and MUAC measurements as independent but complementary admission criteria for SAM.[5]

In practice in South Africa, community health workers (CHW) are trained to use MUAC as a screening tool, as limited scales and measuring equipment may be available in some areas to accurately measure and plot on the WHZ growth chart. Currently the WHO 11.5 cm and 12.5 cm cut-off values are still used by all CHW to refer SAM and MAM cases respectively, to primary health care facilities. In the context of the above concerns, the researchers assessed the value of these and newly calculated MUAC cut-off values as predictors of malnutrition risk in an urban township in the Eastern Cape.

In this descriptive study with a cross-sectional design, data from a convenience sample of 400 infants and young children younger than 24 months were gathered from five clinics and 15 early childhood development (ECD) centres in Motherwell, Nelson Mandela Bay Health District (NMBHD) from October 2015 to February 2016. The weight, length and MUAC of children were measured by trained fieldworkers according to protocols described by the CDC (2008). Since the population of children younger than two years in Motherwell was estimated at 5 817 in 2016 (personal communication, Nutrition Manager NMB, June 2016), an estimated 6.9% of the population participated in the survey. Ethical approval (H15-HEA-002) was obtained from the Research Ethics Committee (Human), NMU and the Eastern Cape Department of Health. The Pearson correlation co-efficient (*r*) was used to measure the strength or degree of the relationship between variables. Sensitivity and specificity tests were used on the data with the existing recommended MUAC cut-off values as well as new calculated MUAC cut-off values to determine whether the new MUAC cut-off values were more sensitive in the identification of children affected by wasting, without including false negatives (children without SAM or MAM).

All participants (n = 400) were of African ethnicity. The sample consisted of 50% (n = 199) male participants. Of the total sample, the mean weight-for-age *z*-score (WAZ) was + 0.44 (SD = 1.26), the height-for-age *z*-score (HAZ) was -0.24 (SD = 1.34) and the mean WHZ was 0.83 (SD = 1.28). One child in the sample (n = 1) was classified as severely wasted, according to WHZ (WHZ < -3), with one percent (n = 3) moderately wasted (WHZ < -2) and six percent mildly wasted (WHZ < -1).

The current WHO MUAC cut-off values to identify MAM have a high specificity, but performed poorly when tested for sensitivity, as shown in Table 1.

The *r*-value (0.78) for the relationship between WHZ and MUAC suggests a dependent relationship between these two indicators. The least squares regression formula ($Y = 15.409 + 0.803x$ (males); $Y = 15.13 + 0.83x$ (females)) was then used to predict where WHZ = -2 is most likely to correspond with a MUAC value in cm. The new predicted MUAC values of 13.8 cm (males) and 13.5 cm (females) were subsequently tested for sensitivity and specificity. The sample was too small to calculate sensitivity for both genders, but 96.4% specificity was achieved for females (Table 1). A sensitivity of 100% and specificity of 94.5% was achieved with the male MUAC cut-off. Thus, the proposed cut-offs identified all of the wasted children (WHZ < -2), while identifying an acceptably low number of false positives.

The poor sensitivity of the current MUAC cut-off values (12.5 cm) for identifying children with MAM (WHZ < -2), suggest that the WHO cut-off values may be too low to effectively identify malnourished children in the community to do timeous referrals and prevent SAM. This problem is crucial in areas where growth monitoring activities rely heavily on MUAC due to its simplicity and low cost, as children screened for malnutrition who could potentially benefit from intervention, are missed.[6]

The low number of moderately wasted children in this sample made it problematic to determine sensitivity and specificity of MUAC in children. Measuring infants and young children in clinics and ECD centres inherently excludes children who do not attend these facilities and thus the results cannot be generalised.

South African Journal of Clinical Nutrition is co-published by Medpharm Publications, NISC (Pty) Ltd and Informa UK Limited [trading as the Taylor & Francis Group]

Table 1. Diagnostic test results for moderate wasting (WHZ < -2) using MUAC.

	12.0 cm	12.5 cm	13.0 cm	13.5 cm	13.8 cm
Sensitivity	0.0%	0.0%	0.0%	Undefined* (females)	100% (males)
Specificity	100.0%	99.6%	99.6%	96.4%	94.5%

*Sample size limitation.

The current WHO MUAC cut-off values lacked the sensitivity to identify cases of MAM in a South African urban township population. A revised, single MUAC cut-off value for males and females younger than two years may increase the correct diagnosis of MAM, thus providing health workers the opportunity to prevent SAM. This new cut-off value should be tested in the field with larger samples.

Disclosure statement – No potential conflict of interest was reported by the authors.

ORCID
Shawn McLaren http://orcid.org/0000-0003-3357-7909
Liana Steenkamp http://orcid.org/0000-0003-1746-0700

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Received: 14-06-2017 Accepted: 02-09-2017

Appendix I: Screening for overweight using mid-upper arm circumference (MUAC) among children younger than two years in the Eastern Cape, South Africa.

South African Journal of Clinical Nutrition 2020; 1–4
https://doi.org/10.1080/16070658.2020.1782027

SAJCN
ISSN 1607-0658 EISSN 2221-1268

ARTICLE

Screening for overweight using mid-upper arm circumference (MUAC) among children younger than two years in the Eastern Cape, South Africa

Shawn McLaren[a,b*], **Liana Steenkamp**[c], **H David McCarthy**[a] **and Alexandra Rutishauser-Perera**[d]

[a]Dietetics Department, Nelson Mandela University, Port Elizabeth, South Africa
[b]School of Human Sciences, London Metropolitan University, London, United Kingdom
[c]HIV & AIDS Research Unit, Nelson Mandela University, Port Elizabeth, South Africa
[d]Action Against Hunger UK, London, United Kingdom
*Corresponding author, email: s.mclaren@londonmet.ac.uk

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Background: The relationship between overweight and under-nutrition, particularly in resource-poor settings, poses practical challenges for targeting nutrition interventions. Current anthropometric indicators including weight for length (WLZ) recommended by the WHO may be challenging in community settings.
Objectives: The aim of this study was to assess whether MUAC can accurately identify children aged younger than two years with overweight and obesity.
Method: A descriptive, cross-sectional study was used to collect data from a non-probability sample of 397 young South African children from October 2015 to February 2016. MUAC cut-off values were tested using a receiver operating characteristic and area under the curve (AUC).
Results: The prevalence of overweight (WLZ > +2) and obesity (WLZ > +3) was 11% (n = 44) and 5% (21) respectively. A MUAC cut-off value for identifying male children 6 to 24 months old with overweight was determined at 16.5 cm (85% sensitivity, 71.4% specificity, AUC = 0.821) and female children at 16.5 cm (100% sensitivity, 76.6% specificity, AUC = 0.938).
Conclusions: MUAC may be an appropriate tool for identifying children younger than two years old with overweight and obesity. The predicted MUAC cut-off values were able to identify infants and young children with overweight accurately.

Keywords: double burden of disease, first 1000 days, MUAC, obesity

Introduction

According to the WHO,[1] 42 million children under the age of five years are overweight or obese. The prevalence of stunting and wasting is reducing in low- and middle-income countries (LMIC), while overweight and obesity is becoming more prevalent among children.[2] Accelerated weight gain in early life may be related to non-communicable disease risk.[3] Overweight at one year old may greatly increase the risk of type 2 diabetes and premature death from cardiovascular disease.[4] High rates of glucose intolerance and pre-hypertension have been observed among rural South African adolescents,[5] indicative of the epidemiological transition taking place.

Major changes to the diet as a result of the nutrition transition include increased consumption of refined carbohydrates, added sweeteners, edible oils and animal source foods. These dietary patterns can result in higher rates in overweight and obesity in both children and adults. In Southern African countries, it has been estimated that 72% of people are not meeting the recommendations for vegetable and fruit consumption.[6] Furthermore, while the rate of initiation of breastfeeding is high in South Arica, the exclusive breastfeeding rate declines rapidly.[7] Early introduction of foods and liquids other than breast milk before the age of six months is common[7] and may be associated with overweight and obesity later in life.[8] High-sugar fruit juices are being introduced to infants from six months of age.[9] A large proportion of South African infants are consuming foods such as processed meats and crisps on a daily basis by the time they are 12 months old. These less healthy foods are rapidly becoming more affordable, accessible and acceptable to all populations in South Africa, including rural and informal settlements.[10] The effects of these shifts in dietary patterns are already being observed, with as many as 10% of infants overweight at six months of age.[11]

The emerging double burden of disease poses significant practical challenges for targeting nutrition interventions, particularly in resource-poor settings. Current anthropometric indicators to identify overweight in children as recommended by the WHO and the World Obesity Federation (WOF)[12] include weight for length (WLZ) or weight for height (WHZ) and BMI for age. Evidence suggests that WHZ and BMI for age yield similar prevalence of overweight and obesity and therefore there is no need to monitor both indicators.[13] However, using the WHZ or BMI for age cut-off values may be challenging at community and household level due to practical limitations, such as community health workers – who may not always have access to transport – carrying bulky equipment. Furthermore, in resource-poor settings, a MUAC tape may offer several advantages such as being non-invasive, cheaper and faster to use when compared with the scales, stadiometers and length boards required for determining WLZ. Community health workers and parents or guardians can also easily be trained to use and interpret MUAC measurements as a screening tool and this may even aid in the reduction of errors occurring in anthropometric measurements of children.[14]

Research has begun to establish that MUAC can be effective in identifying overweight and obese children.[15] The rate of increase in arm circumference has also been reported parallel to the rate of weight gain in children.[14] There is currently no formal recommendation for a single cut-off value for MUAC to identify overweight and obese infants and children in the same way that cut-off values are available for identifying acute malnutrition. The available WHO MUAC field tables can be cumbersome to use, rely on the age of the child and undermine the simplicity of MUAC as a screening tool. There is also a lack of data relating to children younger than two years as many of the studies available, which assess the ability of MUAC to identify obese children, focus on children older than two years.[15,16] Therefore, the aim of this study was to predict MUAC cut-off values to identify overweight and obese infants and children younger than two years old within a specific population.

Methods

This descriptive study was undertaken using a cross-sectional design. Ethical approval was obtained from the Research Ethics Committee (Human), Nelson Mandela University, as well as the Eastern Cape Department of Health (ref. no H15-HEA-002). Inclusion in the study required written informed consent from the primary caregiver of the participant. Data on weight, length and MUAC were collected from infants and young children living in a South African resource-poor peri-urban settlement, aged from birth to two years (n = 408) between October 2015 and February 2016. Date of birth and date of measurement were recorded and participant age calculated in decimals. Procedures for obtaining anthropometric data followed protocols described by the Centres for Disease Control and Prevention.[17] Weight was measured in kilograms (kg) with a Nagata BW 2010 infant scale (capacity 20 kg× 10 g; Eong Huat Corporation Sdn Bhd, Malaysia) and recorded to the nearest 0.01 kg. Length was measured in centimetres (cm) using a Seca infantometer (Seca GmbH, Hamburg, Germany) to the nearest 0.1 cm. Non-stretch MUAC tapes were used to measure arm circumference in centimetres to the nearest 0.1 cm. Scales were calibrated before measurements were taken, and measurements were taken at eye level to avoid parallax errors. Measurements were taken by trained fieldworkers. Fieldworkers were registered dietitians and dietetic students who received training before commencing data collection and throughout the data collection period. Fieldworkers collected data under direct supervision of the principle investigator. Anthropometric data were used to calculate Z-scores for weight for age (WAZ), height for age (HAZ) and weight for length (WLZ) using WHO Anthro software (WHO, Switzerland). Data cleaning criteria were applied according to WHO guidelines.[18]

Descriptive statistics were used to describe the outcomes. As absolute MUAC was expected to increase from younger to older age groups; tests for significance in MUAC between age groups was performed using a Scheffe test. A p-value of < 0.05 was considered significant. A receiver operating characteristic (ROC) curve was generated using SPSS software (v. 25; IBM Corp, Armonk, NY, USA) and used to calculate the area under the curve (AUC) to assess the performance of MUAC as a diagnostic test when using WLZ as the criterion for overweight and obesity. WLZ was used as the standard criterion as it is the recommended indicator of overweight and obesity.[19] An AUC value of > 0.8 was considered an accurate test.[20] The Youden index (J) is the difference between the true positive rate (sensitivity) and the false positive rate with 1 indicating a perfect test, and 0 a useless test. It signifies the optimal sensitivity and specificity values yielding the maximum sums from the ROC curves. The J-value was used to inform the optimal MUAC cut-off values.

Results

Eleven records were removed from the sample as they had implausible Z-scores. The final sample (n = 397) was homogenously (100%) of African ethnicity. The sample was made up of 50% (n = 197) male participants, and 50% (n = 200) female participants. The mean participant age was 9.78 months (SD= 6.13). There was no significant difference between the ages of male and female participants (p = 0.53).

The mean WLZ was 0.83 (SD= 1.28). The prevalence of overweight (+2 < WLZ < +3) and obesity (WLZ >+3) was 11.8% (n = 47) and 5% (n = 21) respectively. There were no significant differences observed between genders for WLZ (p = 0.367), as indicated in Table 1.

Infants younger than 6 months had significantly different MUAC measurements compared with children older than 6 months, but there was no statistically significant difference observed among children between 6 and 24 months old. This resulted in the decision to test a single MUAC for children 6 to 24 months old as these children were found to be comparable.

The AUC for identifying overweight males 0–6 months old (n = 58) was 0.766. The MUAC cut-off value at 14.5 cm had a sensitivity of 88.9% and specificity of 63.3% (J = 0.542). Female children 0–6 months old had an AUC of 0.788 for overweight. The MUAC cut-off with the highest J-value (J = 0.585) was 14.2 cm (100% sensitivity, and 58.5% specificity).

Data obtained from males aged six to 24 months (n = 139) generated ROC curves with AUC of 0.821 for overweight (+2 < WLZ < +3) and 0.905 for obesity (WLZ > +3), presented in Table 2. The MUAC cut-off value of 16.5 cm had the highest J-value (0.589) and a sensitivity of 85% and specificity of 71.4% for identifying overweight. The optimum MUAC cut-off value for identifying obesity among males 6 to 24 months old was 17.2 cm (88.9% sensitivity, 80.8% specificity, J = 0.697). As presented in Table 3, a MUAC cut-off for identifying overweight female children aged 6 to 24 months (n = 130) was determined at 16.5 cm (AUC = 0.938). This cut-off value had a sensitivity of 100% and specificity of 76.7% (J = 0.767). The optimum MUAC cut-off value for identifying obesity was 17.0 cm (J = 0.758).

Discussion

The proposed MUAC cut-off values of 16.5 cm for overweight (+2 < WLZ < +3) males and females, and 17.2 cm for identifying obesity in males and 17.0 cm for females, correctly classified an acceptably high number of children. The simplicity of MUAC measurements could assist with early identification of infants and young children who are clinically overweight or obese in community and household settings. MUAC is simple to use. It also could potentially allow for screening for over- and undernutrition with a single tool reflecting different cut-off values.

The results of this study demonstrate that MUAC may be an appropriate tool for identifying children younger than two years old as overweight and obese. The area under the curve for all groups tested was found to have a very good diagnostic value. Research so far has not addressed the need for a suitable MUAC cut-off value for identifying overweight among children younger than two years. Investigations into the use of MUAC as a screening tool for overweight and obesity have largely focused on children of school-going age. Chaput *et al.*[21] demonstrated a high level of sensitivity and specificity for identifying overweight and obesity among 9- to 11-year-olds using novel

Table 1: Anthropometric indicators in male and female participants ($n = 397$)

Anthropometric indicator	Sex	n	Mean (SD)	*p*-value	Cohen's D
Weight (kg)	Male	197	9.19 (2.59)	0.018*	0.24
	Female	200	8.58 (2.49)		
Height (cm)	Male	197	70.83 (8.86)	0.049*	0.20
	Female	200	69.04 (9.12)		
WLZ	Male	197	0.77 (1.40)	0.367	0.09
	Female	200	0.88 (1.15)		
MUAC (cm)	Male	197	15.59 (1.74)	0.017*	0.24
	Female	200	15.17 (1.75)		

Values = mean (SD). *Denotes statistically significant at $p < 0.05$.

Table 2: Potential MUAC cut-off values for identifying overweight and obesity in males 6 to 24 months old, compared with WLZ ($n = 139$)

+2<WLZ<+3 Male 6–24 months		AUC = 0.821	$n = 139$	WLZ > +3 male 6–24 months		AUC = 0.905	$n = 139$
MUAC (cm)	Sensitivity	Specificity	Youden Index	MUAC (cm)	Sensitivity	Specificity	Youden Index
16.3	0.850	0.664	0.522	16.8	0.889	0.731	0.620
16.4	0.850	0.672	0.564	16.9	0.889	0.738	0.627
16.5	**0.850**	**0.714**	**0.589**	**17.0**	**0.889**	**0.762**	**0.650**
16.6	0.850	0.739	0.573	17.1	0.889	0.792	0.681
16.7	0.800	0.773	0.582	17.2	0.889	0.808	0.697

Note: Bold signifies proposed MUAC cut-off values.

Table 3: Potential MUAC cut-off values for identifying overweight and obesity in females 6 to 24 months old, compared with WLZ ($n = 130$)

+2 < WLZ < +3 female 6–24 months		AUC = 0.938	$n = 130$	WLZ > +3 female 6–24 months		AUC = 0.938	$n = 130$
MUAC (cm)	Sensitivity	Specificity	Youden Index	MUAC (cm)	Sensitivity	Specificity	Youden Index
16.3	1.000	0.717	0.717	16.8	0.900	0.833	0.733
16.4	1.000	0.742	0.742	16.9	0.900	0.850	0.750
16.5	**1.000**	**0.767**	**0.767**	**17.0**	**0.900**	**0.858**	**0.758**
16.6	0.900	0.792	0.692	17.1	0.800	0.867	0.667
16.7	0.900	0.833	0.733	17.2	0.800	0.883	0.683

Note: Bold signifies proposed MUAC cut-off values.

MUAC cut-offs. Craig *et al.*[22] conducted a study that showed similar results using MUAC in South Africa, but again this research focused on children and adolescents older than five years. The areas under the curve for the current study for females and males were both greater than 0.8, considered the threshold for an acceptably accurate test.[20]

Some of the challenges in nutrition screening such as accurately estimating a child's age[23] are avoided using MUAC and weight-for-height indicators. Weight for height still requires trained fieldworkers and equipment,[19] and time available to spend on training fieldworkers may be limited due to overloading roles with tasks and large geographic coverage diluting trained field-workers.[23] Additionally, health workers are capable of measuring and interpreting weight but can be uncomfortable with weight and length measurements in combination, therefore weight for height interpretations may not be performed routinely in the field.[24] According to the results of this study, MUAC is capable of accurately identifying overweight and obese infants and young children. The simplicity of MUAC may also be advantageous in the emerging problem of childhood overweight and obesity as it should help to minimise resource allocation to growth charts, anthropometric equipment, training materials and workshops[18] in community settings.

Kim, Lee and Sungwon[3] report that overweight and obesity between ages two and six years is significantly associated with developing adult metabolic syndrome, while the association between overweight and obesity before the second birthday and development of metabolic syndrome in adulthood exists but is not significant. This may suggest that a window for intervention exists before the second birthday which might have a significant impact on future chronic disease risk. Given that the first 1 000 days is such a crucial time for development, identifying overweight and obesity in this age group could potentially prevent future problems associated with the global double burden of disease. Hawkes *et al.*[25] have recently suggested that as all forms of malnutrition have common drivers, health workers should aim to simultaneously prevent under- and over-nutrition, under the term 'double-duty actions'. Potential double-duty actions include redesigning the existing growth monitoring programmes, including weight for height in primary care settings, and interpreting overweight where feasible.[25] A MUAC cut-off value for overweight and obesity could aid in expanding this action to community and household screening for referral.

This study is limited as the average age of the participants was 9.78 months, creating a bias towards younger children. The study was conducted in primary care facilities and crèches, therefore excluding children who do not attend these facilities. A further limitation of the study was the cross-sectional approach. A longitudinal study would have yielded more information in relation to the dynamic growth of children; however, longitudinal data can be impractical to collect. This study must be repeated with a larger sample size in urban, peri-urban and rural South African communities in order to validate the use of the tool.

Conclusion

MUAC has the potential to identify children with overweight and obesity in South African communities, where community health workers lack adequate access to growth-monitoring equipment. Referrals to health services made during the crucial stage of childhood development before the second birthday can potentially reduce the later risks of overweight and associated chronic diseases of lifestyle in adolescence and adulthood.

To our knowledge, this is the first work to address a MUAC cut-off value for identifying overweight and obesity among children younger than two years. However, further research is needed, using larger samples from different South African contexts to provide better insight into its standardised use.

Disclosure statement – No potential conflict of interest was reported by the author(s).

ORCID

Shawn McLaren http://orcid.org/0000-0003-3357-7909
Liana Steenkamp http://orcid.org/0000-0003-1746-0700

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Received: 21-02-2020 Accepted: 05-06-2020

Appendix J: Design and validation of a double-burden mid-upper arm circumference (MUAC) tape for South African children aged six to 24 months.

Proceedings of the Nutrition Society

Proceedings of the Nutrition Society (2022), **81 (OCE1)**, E11 doi:10.1017/S0029665122000118

Winter Conference 2021, 7–8 December 2021, Obesity and the brain

Design and validation of a double-burden mid-upper arm circumference (MUAC) tape for South African children aged six to 24 months

S. McLaren[1], L. Steenkamp[2] and H.D. McCarthy[1]

[1]*School of Human Sciences, London Metropolitan University, London, UK and*
[2]*HIV and AIDS Research Unit, Nelson Mandela University, Gqeberha, South Africa*

The nutritional double burden refers to a concurrent high prevalence of under- and overnutrition(1).

Mid-upper arm circumference (MUAC) (measured using a tape) and weight-for-height (WHZ) are used to identify malnourished children(2). However, current WHO MUAC and WHZ cut-offs show limited levels of agreement among different childhood populations(3), including South African children(4).

Therefore, alternative MUAC cut-offs have been proposed, achieving improved agreement(5). Additionally, there is current interest in MUAC as a screening tool for overweight and obesity(6). Equipment and personnel in resource-poor environments are shared between situations of under- and over-nutrition. Therefore, the aim of this study was to validate alternative MUAC cut-offs for South African children aged between six and 24 months, with a view to producing a single MUAC tape capable of identifying both under- and overnutrition.

Data from 348 young children were collected from community clinics and creches. Ethics approval (ref. no H15-HEA-DIET-003) and gatekeepers' permission was obtained. Using WHZ categories defined by WHO(2) as the reference, MUAC cut-offs were proposed to define categories of nutritional status. Sensitivity, specificity, positive predictive value (PPV), negative predictive values (NPV) were calculated. The association between MUAC category and WHZ category allocation defined by the proposed MUAC cut-off values was assessed using a chi-square test, with Cramer's V to determine the strength of the association and a Kappa test to determine the level of agreement between the two indicators. Analyses were conducted using SPSS v25.

Mean age was 13.57 months (SD, 5.34) and 49.8% of the sample was male. Mean MUAC = 15.32 cm (SD, 1.04) and mean WHZ = 0.50 (SD, 0.99). WHZ ranged from −3.2 to 4.57.

MUAC < 13.0 cm had a sensitivity of 100% and specificity of 99.1% (PPV = 0.25, NPV = 1.0) for WHZ<-3. MUAC between 13.1 and 13.8 cm had a sensitivity of 100% and specificity of 95.6% (PPV = 0.117, NVP = 1.0) for WHZ<-2. MUAC between 16.5 and 16.9 cm had a sensitivity of 11.1% and specificity of 86.8% (PPV = 0.111, NPV = 0.868) for WHZ>+2. MUAC > 17.0 cm had sensitivity of 90.9% and specificity of 80.1% (PPV = 0.235, NPV = 0.992) for WHZ>+3. There was a significant agreement between MUAC and WHZ (Kappa = 0.255; p < 0.001). There was a significant association between the proposed MUAC cut-offs and WHZ categories (Pearson Chi square = 233.52; df = 16; n = 348; p < 0.001). This association is strong (Cramer's V = 0.410; p < 0.001).

The double-burden MUAC tape proposed has potential for reducing resource requirements for screening for both under- and overnutrition in a South African context. Despite the poor performance of the tool for identifying overweight, it has a high sensitivity and specificity for acute malnutrition and obesity. Further research is warranted using a larger independent sample with a range of states of nutrition as well as measures of clinical outcomes to substantiate these preliminary results.

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Appendix K: Confirmation of contribution

Shawn McLaren is submitting the following six original peer reviewed journal articles for the award of PhD by prior output. The title of the dissertation is:

The double burden of malnutrition in South Africa: risk factors for undernutrition and overnutrition and the development of a novel mid-upper arm circumference (MUAC) screening tool in children

These outputs have been conducted in collaboration with others.

List of original publications

I. McLaren S, Steenkamp L, Feeley A, Nyarko J, Venter D (2018). Food insecurity, social welfare and low birth weight: Implications for childhood malnutrition in an urban Eastern Cape Province township. *South African Journal of Child Health* 12(3): 95-99. H-index 14; Impact factor 0.522.

II. McLaren SW, Steenkamp L (2021). Coverage of vitamin A supplementation, deworming and immunisations: Associations with nutritional status among urban children younger than five years in Nelson Mandela Bay, Eastern Cape. *South African Journal of Child Health.* H-index 14; Impact factor 0.522

III. McLaren SW (2021). The relationship between haemoglobin level and socio-economic indicators among women of childbearing age in South Africa: A secondary analysis of DHS data. *Ecology of Food and Nutrition*. Impact factor 0.894

IV. McLaren SW, Steenkamp L, Venter D (2017). Use of Mid Upper- Arm Circumference (MUAC) as screening tool in an urban township in the Eastern Cape: rationale for testing changed cut-off values to identify malnutrition. *South African Journal of Clinical Nutrition*, 30:4, 118-119. DOI: 10.1080/16070658.2017.1376859. Impact factor 0.64

V. McLaren S, Steenkamp L, McCarthy HD, Rutsihauser-Perera A (2020). Screening for overweight using mid-upper arm circumference (MUAC) among children younger than two years in the Eastern Cape, South Africa. *South African Journal of Clinical Nutrition*, DOI: 10.1080/16070658.2020.1782027. Impact factor 0.64.

VI. McLaren S, Steenkamp L, McCarthy HD (2021). Design and validation of the double-burden mid-upper arm circumference (MUAC) tape for South African children aged six to 24 months. *Proceedings of the Nutrition Society* 81(E11): OCE1. DOI:10.1017/S0029665122000118.

I can confirm that Shawn McLaren was a significant contributor to study I, IV, V and VI, where he was involved in designing the studies, collecting data, analysing data and writing the research report. Shawn McLaren contributed to the conceptualisation, data analysis, and writing the research report for article II.

Signature

Dr J Steenkamp	2022/05/12
Name	Date

Shawn McLaren is submitting the following six original peer reviewed journal articles for the award of PhD by prior output. The title of the dissertation is:

The double burden of malnutrition in South Africa: risk factors for undernutrition and overnutrition and the development of a novel mid-upper arm circumference (MUAC) screening tool in children

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I can confirm that Shawn McLaren was a significant contributor to studies V and VI, where he was involved in designing the studies, collecting data, analysing data and writing the research report.

H. David McCarthy

Signature

Name Prof. H. David McCarthy Date 13.05.2022