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J Dr Behcet Uz Child Hosp

Original Article

Evaluation of the Relationship Between Calf Circumference Measurement and Nutrition in Children Aged 1-5 Years (12-60 Months) Followed Up in Primary Care

Birinci Basamakta Takipli 1-5 Yaş Arası Çocuklarda Baldır Çevresi Ölçümü ile Beslenme Arasındaki İlişkinin Değerlendirilmesi

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ABSTRACT

Objective: This study aims to evaluate the feasibility of using measurement of calf circumference as an alternative method for assessing malnutrition status in children aged 1-5 years presenting to primary health care services.

Method: Measurements of weight, height, mid-upper arm circumference (MUAC), and calf circumference were taken, and body mass index (BMI), weight-for-age, weight-for-height (WFH), height-for-age (HFA), and MUAC Z-scores were calculated for 210 study participants aged 1-5 years. Agreement between anthropometric measurements was assessed using Kappa agreement analysis. Receiver operating characteristic analysis was performed to determine cut-off values for calf circumference so as to discriminate between undernutrition and obesity.

Results: According to Olcay Neyzi reference values, the prevalence rates of undernutrition were calculated as indicated based on WFH (10%), WAG (18.6%), HFA (17.6%), and MUAC (17.2%) Z-scores. The prevalence rates of overweight/obesity were estimated as indicated according to WFH (19.1%), BMI (21.5%), and MUAC (12.3%) Z-scores. Moderate agreement was observed between WFH and MUAC Z-scores, while high agreement was found between WAG and MUAC Z-scores. A high level of agreement was also observed between BMI and WFH in the assessment of obesity. Calf circumference Z-score cut-off values of ≥0.433 for obesity (area under the curve 0.83-0.84) and ≤-0.523 for malnutrition (area under the curve 0.77-0.88) were identified, with wide 95% bootstrap confidence intervals.

Conclusion: Calf circumference measurement can be a practical tool for assessing nutritional status in children; however, the recommended cut-off values need to be validated in independent populations.

Keywords: Calf circumference, malnutrition, obesity, primary care, preschool children

ÖZ

Amaç: Bu çalışmanın amacı, birinci basamak sağlık hizmetlerine başvuran 1-5 yaş arası çocuklarda yetersiz beslenmeyi değerlendirmede baldır çevresi ölçümünün alternatif olarak kullanılabilirliğini değerlendirmektir.

Yöntem: Çalışmaya 1-5 yaş arası dahil edilen 210 çocuğun ağırlık, boy, üst-orta kol çevresi (OKÇ) ve baldır çevresi ölçümleri yapılmış; vücut kitle indeksi (VKİ), yaşa göre ağırlık (YGA), boya göre ağırlık (BGA), yaşa göre boy (YGB) ve OKÇ Z-skoru hesaplanmıştır. Kappa uyum analizleri ile ölçümler arasındaki uyum değerlendirilmiş, alıcı işletim karakteristiği analizi ile baldır çevresi için beslenme yetersizliği ve obeziteyi ayırt etmeye yönelik sınır değerler belirlenmiştir.

Bulgular: Araştırmamızda Olcay Neyzi referans değerlerine göre bakılan beslenme yetersizliği oranı BGA ile %10, YGA ile %18,6, YGB ile %17,6 ve OKÇ Z-skoru ile %17,2 olarak saptandı. Fazla kilolu-obez oranı ise BGA'ya göre %19,1, VKİ'ye göre %21,5, OKÇ Z-skoruna göre %12,3 bulundu. BGA ile OKÇ Z-skoru arasında orta düzeyde, YGA ile OKÇ Z-skoru arasında yüksek düzeyde uyum gözlendi. Obeziteyi

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değerlendirmede VKİ ile BGA arasında yüksek düzeyde uyum saptandı. Baldır çevresi Z-skoru için obezitede ≥0,433 (eğri altında kalan alan 0,83-0,84), beslenme yetersizliğinde ≤-0,523 (eğri altında kalan alan 0,77-0,88) sınır değerleri belirlendi; bootstrap %95 güven aralıkları genişti.

Sonuç: Baldır çevresi ölçümü, çocuklarda beslenme durumunun değerlendirilmesinde pratik bir araç olabilir; ancak önerilen sınır değerlerin bağımsız popülasyonlarda doğrulanması gerekmektedir.

Anahtar kelimeler: Baldır çevresi, yetersiz beslenme, obezite, birinci basamak sağlık hizmetleri, okul öncesi çocuklar

INTRODUCTION

Malnutrition in early childhood remains a major public health issue that affects growth, development, and long-term health outcomes. Specifically, malnutrition during pregnancy and within the first six months of life can cause growth delays, cognitive, motor, and social-emotional setbacks, serious illnesses, and even death in early childhood. Children-especially those with severe acute malnutrition- who experience malnutrition in later stages of life face higher risks of mortality from common childhood diseases such as diarrhea, pneumonia, and malaria[1]. The American Society for Parenteral and Enteral Nutrition study group defines pediatric malnutrition as an imbalance between nutrient needs and intake, leading to deficiencies in energy, protein, or micronutrients that impair growth and development. Acute pediatric malnutrition is characterized by mild malnutrition or risk of malnutrition, with Z-scores less than -1, often related to inflammatory diseases stemming from illness, reduced nutrient intake, and loss of lean body mass. Chronic malnutrition mainly appears as delayed growth, known as stunting[2]. The American Academy of Pediatrics and the World Health Organization (WHO) recommend exclusive breastfeeding for the first six months of life[3]. Data from the 2018 Türkiye Population and Health Survey shows that 98% of children born in the previous two years were breastfed, but only 41% of infants under six months were exclusively breastfed which suggests that the rate of exclusive breastfeeding during the first six months remains insufficient in Türkiye. Ideal infant nutrition involves exclusive breastfeeding for the first six months of life, introducing appropriate amounts of nutritious, safe complementary foods at around six months, and continuing breastfeeding along with complementary feeding until age 2[4].

Measurement of calf circumference reflects peripheral muscle mass and body composition and serves as a nutritional marker across various age groups. Recently, measuring calf circumference has emerged as a promising method for monitoring the nutritional status of critically ill children treated in pediatric intensive care units. Calf circumference which appears to be more pronounced in children than in adolescents may reveal signs of deficiency earlier than mid-upper arm circumference (MUAC)[5]. There is a need for simpler, faster malnutrition screening tools that are easy to use in primary healthcare settings. However, limited evidence exists on its use in preschool children. This study aims both to evaluate the relationship between calf circumference and nutritional status in children aged 1-5 years and to explore its potential as an alternative screening tool for malnutrition.

MATERIALS and METHODS

This study was approved by the Institutional Ethics Committee of Manisa Celal Bayar University (approval no.: 20.478.486/2070, date: 11/08/2023). Written informed consent was obtained from parents or legal guardians of the children before measurements were taken. The study was designed as an analytical cross-sectional study, including a total of 210 children recruited in primary care units in the city centre (n=105) and in a surrounding district (n=105) of the Manisa Province, The sample size was calculated using G*Power, assuming an effect size of 0.50, a power of 0.95, and a margin of error of 0.05. From December 2023 to November 2024, data on age, gender, nutritional status, birth details, family income, and parental education level of children aged 1-5 years presenting to primary care units with any complaint were recorded on a demographic information form. The body weights of children up to 2 years of age were measured with a baby scale, with the participants lying in the prone position or sitting upright. For children older than 2 years, measurements were taken with a standard scale. Height for children up to 2 years old was measured with the child lying on their back using a head-foot board. For children older than 2 years, height was measured while they were standing upright. MUAC was measured with MUAC Z-score tapes, and calf circumference using a non-stretch measuring tape. These measurements were used to calculate MUAC Z-scores, body mass indexes (BMIs), BMI percentiles, weight-for-age, weight-for-height (WFH), and height-for-age (HFA).

Using the measured body weight and height, BMI was calculated as body weight in kilograms divided by height in square meters. Age- and gender-specific BMI percentiles were calculated using reference values proposed by eminent pediatrician professor Olcay Neyzi, MD, PhD as follows: <5%: "underweight", 5-85%: "normal", 85-95%:

"overweight", and ≥95%: "obese". Calculations for WAG, WFH, and HFA, used in the assessment of malnutrition, were performed based on also reference values proposed by Olcay Neyzi, MD, PhD. WAG was calculated using the formula: [(measured body weight/average body weight of a healthy child of the same age) x 100] and evaluated as follows: >90%: "normal", 75-90%: "mild malnutrition", 60-74%: "moderate malnutrition", and <60%: "severe malnutrition". HFA was calculated using the formula: [(measured height/average height of a healthy child of the same age) x 100] as follows: >95%: "normal", 90-95%: "mild malnutrition", 85-89%: "moderate malnutrition", and <85%: "severe malnutrition". WFH, used in both malnutrition and obesity assessments, was calculated using the formula [(measured body weight/average body weight of a healthy child of the same height) x 100] and rated as follows: 90-110%: "normal", 110-120%: "overweight", >120% "obesity", 81-90%: "mild malnutrition", 70-80%: "moderate malnutrition", and <70%: "severe malnutrition".

Statistical Analysis

Statistical analyses were conducted using SPSS 21 software; bootstrap analyses for cut-off confidence intervals (CIs), AUC CIs, and logistic regression analyses were performed with Stata 17.0 statistical software (StataCorp LLC, College Station, TX, USA). Categorical variables in the study were presented as numbers (n) and percentages (%) to illustrate patient distribution, while numerical data were expressed as mean values and standard deviations (SDs). Pearson's chi-square test was used for group comparisons. A p-value less than 0.05 was considered statistically significant. Agreement between variables was assessed with kappa (k) agreement analysis as follows K<0: no agreement; 0.01≤k≤0.20: slight agreement; 0.2≤k≤0.40: fair agreement; 0.4≤k≤0.60: moderate agreement; 0.61≤k≤0.80: substantial agreement; and 0.81≤k≤1.00: almost perfect agreement. To determine the cut-off value for calf circumference measurements based on age and gender, a standardized Z-score was first calculated using the formula "z = (x - mean)/SD," where age- and gender-specific mean and SD values were used. A receiver operating characteristic (ROC) analysis was performed on the Z-score to determine the cut-off value. This analysis evaluated the area under the curve (AUC), sensitivity, and specificity of data obtained. The optimal cut-off value was specified using these parameters and the Youden index, calculated as "sensitivity + specificity – 1". Using this cut-off value, positive and negative predictive values were calculated with the aid of MedCalc statistical software by creating contingency tables. The diagnostic performance of the test was rated based on the AUC values (%) as follows: 0.50-0.60: unsuccessful, 0.60-0.70 poor, 0.70-0.80: moderate, 0.80-0.90: good, and 0.90-1.0 : excellent diagnostic performance. To report the calf circumference threshold in centimetres, the Z-score was converted back to centimetres for each gender and for 12-month age group the same formula (cm = mean + z × SD) was used. Because the ROC analysis was performed on the Z-score in the pooled sample, a single Z-score threshold was obtained for obesity (from the ROC curve for WFH obesity, applied to both obesity classifications) and a single threshold for malnutrition (from the ROC curve for MUAC Z-score malnutrition, applied to all three malnutrition classifications); the age- and gender-specific values in centimetres therefore represented the same threshold expressed on the original scale and were not separate estimates within age subgroups.

The originally determined Youden cut-off values (≥0.4330 for obesity and ≤-0.5227 for malnutrition) were retained as the point estimates. To quantify sampling uncertainty around these thresholds, non-parametric bootstrap resampling was performed (2000 resamples with replacement, percentile method). The Youden-optimal threshold was re-estimated in each bootstrap sample; the bootstrap procedure was used solely to estimate the 95% CIs and did not replace the original point estimates. The confidence limits were converted to centimetres in the same manner as the point estimates. AUCs were presented with 95% CIs derived from the original ROC analyses.

To examine whether the association between calf circumferences and nutritional status was independent of demographic, socio-economic and feeding-related factors, multivariable binary logistic regression models were fitted for each dichotomous outcome (malnutrition according to the MUAC Z-score, WFH and WAG classifications; obesity according to the BMI percentile and WFH classifications). The calf circumference Z-score was entered as a continuous exposure, expressed per 1 SD decrease for malnutrition outcomes and per 1 SD increase for obesity outcomes. Covariates were selected a priori and included: sex, age (months), study setting (city centre vs. district), maternal education (≤ primary vs. ≥ secondary school), family income (income level below expenses vs. otherwise) and duration of breastfeeding (months). Age was retained despite the use of age-standardised measures because the prevalence of the outcomes varied across age groups. Maternal education and income were dichotomised because of sparse categories and to limit the number of parameters relative to the number of

events (17-39 per outcome). For the three outcomes with ≥27 events, maximum-likelihood estimates were reported, with Firth's penalised-likelihood estimates as a sensitivity analysis. Since two WFH-defined outcomes had the fewest events (21 and 17, respectively), Firth's penalised-likelihood logistic regression was used as the primary analysis to reduce potential small-sample bias, with maximum-likelihood estimates reported as a sensitivity analysis. Preterm birth (<37 weeks) was examined in an additional sensitivity analysis. Detailed estimates from the sensitivity analyses are presented in Supplementary Table S1. Crude and adjusted odds ratios (ORs) with 95% CIs were reported. Model calibration was assessed with the Hosmer-Lemeshow test and multicollinearity with variance inflation factors. Obesity defined by the MUAC Z-score (7 events) was not modelled multivariably.

RESULTS

The study population (n=210) consisted of 108 (51.4%) girls and 102 (48.6%) boys aged 12 to 60 months (mean age 37.83±15.20 months). The mean (±SD) duration of breastfeeding, and the time to introduce complementary foods were 14.60±8.46 and the 5.99±1.77 months, respectively. Besides, 46.7% (n=98) of the children received formula at some point from birth, while 53.3% (n=112) of them never used formula. Based on the MUAC Z-scores for malnutrition, the children were classified as being severely (n=2: 1%) moderately (n=4: 1.9%), mildly (n=30: 14.3%) malnourished. According to the WFH classification, calculated from Turkish children's percentile data proposed by Olcay Neyzi, no children had severe malnutrition but they were classified in moderately (n=3: 1.4%), and mildly (n=18: 8.6%) malnourished, normal weight (n=149: 71%), overweight (n=23: 11%) and obese (n=17: 8.1%) categories. Using the BMI percentile classification, our study participants were underweight (n=12: 5.7%), overweight (n=18: 8.6%), obese (n=27: 12.9%) or had normal weight (n=153: 72.9%). Based on Turkish children's percentile data, no children were severely malnourished, while indicated number (%) of our study participants were moderately (n=4: 1.9%), mildly (n=35: 16.7%) malnourished or of normal weight (n=171: 81.4%). In the HFA classification, no children had severe malnutrition. Indeed, they were classified as being moderately (n=1: 0.5%), mildly malnourished (n=36: 17.1%) or as being of normal weight (n=173: 82.4%) (Table 1).

In our study, a moderate level of agreement (kappa =0.502) and a statistically significant p-value (p<0.001) were observed between the WFH and MUAC Z-score classifications for assessing nutritional status of children as overweight/obese, normal, or malnourished (Table 2).

In evaluating childhood obesity, a strong agreement was observed between BMI and WFH classifications, with a kappa value of 0.748 (0.61≤k≤0.80) and a statistically significant p-value (p<0.001) (Table 3).

In another assessment of obesity status, a fair level of agreement (0.21≤k≤0.40) was observed between BMI and MUAC Z-score classifications, with a kappa value of 0.317 and a statistically significant p-value (p<0.001) (Table 4).

In evaluating nutritional deficiencies in children, a substantial level of agreement (0.61≤k≤0.80) was observed between the WAG and MUAC Z-score classifications, with a kappa value of 0.757, and a statistically significant p-value (p<0.001) (Table 5).

Table 1. Malnutrition rates according to various classifications

Classification	MUAC Z-score n (%)	WFH n (%)	WAG n (%)	HFA n (%)
Grade 1 malnutrition (mild)	30 (14.3)	18 (8.6)	35 (16.7)	36 (17.1)
Grade 2 malnutrition (moderate)	4 (1.9)	3 (1.4)	4 (1.9)	1 (0.5)
Grade 3 malnutrition (severe)	2 (1)	0	0	0

MUAC: Mid-upper arm circumference, WFH: Weight-for-height, WAG: Weight-for-age malnutrition classifications

Table 2. Kappa agreement analysis of MUAC Z-score with WFH overweight/obese, normal and malnutrition classifications

MUAC Z-score WFH	Overweight/obese (n)	Normal (n)	Malnutrition (n)	Total
Overweight/obese (n)	22	17	1	40
Normal (n)	4	125	20	149
Malnutrition (n)	0	6	15	21
Total	26	148	36	210

Kappa coefficient=0.502 p<0.001, MUAC: Mid-upper arm circumference, WFH: Weight-for-height

Table 3. Kappa agreement analysis of BMI and WFH obesity			
BMI WFH	**Not obese (n)**	**Obese (n)**	**Total (n)**
Non-obese (n)	183	10	193
Obese (n)	0	17	17
Total (n)	183	27	210
Kappa coefficient =0.748, p<0.001, WFH: Weight-for-height, BMI: Body mass index			

Table 4. Kappa agreement analysis of BMI and obesity with MUAC Z-score			
MUAC Z-score BMI	**Non-obese (n)**	**Obese (n)**	**Total (n)**
Non-obese (n)	182	1	183
Obese (n)	21	6	27
Total (n)	203	7	210
Kappa coefficient =0.317, p<0.001, BMI: Body mass index, MUAC: Mid-upper arm circumference			

Table 5. Kappa agreement analysis between MUAC Z-score and WAG, according to malnutrition presence/absence classification			
MUAC Z-score WAG	**Malnutrition (-) (n)**	**Malnutrition (+) (n)**	**Total (n)**
Malnutrition (-) (n)	165	6	171
Malnutrition(+) (n)	9	30	39
Total (n)	174	36	210
Kappa coefficient =0.757, p<0.001, MUAC: Mid-upper arm circumference, WAG: Weight-for-age malnutrition classification			

The sex- and age-group-specific mean values for calf circumference used for back-transformation were 19.8 cm for girls at age 1, 20.0 cm for age 2, 21.6 cm for age 3, and 22.2 cm for age 4; and 19.9 cm for boys at age 1, 20.5 cm for age 2, 21.4 cm for age 3, and 21.6 cm for age 4. The ROC analysis for calf circumference yielded an AUC of 0.835 (95% CI: 0.742-0.929, p<0.001) for the WFH obesity classification. The optimal Z-score was 0.4330, with a sensitivity of 76.5% and a specificity of 79.3% (Figure 1). For the BMI-based obesity classification, the AUC was 0.834 (95% CI: 0.748-0.921, p<0.001). When the same Z-score threshold (0.4330) was applied, sensitivity was 74.1% and specificity was 82% (Figure 2). When this threshold was converted into centimeters based on age and gender, the obesity cut-off values for calf circumference were calculated as follows: for girls, 20.5 cm at age 1, 20.6 cm at age 2, 22.5 cm at age 3, and 23.2 cm at age 4; and for boys, 20.7 cm at age 1, 21.2 cm at age 2, 22.4 cm at age 3, and 22.2 cm at age 4 (Tables 6-8). The bootstrap 95% CI of the cut-off value for obesity was 0.190 to 1.143 on the Z-score scale (Table 6); the corresponding age- and gender-specific values in centimetres with their 95% CIs are presented in Table 8.

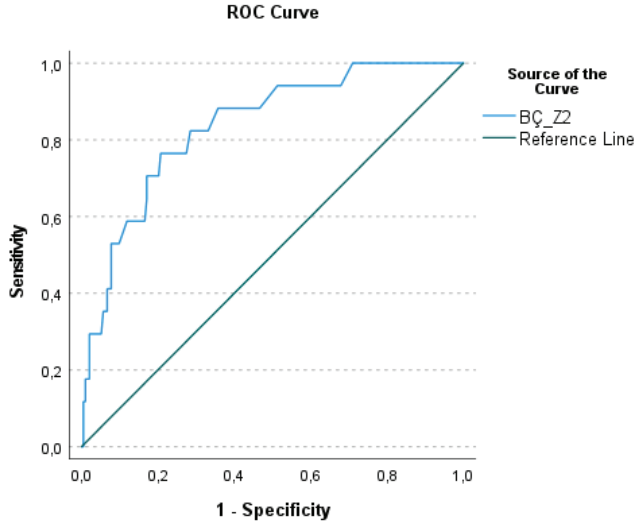


Figure 1. ROC curve according to WFH obesity classification
ROC: Receiver operating characteristic, WFH: Weight-for-height

In malnutrition classification based on MUAC Z-scores, the ROC analysis for calf circumference resulted in an AUC of 0.876 (95% CI: 0.805-0.946, p<0.001). The most appropriate Z-score was -0.5227, with a sensitivity of

86.1% and a specificity of 81.6% (Figure 3). For the WFH malnutrition classification, the AUC was 0.766 (95% CI: 0.655-0.877, p<0.001). When the same Z-score threshold (-0.5227) was applied, sensitivity was 71.4% and specificity was 74.6% (Figure 4). For the WAG malnutrition classification, the AUC was 0.828 (95% CI: 0.752-0.903, p<0.001). When the same Z-score threshold (-0.5227) was applied, sensitivity was 74.4% and specificity was 80.1% (Figure 5). When this threshold was converted to centimeters based on age and gender, the cut-off points for malnutrition based on calf circumferences were calculated as follows: for girls, 19 cm at 1 year, 19.3 cm at 2 years, 20.5 cm at 3 years, and 21.1 cm at 4 years; for boys, 18.9 cm at 1 year, 19.7 cm at 2 years, 20.3 cm at 3 years, and 20.8 cm at 4 years (Tables 7 and 8). The bootstrap 95% CI of the malnutrition cut-off was -1.000 to -0.409 on the Z-score scale (Table 7); the corresponding intervals in centimetres are given in Table 8. Both CIs were wide, reflecting the limited number of events (17 WFH-obese and 36 MUAC-malnourished children), and the cut-off values should therefore be regarded as preliminary.

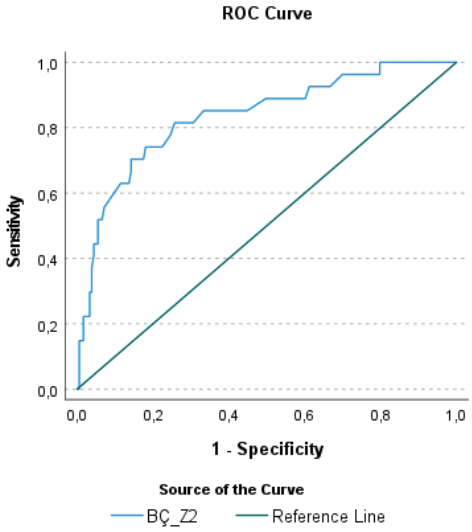


Figure 2. ROC curve according to the BMI classification of obesity

ROC: Receiver operating characteristic, BMI: Body mass index

In the multivariable logistic regression models adjusted for sex, age, study setting, level of maternal education, family income and duration of breastfeeding, the calf circumference Z-score remained independently associated with every modeled outcome (Table 9).

Table 6. Diagnostic performance of the calf circumference Z-score cut-off for obesity according to WFH and BMI classifications (n=210)

Classification	AUC (95% CI)	p	Z-score cut-off (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
WFH obese	0.835 (0.742-0.929)	<0.001	≥0.4330 (0.190-1.143)	76.5	79.3	24.5	97.5
BMI obese	0.834 (0.748-0.921)	<0.001	≥0.4330 (0.190-1.143)	74.1	82.0	37.7	95.5

AUC: Area under the ROC curve, CI: Confidence interval, PPV: Positive predictive value, NPV: Negative predictive value, WFH: Weight-for-height, BMI: Body mass index. The originally identified cut-off (Z≥0.4330), derived from the ROC curve for WFH obesity and applied to both obesity classifications, was retained as the point estimate. Sampling uncertainty was quantified by non-parametric bootstrap resampling (2000 resamples, percentile method); bootstrap was used only to obtain the 95% CI and did not replace the original point estimate. AUCs are presented with 95% CIs from the original ROC analyses. Age- and gender-specific values in cm are given in Table 8

Table 7. Diagnostic performance of the calf circumference Z-score cut-off for malnutrition according to MUAC Z-score, WFH and WAG classifications (n=210)

Classification	AUC (95% CI)	p	Z-score cut-off (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
MUAC Z-score malnutrition	0.876 (0.805-0.946)	<0.001	≤-0.5227 (-1.000 to -0.409)	86.1	81.6	49.2	96.6
WFH malnutrition	0.766 (0.655-0.877)	<0.001	≤-0.5227 (-1.000 to -0.409)	71.4	74.6	23.8	95.9
WAG malnutrition	0.828 (0.752-0.903)	<0.001	≤-0.5227 (-1.000 to -0.409)	74.4	80.1	46.0	93.2

AUC: Area under the ROC curve, CI: Confidence interval, PPV: Positive predictive value, NPV: Negative predictive value, MUAC: Mid-upper arm circumference, WFH: Weight-for-height, WAG: Weight-for-age. The originally identified cut-off (Z≤-0.5227), derived from the ROC curve for MUAC Z-score malnutrition and applied to all three malnutrition classifications, was retained as the point estimate. Sampling uncertainty was quantified by non-parametric bootstrap resampling (2000 resamples, percentile method); bootstrap was used only to obtain the 95% CI and did not replace the original point estimate. AUCs are presented with 95% CIs from the original ROC analyses. Age- and gender-specific values in cm are given in Table 8

Table 8. Age and gender-specific calf circumference cut-off values (cm) with 95% confidence intervals					
Gender	**Age group**	**Age (months)**	**n**	**Obesity cut-off, cm (95% CI)**	**Malnutrition cut-off, cm (95% CI)**
Female	1	12-23	24	20.5 (20.1-21.6)	19.0 (18.2-19.1)
Female	2	24-35	20	20.6 (20.3-21.5)	19.3 (18.7-19.5)
Female	3	36-47	22	22.5 (22.0-23.9)	20.5 (19.5-20.7)
Female	4	48-59	42	23.2 (22.6-24.8)	21.1 (20.0-21.3)
Male	1	12-23	25	20.7 (20.3-22.1)	18.9 (18.0-19.2)
Male	2	24-35	21	21.2 (20.8-22.4)	19.7 (18.9-19.8)
Male	3	36-47	25	22.4 (21.8-23.9)	20.3 (19.2-20.5)
Male	4	48-59	31	22.2 (21.9-23.3)	20.8 (20.0-20.9)
Values are the previously reported cm cut-off point estimates with bootstrap 95% confidence intervals (CIs). The original point cut-offs were retained unchanged. Only the 95% CI limits were obtained by back-transforming the bootstrap Z-score confidence limits (Tables 6 and 7) using the gender- and age-group-specific sample mean and standard deviation of calf circumference (cm = mean + z × standard deviation). Obesity: calf circumference ≥ value; malnutrition: calf circumference ≤ value. These values are preliminary and require validation in independent samples					

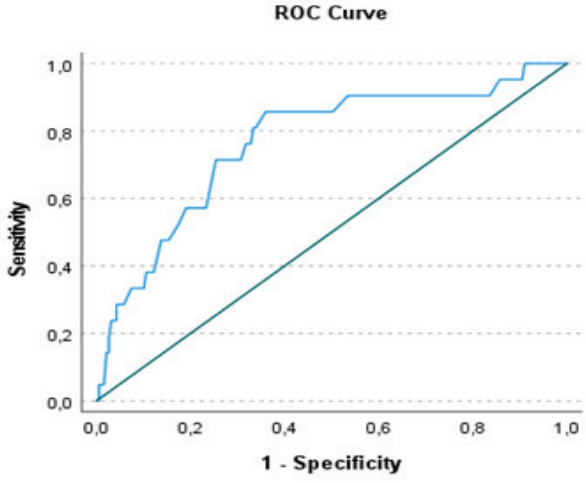


Figure 3. ROC curve according to MUAC Z-score

ROC: Receiver operating characteristic, MUAC: Mid-upper arm circumference

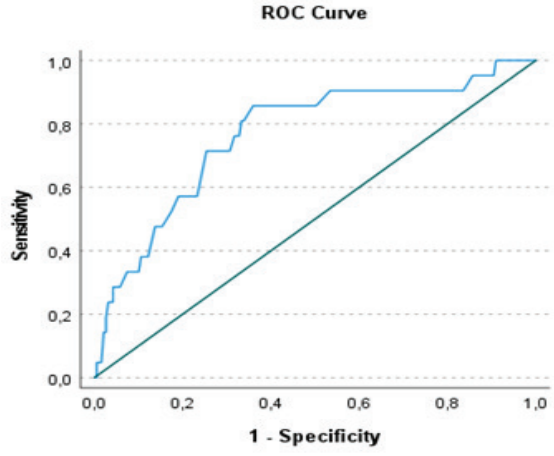


Figure 4. ROC curve according to WFH malnutrition classification

ROC: Receiver operating characteristic, WFH: Weight-for-height

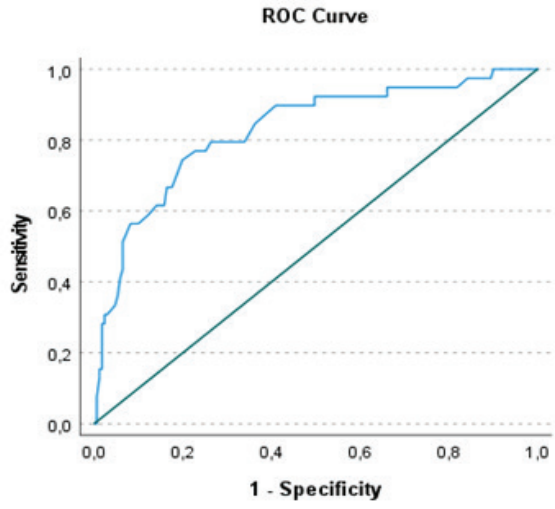


Figure 5. ROC curve according to WAG malnutrition classification

ROC: Receiver operating characteristic, WAG malnutrition classification: Waterlow, Aliar, and Gomez malnutrition classification

Each 1-SD decrease in calf circumference Z-score was associated with 14.7-fold (95% CI 5.7-38.3), 2.7-fold (Firth; 1.5-4.9) and 5.4-fold (2.9-10.3) higher odds of malnutrition according to the MUAC Z-scores, WFH and WAG classifications, respectively, and each 1-SD increase with 3.5-fold (Firth; 2.0-6.1) and 4.6-fold (2.6-8.2) higher odds of obesity according to the WFH and BMI classifications. Sensitivity analyses using alternative estimation methods yielded broadly comparable estimates, with no changes in the direction or statistical significance of the associations (Supplementary Table S1). Among the covariates, older age was associated with higher odds of MUAC-defined malnutrition and of both obesity outcomes (OR 1.04-1.05 per month), while boys had lower odds of BMI-defined obesity than girls (OR 0.29, 95% CI 0.10-0.86),

Table 9. Crude and adjusted odds ratios for malnutrition and obesity per 1-SD change in calf circumference Z-scores: multivariable logistic regression (n=210)

	MUAC Z-score malnutrition	WFH malnutrition	WAG malnutrition	WFH obese	BMI obese
Crude OR (CC Z-score)	11.70 (5.11-26.76)	3.11 (1.68-5.77)	5.34 (2.90-9.86)	3.30 (1.95-5.56)	3.87 (2.32-6.46)
p	<0.001	<0.001	<0.001	<0.001	<0.001
Adjusted OR (CC Z-score)	14.74 (5.67-38.31)	2.66 (1.45-4.86)	5.43 (2.87-10.28)	3.51 (2.00-6.13)	4.61 (2.60-8.16)
p	<0.001	0.002	<0.001	<0.001	<0.001
Male sex (vs. female)	2.19 (0.84-5.69)	1.16 (0.45-2.97)	1.97 (0.86-4.52)	0.34 (0.10-1.16)	0.29 (0.10-0.86)
p	0.107	0.758	0.110	0.085	0.026
Age (per month)	1.04 (1.00-1.08)	0.99 (0.96-1.03)	1.01 (0.98-1.04)	1.05 (1.00-1.09)	1.04 (1.00-1.08)
p	0.028	0.752	0.438	0.036	0.037
District setting (vs. city centre)	1.29 (0.46-3.60)	3.42 (1.12-10.44)	1.16 (0.47-2.82)	0.78 (0.24-2.48)	0.93 (0.33-2.58)
p	0.627	0.031	0.748	0.671	0.886
Maternal education ≥ secondary (vs. ≤ primary)	1.14 (0.36-3.61)	2.55 (0.71-9.14)	1.08 (0.41-2.84)	1.91 (0.48-7.68)	1.58 (0.47-5.35)
p	0.829	0.152	0.884	0.360	0.460
Income below expenses (vs. otherwise)	1.96 (0.72-5.34)	1.33 (0.44-4.00)	2.45 (1.01-5.95)	1.24 (0.35-4.33)	0.68 (0.20-2.35)
p	0.190	0.611	0.047	0.737	0.542
Breastfeeding duration (per month)	0.99 (0.93-1.06)	1.01 (0.95-1.07)	1.02 (0.97-1.07)	0.96 (0.89-1.03)	0.96 (0.90-1.02)
p	0.809	0.801	0.498	0.232	0.207
Events/n	36/210	21/210	39/210	17/210	27/210
Estimation	ML	Firth	ML	Firth	ML
Pseudo R^2 (McFadden)	0.393	–	0.260	–	0.307
Hosmer-Lemeshow p	0.014	–	0.038	–	0.371

Values are OR (95% CI). The calf circumference Z-score is expressed per 1-SD decrease for malnutrition outcomes and per 1-SD increase for obesity outcomes. Adjusted models include all covariates listed. ML: maximum likelihood; Firth: Firth's penalised-likelihood estimation, used as the primary analysis for the two WFH-defined outcomes because of the small number of events (ML estimates for these outcomes: WFH malnutrition OR 2.90 (1.53-5.48); WFH obese OR 4.12 (2.22-7.65); Firth estimates for the other outcomes: 11.69 (4.78-28.56), 4.82 (2.62-8.86), 3.99 (2.35-6.78). Obesity defined by MUAC Z-score (7 events) was not modelled multivariably (crude OR 8.18; 95% CI 2.96-22.64). Variance inflation factors for all covariates <1.2

and income levels below expenses were associated with WAG-defined malnutrition (OR 2.45, 95% CI 1.01-5.95). Children recruited in the district had 3.4-fold higher odds of WFH-defined malnutrition than those recruited in the city centre (95% CI 1.12-10.44), whereas study setting was not associated with the other outcomes. Adding preterm birth to the models did not change the calf circumference estimates (adjusted OR 16.1, 3.0, 5.7, 4.1 and 4.6 in the same order), and preterm birth itself was not significantly associated with any outcome. Among the maximum-likelihood malnutrition models, since the Hosmer-Lemeshow test suggested imperfect calibration for MUAC-defined malnutrition (p=0.014) and WAG-defined malnutrition (p=0.038), these models were therefore interpreted cautiously. The direction and magnitude of the association of the calf circumference with malnutrition were nonetheless stable across all model specifications. Variance inflation factors were below 1.2 for all covariates.

DISCUSSION

The WHO and the Pan American Health Organization recommend that infants be exclusively breastfed for the first 6 months of life and that breastfeeding must continue with complementary feeding for at least 24 months[6]. Based on our study conducted in a city centre and surrounding districts, the average duration of breastfeeding (14.6±8.46 months) was slightly shorter than that reported from Türkiye and the Western Anatolia Region. However, the high standard deviation (±8.46 months) in our breastfeeding duration data indicates considerable variability among individuals which suggests that some mothers breastfeed for a very short period, while others do so for the recommended duration. This variation is likely related to factors such as education levels of mothers, workforce participation, access to healthcare services, and cultural influences. In our study, the stunting

rate (HFA in Waterlow classification) was 17.6%. This stunting rate is below that (22.3%) reported globally by UNICEF, WHO, and the World Bank Group for 2022 in children under 5 years of age, but significantly higher than that (6%) reported in the TNSA-2018 data for Türkiye. The stunting rate of 17.6% falls within the mild malnutrition range, with values close to normal. These findings indicate that chronic malnutrition rate among children in the Manisa Region exceeds the national average but is comparable to that of some other regions in the country. In our study, the underweight rate, as defined by WHO, was 10% and was also classified as mild malnutrition, with some values near the normal threshold. This rate exceeds the global average (6.8%) and the Turkish average (2%) for children under 5 years of age. This phenomenon suggests that acute malnutrition is also at a level warranting attention in Manisa, and that regional nutrition programs should address not only chronic but also acute nutritional deficiencies[4,7].

Malnutrition and related risk factors in children have been assessed using various parameters including but not limited to standard anthropometric measurements such as body weight, height and their percentiles, BMI, waist, head, and arm circumferences. Other measurable parameters include total body water, fat mass, triceps skinfold thickness, calf circumference, Z-scores, and biochemical markers such as hemoglobin, ferritin, and albumin[8,9]. In our study, the agreement among measures such as weight-for-age, WFH, HFA, BMI, and the MUAC Z-scores in detecting malnutrition in children under 5 years of age was evaluated. The results showed that all kappa agreement analyses between these indicators were statistically significant. A moderate level of agreement was observed between WFH and MUAC Z-scores, suggesting that both measurements complement each other in identifying malnutrition. A stronger agreement was found between the MUAC Z-scores and WAG which supports the assumption that the MUAC measurement is a reliable indicator, particularly in diagnosing nutritional deficiencies. The study by Abdel-Rahman et al.[10] also indicated that MUAC measurement was superior to BMI and WFH for predicting malnutrition-related morbidity and mortality. Additionally, the fact that this method is cost-effective, practical, and easily applicable for healthcare professionals to perform enhances its value. Likewise, in a study conducted by Zaba et al.[11] in Mozambique with children aged 6-59 months, a reasonable agreement was observed between the MUAC z-scores and WFH indices[10]. The higher level of agreement in our study may be due to meticulous measurements conducted under field conditions. Overall, the strong correlation between MUAC Z-scores and WFH indices in our findings supports the broader use of MUAC Z-scores in screening programs.

Recent studies have indicated that measuring calf circumferences may be useful in assessing nutritional status in children. However, reference ranges for calf circumferences in children have not yet been established. Vieira and Zamberlan[5] reported that calf circumferences correlates with MUACs during nutritional assessments in pediatric intensive care patients and that this measurement can detect early changes in nutritional status, especially in children. Similarly, a study by Taha et al.[12] on infants and children managed in intensive care units revealed a significant correlation among changes in calf circumferences, MUACs, and weight during hospitalization, highlighting the usefulness of these anthropometric measurements in clinical monitoring. In a study on children and adolescents with malignancies Ferretti et al.[13] stated that calf circumference is a simple, easy-to-apply, and independent anthropometric measure for predicting malnutrition. They also proposed calf circumference thresholds by age and gender to identify malnutrition (boys: 0-1 years: ≤17.2 cm; 2-5 years: ≤18.8 cm; girls: 0-1 years: ≤15.4 cm; 2-5 years: ≤18.9 cm). In our study, calf circumference was found to be a significant factor in differentiating between malnutrition and obesity. The sensitivity and specificity of MUAC Z-scores for diagnosing malnutrition were 86.1% and 81.6%, respectively. In comparison, sensitivity and specificity above 70% were observed when WFH and WAG classifications were used (for boys: 1 year: 18.9 cm, 2 years: 19.7 cm, 3 years: 20.3 cm, 4 years: 20.8 cm; for girls: 1 year: 19 cm, 2 years: 19.3 cm, 3 years: 20.5 cm, 4 years: 21.1 cm). Cut-off values for detecting obesity using the WFH classification demonstrated 76.5% sensitivity and 79.3% specificity, while BMI classification indicated 74.1% sensitivity and 82% specificity for diagnosing malnutrition (for boys: 1 year: 20.7 cm, 2 years: 21.2 cm, 3 years: 22.4 cm, 4 years: 22.2 cm; for girls: 1 year: 20.5 cm, 2 years: 20.6 cm, 3 years: 22.5 cm, 4 years: 23.2 cm).

Study Limitations

Some limitations of this study should be acknowledged. First, its cross-sectional design precludes any inference about the predictive value of calf circumference for subsequent growth and developmental outcomes. Therefore, longitudinal studies are needed to establish whether changes in calf circumference anticipate changes in nutritional status. Second, since the sample was drawn from a single region, the prevalence of stunting and underweight was higher than the national estimates.

Half of the children were recruited in a district family health centre serving a predominantly lower-income population. Indeed, 27% of families reported an income level below their expenses and 28% of mothers had primary education or less. In the multivariable analysis, district recruitment was independently associated with WFH-defined malnutrition (adjusted OR 3.4; Table 9). Children attending primary care units may also differ from the general population regarding healthcare-seeking behaviours, and the percentage-of-median classifications used herein verified that a larger proportion of children was mildly malnourished according to Z-score-based standards. Since cut-off values were derived from calf circumference Z-scores and the association with nutritional status persisted after adjustment for study setting and socio-economic factors which might have distorted the diagnostic estimates, selection bias cannot be excluded, and our prevalence estimates should not be generalised to the Turkish preschool population. Third, although the cut-off values were estimated for the whole sample using age- and gender-standardised Z-scores, only small number of children were classified as obese or malnourished, and the bootstrap CIs of the cut-off values were correspondingly wide. Besides, the number of events also limited the number of covariates that could be included in the regression models. Fourth, the cut-off values have not been externally validated. Fifth, body composition was not measured, so the physiological basis of the differences between calf and MUACs, and the reasons for the heterogeneous agreement between the anthropometric indices (κ=0.317 to 0.757), could not be examined in this study and remain to be clarified. The proposed thresholds should therefore be regarded as preliminary, exploratory values rather than definitive reference standards, and they require validation in independent and larger populations before being recommended for routine use.

CONCLUSION

Most studies assessing nutritional status cited in the literature in children using calf circumference have been conducted among hospitalised children, particularly those with oncological diseases. Our study has focused on healthy children aged 1-5 years who visited primary care units without any chronic illnesses. As a result, the cut-off values for calf circumference we established were higher than those reported in hospital-based studies. Family medicine practices are evaluated within the context of low-prevalence medicine; that is, environments where serious illnesses are uncommon, but many healthy individuals are monitored. Therefore, our findings reflect a predominantly healthy primary care population. Since, our findings pertain to a pediatric population selected from a single region, they should be regarded as preliminary reference points rather than definitive standards.

Our study suggests that measurement of calf circumferences is a practical adjunctive anthropometric tool for assessing both malnutrition and obesity among preschool children. It proposes preliminary age- and gender-specific cut-off values which, once validated in independent populations, could be integrated into routine growth monitoring in family health centres and community screening programmes, for example, as a rapid tape-measure screen at well-child visits, prompting a full anthropometric assessment and referral to the appropriate specialist when body mass indices of a child falls below the malnutrition or above the obesity threshold. Because the measurement requires only a non-stretch tape and can be performed in a few seconds, it is particularly suited to settings where scales or stadiometers are unavailable or where a child cannot be weighed or his/her height can not be measured reliably.

Ethics

Ethics Committee Approval: This study was approved by the Institutional Ethics Committee of Manisa Celal Bayar University (approval no.: 20.478.486/2070, date: 11/08/2023).

Informed Consent: Written informed consent was obtained from parents or legal guardians of the children before measurements were taken.

Declaration of AI Use: No artificial intelligence tools were used in the preparation of this manuscript.

Footnotes

Author Contributions

Surgical and Medical Practices: Z.B.K., H.C., H.E., Concept: Z.B.K., H.C., H.E., Design: Z.B.K., H.C., H.E., Data Collection or Processing: Z.B.K., H.C., Analysis or Interpretation: Z.B.K., H.C., I.T., H.E., F.Ö., Literature Search: Z.B.K., H.C., T.B., Writing: Z.B.K., H.C., T.B.

Conflict of Interest: No conflict of interest was declared by the authors.

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Supplementary Table S1: https://d2v96fxpocvxx.cloudfront.net/bd1986e1-0bc1-4f4d-af66-3a184850a065/content-images/165f58b9-e121-45e7-9a4a-fe8c9836ffb7.pdf

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