MID-UPPER ARM CIRCUMFERENCE AND NUTRITIONAL RISK IN MACROCEPHALIC PEDIATRIC PATIENTS

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Christina Ann Wadelton

MID-UPPER ARM CIRCUMFERENCE AND NUTRITIONAL RISK

IN MACROCEPHALIC PEDIATRIC PATIENTS

Objective: Nutritional assessment and diagnosis of malnutrition in pediatric patients is dependent on anthropometric measurements. In macrocephalic children, current anthropometric measures may fail to correctly diagnose malnutrition. The purpose of this study is to determine if the measurement of mid-upper arm circumference (MUAC) in pediatric patients with macrocephaly better identifies children at nutritional risk as compared to weight-for-length (WFL) or body mass index (BMI).

Methods: A cross-sectional pilot study of children aged 6-36 months with a head circumference 2 SD above the mean was performed. Visual assessment was used as the clinical "gold standard" for presence of malnutrition. MUAC was compared to the WFL or BMI for each child to determine which anthropometric measurement better identified presence of malnutrition.

Statistics: Two-way contingency tables were used to summarize the relationships between each pair of assessments of whether a child is malnourished. Agreement between the methods was evaluated using kappa statistics and percent agreement. Analyses were performed using SAS version 9.4 ™ statistical software.

Results: Twenty patients were included who met study criteria. The mean head circumference z-score was 2.6. The mean BMI/WFL z-score was 0.9, which would qualify the child as “nourished.” Of the 20 children included in the study, 20% (n=4) appeared visually malnourished on physical exam. BMI/WFL confirmed diagnosis of malnutrition in 75% (n=3) of children. MUAC confirmed diagnosis of malnutrition in 75% (n=3) of children. Diagnosis of malnutrition using BMI/WFL as compared to visual assessment had a non-significant p-value of 0.317. Diagnosis of malnutrition using MUAC as compared to visual assessment had a non-significant p-value of 0.317. With a p-value of >0.5, there is no statistically significant difference between BMI/WFL and MUAC in diagnosis of malnutrition.

Conclusion: MUAC did not perform better than BMI/WFL at identifying malnutrition in pediatric macrocephalic patients.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

The following terms appear throughout this paper:

MUAC	Mid-upper arm circumference
WFL	Weight-for-length
BMI	Body mass index
OFC	Occipital frontal circumference
EMR	Electronic medical record
SD	Standard deviation
WHZ	Weight-for-height z-score
NFPE	Nutrition focused physical exam

Chapter One: Background

Introduction

The development of this project originated from the observed clinical need to better identify nutritional risk in macrocephalic pediatric patients. The current use of weight-for-length or body mass index may not accurately reflect presence or degree of malnutrition. Macrocephalic children may have a weight-for-length (WFL) or body mass index (BMI) that is within normal parameters, but visually appear malnourished. Though visual and physical assessments of pediatric patients are an important part of a full nutrition assessment, visual assessment alone is not enough for formal diagnosis of malnutrition. It is vital to establish an objective measurement to identify these at risk patients in order to optimize their nutrition care.

Review of Literature

In childhood, anthropometric measurements are monitored regularly to assess growth and nutritional status. The anthropometric measurements commonly used for monitoring are weight, length/height, and head circumference.[1] Anthropometric measures are plotted onto growth charts specific for age and sex to monitor growth trends.

Weight and length/height measurements are routinely performed in most pediatric clinical settings. Weight-for-length (WFL) and body mass index (BMI) are measures of proportionality and are used to categorize degree of malnutrition, normal body composition, or overweight/obesity.[1] BMI/WFL can be easily determined and are often automatically calculated and plotted on electronic growth charts through entry into the electronic medical record (EMR). Weight-for-length is the current anthropometric standard, as recommended by the American Academy of Pediatrics (AAP), for the first 2 years of life.[2] Weight-for-length is determined by plotting on a growth chart graph with length on the *x*-axis and weight on the *y*-axis. At age 2, children are transitioned to the BMI-for-age growth charts for assessment of nutritional status, as recommended by the AAP. BMI is calculated as weight in kilograms divided by the square of length in meters. BMI is then plotted on a growth chart according to age, with age in years on the *x*-axis and BMI on the *y*-axis. Percentiles can be estimated for both the weight-for-length and BMI by plotting on sex specific growth charts.[2] Electronic software such as Peditools.org, an online clinical tool for pediatric providers including growth charts, can be used for specific and accurate percentiles and z-scores.[3]

Routine monitoring of growth in order to track trends is important as abnormal growth may indicate malnutrition or an underlying health condition.[4] Weight-for-length and BMI charts are important for assessing a child's proportionality, or the appropriateness of their weight compared to their length/height.

Dietitians rely on accurate anthropometric measurements to identify when nutrition intervention is needed. Measuring growth accurately can have significant impact on important health outcomes.[5] Early recognition of abnormal growth or growth failure can contribute to earlier medical and nutritional intervention, which can result in improved nutritional status, reduced morbidity, and reduced mortality.[5] Frequent monitoring of growth during this age is important because children can become malnourished much more quickly than adults. Particularly children under the age of 3 years, rapid rate of growth and high nutritional needs make them even more susceptible to growth failure.[6] Acute malnutrition at this age can lead to severe wasting and chronic malnutrition can lead to stunting. Chronic and untreated malnutrition can also lead to decreased brain growth, which can have irreversible neurodevelopmental consequences.[1] Studies have shown that chronic malnutrition in early childhood can cause delayed motor development, lower IQ, deficient social skills, decreased attention, and deficient learning.[6]

Head circumference is routinely measured during the first 3 years of life as this is the period of time in which brain growth occurs most rapidly.[1] Head circumference is measured using a non-stretchable measuring tape and is plotted onto corresponding growth charts for age and sex, with age in months on the *x*-axis and head circumference in centimeters on the *y*-axis.

Macrocephaly is defined as a head circumference or occipital frontal circumference (OFC) greater than 2 standard deviations (SD) above the mean for the given age and sex.[7] Macrocephaly is a broad term with a variety of etiologies. Macrocephaly can be benign and isolated or can be an indication of an underlying condition, which can be congenital, genetic, or acquired.[8] Macrocephaly is a common feature of some genetic conditions, such as Fragile X syndrome, Gorlin syndrome, Cowden syndrome, and Sotos syndrome, among others. [9, 10] Macrocephaly may also be the result of hydrocephalus, or an abnormally high amount of cerebrospinal fluid.[9] Intercranial hemorrhage, such as in the case of non-accidental traumas, can also result in macrocephaly.[9]

Macrocephaly occurs in up to 5% of the pediatric population.[8] Structurally, infants and children are very different than adults; they are not miniature adults. A child’s head is proportionately larger than an adult’s, representing a greater proportion of their total body weight.[11] A macrocephalic child may have a body weight significantly and disproportionately represented with head weight, which will affect their BMI or weight-for-length measurement.

Though growth charts are appropriate and useful for children who plot within a normal range (3rd to 97th percentile), assessment of nutritional status can be more difficult for those who fall outside of the normal range, such as macrocephalic children.[1]

In clinical practice, it is observed that macrocephalic children often have a BMI or WFL within normal parameters, but upon physical and visual assessment appear grossly undernourished. For macrocephalic children, their disproportionate head weight may result in a healthy BMI or WFL. These macrocephalic pediatric patients do not fit on traditional growth charts and as a result will be classified as "nourished." Potentially, this could be masking a large percentage of the pediatric population that need better nutrition support.

Because these children appear "healthy" or within normal growth parameters on standardized growth charts, clinicians must rely on physical and visual exam as the clinical "gold standard" to assess for malnutrition in this population.

A nutrition focused physical exam (NFPE) is a physical and visual assessment of a patient looking for clinic symptoms of nutritional deficiencies.[12] NFPE is a critical part of a complete nutrition assessment in order to fully assess for indicators of malnutrition such as muscle wasting, fat loss, or presence of edema.[13] NFPE is even more critical in pediatric patients as the risk of malnutrition is much greater and prolonged malnutrition can profoundly affect growth and development.[13] NFPE helps to strengthen nutrition assessment and malnutrition diagnosis in order to initiate proper nutrition interventions.[13]

A NFPE typically begins with a visual inspection, head to toe, of the patient. General inspection can immediately identify if patients are underweight or overweight, though assessment of muscle mass and fat stores can be highly subjective and therefore interpretation of the exam is highly dependent on the observer.[12-13] Assessment for subcutaneous fat loss and muscle wasting in infants and toddlers includes visual assessment and appreciation of a child's face, arms, chest, back, buttocks and legs. Indications of subcutaneous fat loss or muscle mass include protruding bone structures, hollow cheeks, hollow temples, and flat buttocks.[13]

Though NFPE can be useful in confirming diagnosis of malnutrition, a physical exam can be subjective, easily misinterpreted if not performed correctly and is not alone enough for a formal diagnosis of pediatric malnutrition. A physical exam can be used as supporting evidence for a diagnosis of malnutrition, but an objective measure is needed for formal diagnosis according to the Consensus Statement.[14]

The Consensus Statement is a definition of pediatric malnutrition developed by an interdisciplinary team of nutrition professionals. The Consensus Statement incorporates etiology and is based on malnutrition in the hospitalized pediatric patient in developed countries, whereas previous definitions of pediatric malnutrition have historically used third-world population data.[15] The malnutrition diagnosis is based on weight, height or length, head circumference (OFC), or mid-upper arm circumference. The measures are plotted on growth curves, and a *z*-score is determined. Degree of malnutrition (mild, moderate, severe) is determined by the *z*-score (Table 1.).[16]

Table 1: Consesus Statement for Pediatric Malnutrition Diagnosis[16]

	Mild Malnutrition	Moderate Malnutrition	Severe Malnutrition
Weight-for-height *z* score	−1 to −1.9 *z* score	−2 to −2.9 *z* score	−3 or greater *z* score
BMI-for-age *z* score	−1 to −1.9 *z* score	−2 to −2.9 *z* score	−3 or greater *z* score
Length/height-for-age *z* score	No data	No data	−3 *z* score
Mid–upper arm circumference	Greater than or equal to −1 to −1.9 *z* score	Greater than or equal to −2 to −2.9 *z* score	Greater than or equal to −3 *z* score

BMI, body mass index.

Measurement of MUAC is an objective measurement of nutrition status that can be used for a formal diagnosis of malnutrition, according to the Consensus Statement.[16] The measurement of MUAC is useful for assessing body composition, especially in patients that have measurements that plot on extreme ends of standard growth charts.[1] MUAC may more accurately capture the potential nutrition risk of this vulnerable population. The measurement of MUAC is relatively easy to perform, low cost and requires little training.[17]

Mid-upper arm circumference (MUAC) is the circumference of the left upper arm, measured at the mid-point between the olecranon process (elbow) and the acromion (shoulder). This mid-point is determined by using a paper measuring tape, starting at the acromion and stopping at the olecranon process. MUAC is generally as good as other anthropometric measures at predicting mortality and has been found to be as effective as BMI in identifying adults with severe malnutrition.[17]

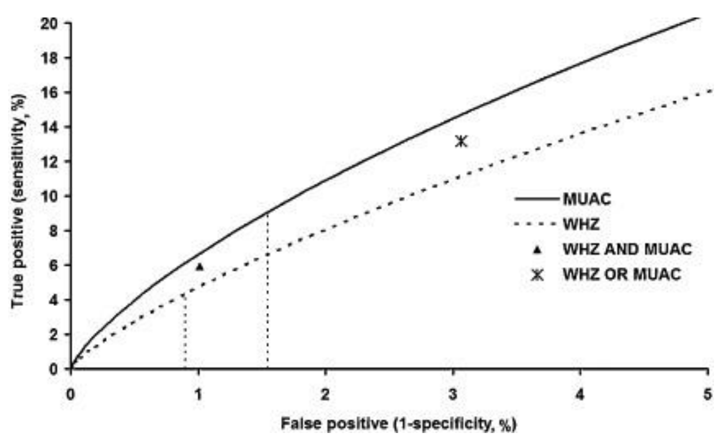
Mid-upper arm circumference (MUAC) is a useful measurement for assessing body composition, particularly in children with growth measurements that plot at extreme ends on standard growth curves.[1] MUAC is a measurement of the muscle, fat, and bone at the mid-upper arm, and is a relatively stable measure from 6 to 59 months.[1] Unlike weight, MUAC is not sensitive to changes in fluid status. Fluid status can greatly affect weight, and consequently weight-based ratios like BMI/WFL. Fluid status can vary greatly in children with severe malnutrition, because of factors such as dehydration, emesis, and diarrhea.[18]

Modi et al compared the effectiveness of MUAC compared to weight-based anthropometrics in the setting of diarrhea and severe dehydration.[18] Their study in rural Bangladesh used a prospective cohort approach and included children under the age of 60 months admitted to a rehydration unit in the study. The investigators randomly selected, enrolled, and had complete data for analysis for 721 children. Anthropometric measurements including weight, length, WFL/BMI and MUAC were taken pre- and post-hydration to assess for the validity of identifying undernutrition. MUAC demonstrated a 92-94% agreement pre- and post-hydration compared to 69-76% agreement for WFL/BMI. The study concluded that MUAC was the most accurate predictor of undernutrition and weight-based anthropometrics were significantly affected by hydration status. The study also found that MUAC was more accurate in determining severity of malnutrition, as weight-based measurements misclassified 14% of patients with severe acute malnutrition compared to only 1-2% for MUAC.

In another study, Abitew et al looked at the use of MUAC versus weight-for-height in the identification of severe acute malnutrition.[19] A cross-sectional study of 2,040 children aged 6-59 months at community-based programs in South Gondar Zone, Ethipoia was conducted to compare the ability of MUAC and weight-for-height to identify severe acute malnutrition in children. Children were considered severely malnourished if they had an MUAC <11.5 cm or a weight-for-height z-score of <-3. The prevalence of severe malnutrition was 11.2% using MUAC and 11.0% using weight-for-height z-score. MUAC and weight-for-height were 94.6% agreeable with a k=0.729. The findings of the study indicated that identification of severe acute malnutrition by the two indicators was comparable, though MUAC was shown to be slightly more sensitive and specific in identification. When considering global acute malnutrition, which includes both moderate and severe malnutrition diagnoses, MUAC identified more moderately malnourished children than weight-for-height (32.0% vs. 27.3%, respectfully). Abitew et al suggested that the variation in prevalence of both severe and moderate malnutrition based on these two indicators could be associated with differences in body composition.

Briend et al examined the benefit of using both MUAC and weight-for-height as diagnostic criteria for severe malnutrition in order to determine if there was a benefit to using both methods as opposed to using a singular anthropometric measure.[20] The specific objective of this study was to determine if the use of both MUAC and weight-for-height improved identification of high-risk children. The study followed a cohort of about 5000 children over a 2-year period, with comprehensive anthropometric measurements (weight, height, head circumference, arm circumference, triceps skin fold, and subscapular skin fold) taken every 6 months. Receiver operating characteristic (ROC) curves were used to analyze their data. ROC curves are used to choose the most appropriate cut-off for a test, by showing in graph the sensitivity and specificity of the tests. ROC curves of MUAC and weight-for-height z-scores (WHZ) to predict mortality were drawn and then cutoff points of WHZ <-3 and/or MUAC <115 mm were positioned. As seen in Figure 2, MUAC had the highest ROC curve, which indicated that it identified high-risk children better than WHZ. This study found that MUAC was superior to weight-for-height in identifying high-risk children and was better at assessing the risk of mortality. The study found that use of both weight-for-height and MUAC did not improve identification of high-risk children and suggested that using MUAC alone increased specificity.

Figure 1: ROC curves of MUAC and WHZ[20]



MUAC is extensively studied for use in low-income countries as a way to identify severe malnutrition and increased risk of mortality in children.[21] More recently, it has been supported that MUAC be used in clinic settings, not just low-income settings, to diagnose degree of malnutrition.[22] MUAC was included in the 2014 ASPEN Pediatric Malnutrition Indicators as an anthropometric measurement for identification and diagnosis of malnutrition.[16] The Consensus Statement recommends using MUAC as a malnutrition diagnostic tool only for infants and children aged 6-59 months as WHO growth standard z-scores are only available for this age group.[14, 16]

Current guidelines from the WHO approve of using MUAC in community-based settings and health facilities to diagnose malnutrition in children.[18] Despite the relative ease at which MUAC can be measured, it has not become at widely adopted tool in pediatric clinical settings. One of the key steps in treating malnutrition in children is accurate and rapid identification.

Accurate diagnosis of pediatric malnutrition is critical for several reasons. Malnutrition in the pediatric patient can result in changes in muscle strength, delayed cognitive and/or physical development, increased infections, immune dysfunction, extended hospital stays and delayed healing.[23] Malnutrition puts children at a much higher risk of mortality. Acute malnutrition accounts for almost one third of all deaths in children under the age of five.[24] In a study of severe acute malnutrition and mortality, children identified as severely, acutely malnourished by either low MUAC or low weight-for-height, mortality risk was 4 times higher than healthy children.[25] Children diagnosed as severely acutely malnourished with both a low MUAC and a low weight-for-height had a mortality risk that was 8 times higher than healthy children.[25] This study retrospectively analyzed anthropometric measures from 15,060 children across multiple countries to identify mortality risk of severely malnourished children.[25]

In a pooled analysis involving 53,809 children 1 week old to 59 months old, researchers looked at the association between suboptimal growth and mortality.[26] According to their research, all degrees of malnourishment were associated with significantly higher mortality. Even mild malnutrition significantly increased mortality. As z-scores decreased, risk of mortality increased.

Among the children who survive childhood malnutrition, many will have permanent physical and cognitive impairments.[24] Especially in the first three years of life during peak brain development, malnutrition can have detrimental, irreversible effects.[14] Acute malnutrition can result in a reduced brain size, thinning of the cerebral cortex and slowed brain growth, which can result in global developmental delay.[24]

Appropriate understanding of nutrition status is crucial for clinicians to provide adequate nutrition support, particularly in children.[15] Early and accurate diagnosis of malnutrition can drive earlier intervention and prevent long-term health and developmental issues.[15]

Along with the importance of accurately and rapidly diagnosing presence of malnutrition, correctly diagnosing the severity of malnutrition is equally important. Severity of malnutrition (mild, moderate, severe) helps to inform risk of mortality and the urgency of treatment.[14, 16] Diagnosing severity of malnutrition in children will allow of appropriate allocation of resources and targeted nutrition interventions.[14]

In addition to providing the best nutrition support to the child, accurate diagnosis of malnutrition is important from a financial perspective. Malnutrition is associated with increased hospital costs, longer lengths of stay, and increased complications.[15,27] Timely and accurate diagnosis of malnutrition will allow for clinicians to provide appropriate nutrition support, which can reduce length of stay and risk of infections.[27] Additionally, when diagnosis of malnutrition is made and coded for, the facility has a higher chance of increased reimbursement. Accurately diagnosing the severity of malnutrition allows for correct level of reimbursement for institutions.[14] Reimbursement is important because it can support the need for more nutrition-focused professionals.[15]

If routine measurement of MUAC can lead to better identification of children at nutritional risk, providers will be able to intervene earlier, minimize risk of prolonged malnutrition and optimize health outcomes. Macrocephalic children may be at higher nutritional risk due to the difficulty of assessing their growth trends on standard growth charts. The current clinical "gold standard" of visual assessment can support a malnutrition diagnosis, but an objective anthropometric measurement is needed to make a formal malnutrition diagnosis. Literature for the specific population of macrocephalic malnourished children is extremely limited and to the knowledge of the principal investigator, comparison of MUAC to BMI/WFL in this population has not been studied before. However, the importance of early and accurate diagnosis of malnutrition in children is well-understood. There is a clinical need for an accurate, objective anthropometric measurement for this population. This project will address whether MUAC is better than weight-for-length or body mass index at identifying nutritional risk in macrocephalic pediatric patients.

Research Question

Does the measurement of MUAC in macrocephalic pediatric patients better identify children at nutritional risk compared to use of BMI/WFL?

Chapter Two: Methodology

Methods

This study was a cross-sectional pilot study of patients seen in outpatient Developmental Medicine clinic at Riley Hospital for Children located in downtown Indianapolis, Indiana. The study was approved by the IUPUI IRB (IRB # 10418).

Trained clinical assistants completed measurements on all patients, including weight, length or height and head circumference. Clinical assistants undergo training on how to complete accurate anthropometric measurements for pediatric patients. The training module includes a presentation (Weight and Measures: Accuracy and Competency) as well as an exam to assess for competency.

Weights were performed using an electronic scale (WelchAllyn Scale-Tronix 4802D), with infants <36 months measured without clothing or diapers to the nearest 0.01 kg. Linear growth was assessed using a custom-made length board (designed by the Riley Clinical Engineering Department) for children <24 months or children who were unable to stand erect unsupported. Children >24 months who were able to stand unsupported were measured using a wall-mounted stadiometer (Seca 213). Head circumference (OFC) was measured using a non-stretchable paper measuring tape (Grafco 1336). This information was entered into the EMR (Cerner) by the clinical assistants. The EMR automatically plotted the measurements onto appropriate age and sex specific growth charts, including BMI or WFL growth charts. Children under the age of 24 months are plotted onto WHO (0-2 year) growth charts, while children over 24 months are plotted onto CDC (2-20 year) charts.

After weight, length/height and OFC measurements were completed, identification of eligibility was determined by the principal investigator through chart review of the EMR.

Children between the ages of 6-36 months with a head circumference (OFC) 2 SD above the mean were eligible for inclusion. Non-English speakers were excluded from the study.

Informed Consent

After identification of eligible patients, the procedure was explained to the caregiver in the presence of the child. Due to the age of the patient population, caregivers were asked to give verbal consent for measurement of mid-upper arm and use of data for research. The caregiver was asked to fill out written consent form (Appendix B). Children who were verbal were asked to give assent prior to the principal investigator performing physical assessment.

MUAC Measurement and NFPE Procedures

After receiving consent and assent, if applicable, the principal investigator measured the child's mid-upper arm circumference. Non-stretchable, paper measuring tapes (Grafco 1336) were used to ensure sterility and standardization. If the child was wearing clothing that interfered with measurement, the caregivers were asked to remove the child's clothing. The principal investigator measured the mid-point between the olecranon process and the acromion and the mid-point was marked by making a small dot with a marker. If able, the child was asked to bend their arm at a 90-degree angle during this measurement. When necessary, the caregiver was asked to assist with this position.

The tape measure was then placed around the child's relaxed arm at the marked mid-point, without pinching the arm. The measurement was read and recorded to the nearest 0.1 cm. The measurement process was repeated two times to ensure accurate interpretation. If the measurements were different, two closest measurements were taken and averaged.

The principal investigator completed a physical and visual exam for each child, using nutrition focused physical exam (NFPE) guidelines for inspection and palpation. Visual inspection began with a general inspection of the body and skin. The principal investigator looked for signs of muscle loss, subcutaneous fat loss or wasting. The principal investigator made note of areas of bony prominence, such as a protruding rib cage or scapula, and hollowing areas, such as the temple and cheeks. Children were identified as either visually appearing "malnourished" or "nourished." This visual assessment would then be compared to BMI/WFL and MUAC diagnosis of malnutrition.

Data Collection

The principal investigator recorded all measurements (weight, length, head circumference and MIUAC) as well as notes from physical and visual assessment. The principal investigator then manually entered all anthropometric data into Peditools.org to determine percentiles and z-scores for BMI/WFL and MUAC. The z-scores were used to determine nutrition status and diagnose malnutrition, if applicable. All data were then manually entered into REDCap, a secure online research database. The form used for data collection can be viewed in Appendix A.

Statistical Methods

The visual assessment was used as the clinical "gold standard". BMI/WFL and MUAC were evaluated for each subject. Z-score cut offs for malnutrition diagnosis were used for each of the assessment methods. Two-way contingency tables were used to summarize the relationships between each pair of assessments of whether a child is malnourished. Agreement between the methods was evaluated using kappa statistics and percent agreement. McNemar's tests were used to compare the percent malnourished between methods. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) and specificity of the BMI and

MUAC methods compared to the gold standard were calculated. Analyses were performed using SAS version 9.4 (SAS Institute, Inc., Cary, NC).

With a sample size of 20 subjects, the study had 80% power to detect a 41% difference between methods in the percent of subjects with malnutrition using a McNemar's test, assuming a two-sided 5% significance level and 45% discordance.

Chapter Three: Results

Results

This study included 20 children identified as eligible for inclusion based on age (6-36 months) and head circumference measurement (z-score > 2SD above mean). The mean age was 19.2 months old. The mean head circumference z-score was 2.6 (>97%ile). The mean BMI/WFL z-score was 0.9, which would qualify the patient as "nourished." (Table 2).

Table 2: Descriptive Statistics for Study Sample (n=20)

	Mean (SD)	Min	Max
Age (months)	19.2 (9.1)	6.5	35.6
OFC %ile	99.0 (1.2)	97	100
OFC z-score	2.6 (0.9)	2.0	5.88
MUAC %Ile	65.8 (34.4)	0	100
MUAC z-score	0.5 (1.9)	-3.91	3.84
WFL BMI %ile	68.8 (34.4)	3	100
WFL BMI z-score	0.9 (1.6)	-1.96	4.24

Table 3: Descriptive Statistics for Study Sample, cont. (n=20)

		N (%)
Sex	F	9 (45%)
	M	11 (55%)
Malnutrition (visual assessment)	N	16 (80%)
	Y	4 (20%)

Collection of data took place from February 2021-August 2021. Of the 20 children included in the study, 20% (n=4) appeared visually malnourished based on the nutrition focused physical exam (Table 3). BMI/WFL confirmed diagnosis of malnutrition in 75% of the children that appeared malnourished on physical exam (n=3). Similarly, MUAC confirmed diagnosis of malnutrition in 75% of the children that appeared malnourished on physical exam (n=3) (Table 4).

As shown in Table 4, the diagnosis of malnutrition using WFL/BMI compared to visual assessment had a non-significant p-value of 0.317 and a 95% agreement, demonstrating that use of visual assessment was not significantly better at identifying malnutrition than standard use of WFL/BMI. The diagnosis of malnutrition using MUAC compared to visual assessment also had a non-significant p-value of 0.317 and a 95% agreement, again demonstrating that visual assessment was not significantly better at identifying malnutrition than measurement of MUAC. One child appeared visually malnourished, but according to both BMI and MUAC, they were within normal growth parameters (Table 5). Measurement of MUAC did identify two cases of severe malnutrition, whereas BMI diagnosed these children with mild malnutrition (Table 4).

Of the children that appeared visually nourished (n=16), both BMI/WFL and MUAC had a 100% agreement with a nourished diagnosis (Table 4).

With a p-value > 0.5 (p-value 1.00), there is no statistically significant difference between BMI/WFL and MUAC in diagnosis of malnutrition. There was a 100% agreement between diagnosis of malnutrition using BMI/WFL and MUAC (Table 6).

Table 4: BMI/WFL and MUAC malnutrition vs. visual assessment

Method	malnutrition	Malnutrition – visual N	Malnutrition – visual Y	Total	McNemar test p-value	% Agree	Kappa	Sensitivity	Specificity	PPV	NPV
BMI/WFL-levels	mild malnutrition	0	3	3							
	nourished	16	1	17							
	Total	16	4	20							
BMI/WFL-malnutrition	N	16	1	17	0.317	95%	0.83	75	100	100	94
	Y	0	3	3							
	Total	16	4	20							
MUAC-levels	mild malnutrition	0	1	1							
	severe malnutrition	0	2	2							
	nourished	16	1	17							
	Total	16	4	20							
MUAC-malnutrition	N	16	1	17	0.317	95%	0.83	75	100	100	94
	Y	0	3	3							
	Total	16	4	20							

Table 5: Visually malnourished child unidentified by objective measures

Age (mth)	Sex	OFC %	OFC z-score	MUAC %	MUAC z-score	WFL/BMI %	WFL/BMI z-score	Visual
12	F	100	2.64	40	-0.26	42	-0.21	visually, appears thin, no appreciable fat stores, ribs and scapula prominent

Table 6: BMI/WFL vs. MUAC

		MUAC			McNemar		
Method	malnutrition	N	Y	Total	test p-value	% Agree	Kappa
BMI	N	17	0	17	1.00	100%	1.00
	Y	0	3	3			
	Total	17	3	20			

Discussion

Children with macrocephaly can be difficult to assess for malnutrition using current standards of practice. Their head size relative to their weight and length/height can misrepresent their nutritional status on traditional growth charts. Visual assessment is the current standard for identifying malnutrition in these patients, however a malnutrition diagnosis cannot be made with visual assessment alone. It is crucial to determine which objective method of measuring malnutrition is most accurate in these vulnerable populations in order to give them appropriate nutrition support and prevent the long-term detrimental effects of malnutrition on the developing brain and body. It has been suggested that MUAC may be better than BMI/WFL at identifying malnutrition in children that do not fit traditional growth charts.

In this pilot study, MUAC performed as well as, but did not identify malnutrition better than the use of BMI/WFL. There was no statistically significant difference between the use of either objective anthropometric measurement. In children that appeared visually malnourished, BMI/WFL and MUAC identified malnutrition at the same rate with 100% agreement. In children that appeared visually nourished, objective measurements were in agreement with a nourished diagnosis. No children that appeared visually nourished were identified as being malnourished using either anthropometric measurement.

MUAC may be slightly better at identifying severe malnutrition than WFL/BMI, though this was not statistically significant. In two of the children that appeared visually malnourished, MUAC identified these children as severely malnourished, while BMI/WFL identified these children as mildly malnourished. Although not statistically significant in this study, it has been suggested by previous studies that MUAC is better at specifically identifying severe malnutrition. Accurate diagnosis of severity is critical for determining appropriate nutrition interventions and urgency of treatment. Additionally, an accurate diagnosis of malnutrition will result in the correct level of reimbursement for healthcare facilities and can also be used to aid in providing insurance coverage for nutritional supplements.

Interestingly, both BMI/WFL and MUAC identified one child as “nourished” when the child appeared visually malnourished. This child appeared nourished on all anthropometric measurements, though visually appeared grossly underweight with visual assessment noting: no appreciable fat stores, rib cage and scapula prominent. This case exemplifies the need for an objective anthropometric measurement to diagnose malnutrition in this complicated population. Without visual assessment, it is likely that no nutrition intervention would be suggested or provided. However, even with visual assessment, malnutrition cannot be diagnosed, and this child is at risk for not getting the appropriate nutrition interventions.

Though this pilot study did not demonstrate the importance of regular use of MUAC for this population, it does recognize the importance of NFPE as a standard of practice. A NFPE is a key component to complete nutrition care, especially in high-risk pediatric patients that can become malnourished quickly. Malnourishment in childhood can have lifelong impacts on growth and development, making early nutrition intervention crucial. Visual assessment remains the “gold standard” for identifying malnutrition in macrocephalic pediatric patients and the best practice for diagnosis in this population is important future research.

Limitations

The main limitation of this study is the small sample size. A sample size of 20 children limited the power of this study. Additionally, the inclusion criteria was non-specific and allowed for inclusion of macrosomic children. In future studies, would recommend excluding macrosomic children (weight, length/height and OFC all >97%ile) and changing inclusion criteria to only include children who visually appear malnourished.

There were also several limitations due to the COVID-19 pandemic. Up to 50% of patient appointments in Developmental Medicine clinic were conducted virtually, which limited the sample size as it was not possible to directly measure children virtually. Additionally, some caregivers were hesitant to participate in the study due to concerns about physical contact and potential spread of disease. The COVID-19 pandemic also saw widespread medical misinformation and subsequent mistrust of medical professionals, which seemingly impacted caregivers' willingness to participate in a research study.

Future Research

This pilot study serves as a starting point for this important research. Future research should include specific inclusion criteria of children who visually appear malnourished to ensure the correct population is being targeted and allow for better comparison of the diagnostic tools. It may also be beneficial to create inclusion criteria that includes children with relative macrocephaly. Children with relative macrocephaly do not have a head circumference that is >2 SD above the mean but have a head circumference z-score well above their weight and length/height z-scores. Relative macrocephaly is not well-defined in medical literature. To the knowledge of the principal investigator, there is no consistent definition of relative macrocephaly, which is why these children were not included in this pilot study. However, children with relative macrocephaly often fit the same clinical picture and similarly may not fit on traditional growth charts, which can make it difficult to assess for malnutrition and put them at increased nutritional risk. Establishing a definition of relative macrocephaly and including this group in future studies will help to evaluate MUAC as a potential tool for these children who do not fit on standard growth charts.

In addition to changing inclusion criteria, it will be beneficial for future studies to be more expansive and include a larger sample size to increase the power of the study. Collecting data over a longer period of time and in a variety of clinical settings, rather than just one outpatient clinic, will increase the power of the study and the generalizability of the results.

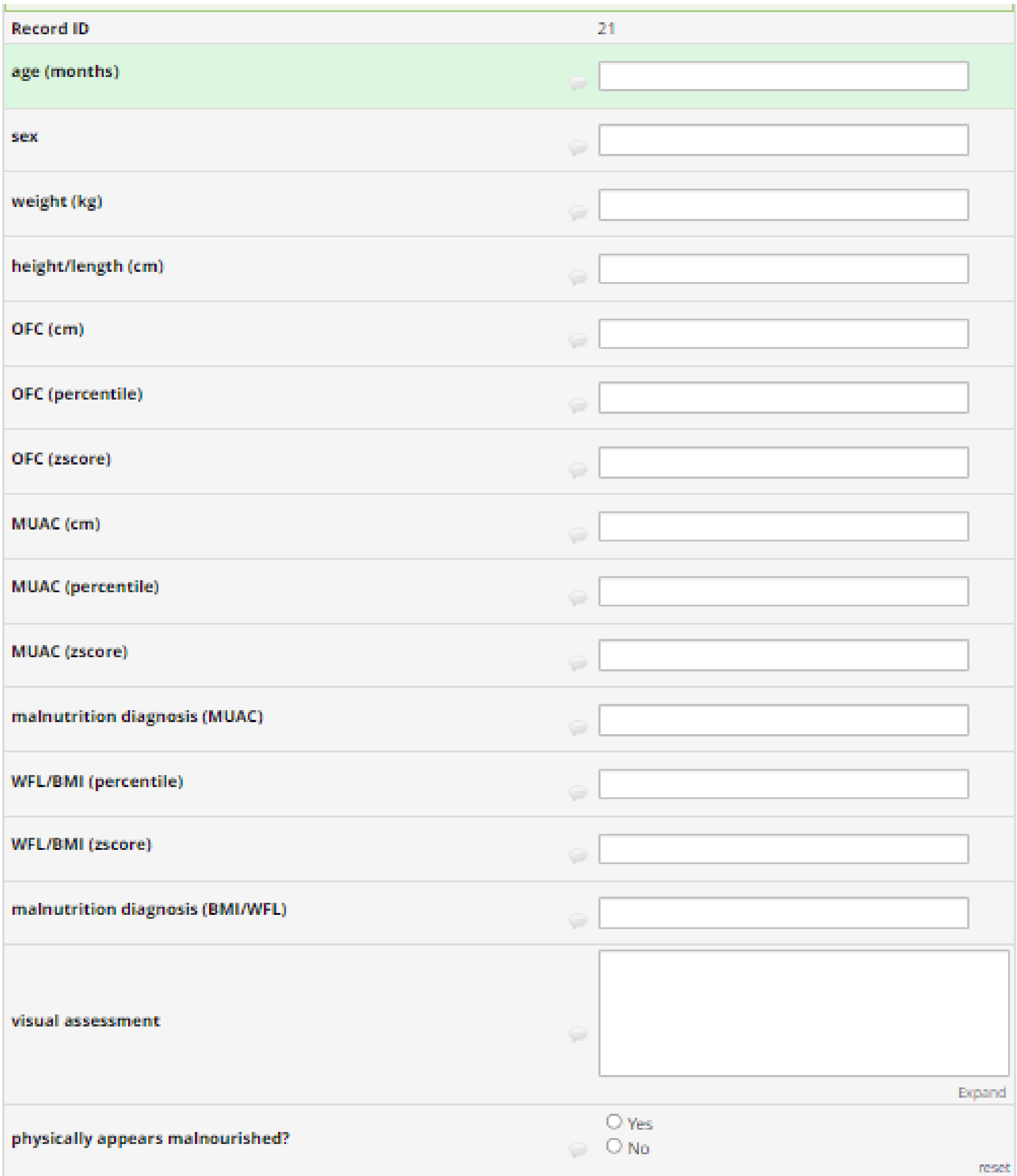
As noted in the review of literature, visual and physical exams can be very subjective to the observer. It may be beneficial for future studies to have the visual assessment blinded to the principal investigator to prevent bias from anthropometric assessment or to have more than one observer performing visual and physical assessments.

Conclusion

In summary, in this pilot study MUAC did not perform better than BMI/WFL at identifying malnutrition in macrocephalic pediatric patients. This study found that MUAC identified malnutrition with the same sensitivity as BMI/WFL, though MUAC identified severe malnourishment when BMI/WFL did not. With the difference in detection of severity of malnutrition, it is possible that MUAC may still be a useful tool for diagnosis of malnutrition in this population. Future studies of macrocephalic pediatric patients that exclude macrosomic children are needed to better evaluate the use of MUAC for identification of malnutrition, as these children remain at high-risk for nutritional complications.

Appendices

Appendix A- REDCap Data Entry Form



Record ID	21
age (months)	
sex	
weight (kg)	
height/length (cm)	
OFC (cm)	
OFC (percentile)	
OFC (zscore)	
MUAC (cm)	
MUAC (percentile)	
MUAC (zscore)	
malnutrition diagnosis (MUAC)	
WFL/BMI (percentile)	
WFL/BMI (zscore)	
malnutrition diagnosis (BMI/WFL)	
visual assessment	Expand
physically appears malnourished?	○ Yes ○ No reset

Appendix B- Consent Form

INDIANA UNIVERSITY INFORMED CONSENT STATEMENT AND AUTHORIZATION FOR RESEARCH

Mid-upper Arm Circumference and Nutritional Risk in Macrocephalic Pediatric Patients
Christina Wadelton, RD, LD
IRB # 10418

ABOUT THIS RESEARCH

You are being asked to participate in a research study. Scientists do research to answer important questions which might help change or improve the way we do things in the future.

This consent and Authorization form will give you information about this study to help you decide whether you want to participate. It is your choice whether or not you want to be in this research study. Please read this form, and ask any questions you have, before agreeing to be in this study.

Please note that use of the words "You/your" throughout this document refer to an adult signing consent and authorization for a child for whom a parent will be signing consent and authorization for their child's participation.

WHY IS THIS STUDY BEING DONE?

The purpose of this study is to compare the use of mid-upper arm circumference (MUAC) to the use of weight-for-length or body mass index in children with head circumferences above the 97%ile. The goal of the study is to determine which measurement is best for identifying children who are underweight, or malnourished.

You were selected as a possible participant because your child has a head circumference that is above the 97%ile (macrocephalic).

The study is being conducted by Dr. Jackie O'Palka and Christina Wadelton, RD, LD and Indiana University Purdue University of Indianapolis (IUPUI).

HOW MANY PEOPLE WILL TAKE PART?

If you agree to participate, you will be one of 20 participants taking part in this research.

WHAT WILL HAPPEN DURING THE STUDY?

This study involves collection of information about you or from you. If you agree to be in the study, you will do the following things:

Your child's weight, length/height, head circumference will be recorded at a regularly scheduled doctor's visit. Your child's mid-upper arm circumference will be measured and recorded. Your child's age and sex will also be recorded. No other identifiable information will be recorded. The measurements will only be taken once. There is no follow up necessary for this study.

You will not receive the results of any of these tests or procedures because they are being done only for research purposes.

WHAT ARE THE RISKS OF TAKING PART IN THE STUDY?

Since this study only includes collection of information about your child, the only risk to you and your child is a possible loss of confidentiality; although we will do everything possible to protect your information. Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. No information which could identify you will be shared in publications about this study.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the Indiana University Institutional Review Board or its designees, and any state or federal agencies who may need to access your medical and/or research records (as allowed by law).

WHAT ARE THE BENEFITS OF TAKING PART IN THE STUDY?

We don't think you will have any personal benefits from taking part in this study, but we hope to learn things that will help other people in the future.

WILL I BE PAID FOR PARTICIPATION?

You will not be paid for participating in this study.

WILL IT COST ME ANYTHING TO PARTICIPATE?

There is no cost to you for taking part in this study.

HOW WILL MY INFORMATION BE USED?

The study team will collect information about you from your medical records. This information, some of which may identify you, may be used for research-related purposes. This may include making sure you meet the criteria to be included in the study, and recording measurements (weight, length/height, head circumference), or to inspect and/or copy your research records for quality assurance and data analysis.

The information released and used for this research will include your child's:

- Age
- Gender
- Weight
- Length/height
- Head circumference

If you agree to participate, you authorize the following to disclose your medical record information:

- Developmental Pediatrics at Riley Hospital for Children

The following individuals and organizations may receive or use your identifiable health information:

- The researchers and research staff conducting the study
- The Institutional Review Boards (IRB) or its designees that review this study
- Indiana University

HOW WILL MY INFORMATION BE PROTECTED?
Every effort will be made to keep your personal information confidential, but we cannot guarantee absolute confidentiality. No information which could identify you will be shared in publications about this study. Your personal information may be shared outside the research study if required by law and/or to individuals or organizations that oversee the conduct of research studies and these individuals or organizations may not be held to the same legal privacy standards as are doctors and hospitals.

WHO SHOULD I CALL WITH QUESTIONS OR PROBLEMS?
For questions about the study, contact the researchers Christina Wadelton or Jackie O'Palka.

For questions about your rights as a research participant, to discuss problems, complaints, or concerns about a research study, or to obtain information or to offer input, please contact the IU Human Subjects Office.

WHAT IF I DO NOT PARTICIPATE OR CHANGE MY MIND?

After reviewing this form and having your questions answered, you may decide to sign this form and participate in the study. Or, you may choose not to participate in the study. This decision is up to you. If you choose not to participate in this study or change your mind after signing this document, it will not affect your usual medical care or treatment or relationship with Developmental Pediatrics or Riley Hospital for Children.

If you change your mind and decide to leave the study in the future, the study team will help you withdraw from the study safely. If you decide to withdraw, please contact the researcher, Christina Wadelton.

If you choose to withdraw your authorization for use and disclosure of your protected health information, you must do so in writing by notifying:

Christina Wadelton

Or

Dr. Jackie O'Palka

If you withdraw your authorization, you will not be able to continue in this study. However, even if you cancel this authorization, the research team, research sponsor(s), and/or the research organizations may still use information about you that was collected as part of the research project between the date you signed this document and the date you cancelled this authorization. This is to protect the quality of the research results. Otherwise, this authorization remains valid until the research ends and required monitoring of the study has been completed.

PARTICIPANT'S CONSENT AND AUTHORIZATION

In consideration of all of the above, I agree to participate in this research study. I will be given a copy of this document to keep for my records.

______________________	______
Printed Name of Parent	**Date**
______________________	______
Signature of Parent	

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Curriculum Vitae

Christina Ann Wadelton

Education

2017-2022 **Master of Science in Nutrition and Dietetics** earned at Indiana University-Purdue University Indianapolis

2011-2015 **Bachelor of Science,** University of Dayton, Dietetics

Professional Experience

2019- Present Developmental Medicine, Riley Hospital for Children

Pediatric Clinical Dietitian

2016-2019 Infant Growth and Development, Riley Hospital for Children

Pediatric Clinical Dietitian

Training Experience

2015-2016 Pediatric Dietetic Internship, University of Michigan

Qualifications

Registered Dietitian Nutritionist (RDN), Commission on Dietetic Registration

Licensed Dietitian, Indiana Professional Licensing Agency