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Assessment of Body Composition and Nutritional Status Utilizing Upper Arm Anthropometry and Its Determinants among Preschool Children of West Bengal, India

Arindam Biswas† Argina Khatun‡ Nitish Mondal§*

Abstract

Body composition is closely linked to nutritional status, dietary habits, physical activity, sex, and the prevalence of disease. Poor body composition and low nutritional status can increase morbidity and reduce the capacity for physical activity and performance. Upper arm anthropometry has the potential to estimate body composition and nutritional assessment in children and adults. The present cross-sectional study was undertaken among 1122 children (570 boys, 552 girls) aged 24-71 months in Maynaguri Block, Jalpaiguri District, West Bengal, India. The present study aimed to assess body composition and nutritional condition by upper arm muscle area by height (UAMAH). Anthropometric and skinfold measurements were used to assess upper arm body composition by utilizing the standard methods developed by Frisancho (1981, 1990). Most of the anthropometric and body composition variables showed significant age-related variation. Overall, the prevalence of UAMAH-defined wasting was 48.13 percent (52.63 percent in boys, 43.48 percent in girls). Age- and sex-specific comparison with the National Health Statistics Report showed that mean height, weight, and BMI are lower than the reference values. Body composition and nutritional status of these children were found to be unsatisfactory. Most of the socio-economic and demographic variables were significantly associated with low UAMAH (i.e., wasting). Binary logistic regression showed that boys are at greater risk of wasting than girls. Ethnicity, type of delivery, birth weight of child, number of rooms, fuel for cooking, type of bath place, monthly family income, and maternal BMI all were statistically related to wasting. The combined use of upper arm anthropometry and conventionally used anthropometric measures appears to be a useful tool for assessing body composition and nutritional status.

Keywords: Anthropometry, Body composition, Nutritional assessment, Preschool children, Upper arm muscle area for height

1 Introduction

Assessing body composition utilizing anthropometric measurements is a vital method in epidemiological and clinical investigations (Addo et al., 2017; Debnath et al., 2017; Dutta & Sengupta, 2023; Lambebo et al., 2023; Muñoz Esparza et al., 2019; Ngaboyeka et al., 2025; Nwankwo et al., 2024; Oyhenart et al., 2019; Yavuz & Özer, 2020). Body composition is closely linked to nutritional status, dietary habits, physical activity, sex, and the prevalence of disease (Oukheda et al., 2023; Pelc et al., 2024; Sen & Mondal, 2013; Thibault & Pichard, 2012). Poor body composition and inadequate nutritional status can increase morbidity and lead to decreased physical activity and performance (Manikandan et al., 2024; Oukheda et al., 2023; Sen et al., 2015; Thibault & Pichard, 2012; Thibault et al., 2012). The assessment of body composition provides a relative estimation of changes in muscle mass and adiposity due to environmental influences, early diseases, and nutritional status during childhood (Debnath et al., 2017; Dutta & Sengupta, 2023;

† Research Scholar (NET-SRF), Department of Anthropology, University of North Bengal. rs_arindamb@nbu.ac.in
‡ Assistant Professor, Department of Anthropology, University of North Bengal. argina.khatun@nbu.ac.in
§ Professor, Department of Anthropology, School of Human Sciences, Sikkim University. nmondal@cus.ac.in
* Corresponding author, email: nmondal@cus.ac.in

Holmes & Racette, 2021). The BMI centile characterizes children's adiposity but fails to quantify body mass components (Chainoglou et al., 2025; Cole et al., 2005), but upper arm muscle area (UMA) denotes muscularity and body protein reserves, whereas upper arm fat area (UFA) represents adiposity and calorie reserves (Debnath et al., 2017; Dutta & Sengupta, 2023; Senbanjo et al., 2014). Body composition and nutritional status are affected by socio-economic variables (Ayele et al., 2022; Cheruiyot, 2024; Sen et al., 2011, 2015; Sen & Mondal, 2013; Singh & Mondal, 2014).

Several recommended methods are available for measuring body composition, including underwater weighing, air displacement plethysmography, bioelectrical impedance analysis (BIA), and dual-energy X-ray absorptiometry (DEXA) (Kontogianni et al., 2005; Sala et al., 2007; Sun et al., 2003; Thomas et al., 2025; Wells, 2010; Zemel, 2021).

Dual-energy X-ray absorptiometry in the four-compartment model estimates body composition and can be used for adiposity and leanness estimation (Cherian et al., 2021). The BIA scale is found to be relatively inaccurate in bone mineral content compared to DEXA (Lee et al., 2020). Researchers often used BIA in combination with DEXA to improve accuracy or validation and to avoid the logistical challenges for assessment of body composition argued by scholars (Dumitriu et al., 2025; Manole et al., 2025; Stone et al., 2018). BIA-derived mineral content in place of DEXA can be used in multi-compartment models in which DEXA also estimates whole-body skeletal muscle mass based on lean tissue measures (Messina et al., 2020; Nickerson & Tinsley, 2018). To assess body composition, the 3D body scanners use digital images to estimate volume, size, and circumference in various anatomical locations (Balasubramanian & Sheykhmaleki, 2025; Tinsley et al., 2020). Fat-free mass is calculated from the measurement of total body water (TBW) using the hydration factors. This is considered a safe, effective, and non-invasive means of measuring the size of the total body water pool in infants and children (Zemel, 2021). The H_2O overestimates TBW by about 4%, and O^{18} overestimates TBW by about 1%. While advanced techniques such as DEXA, BIA, TBW, and 3D body scanning provide accurate and detailed assessments of body composition, their use is limited by high cost, technical complexity, and lack of portability. In contrast, anthropometric methods are low-cost, non-invasive, and feasible for large-scale field use, making them the preferred approach for screening undernutrition and assessing body composition in low-resource and community settings (Nwankwo et al., 2024; Puttaswamy et al., 2024).

Anthropometric measures are widely used to estimate whole-body fat-free mass, fat mass as a percent of body mass, and upper arm composition (Zemel, 2021). However, measuring skinfold thickness remains a widely accepted, simple, reliable, and cost-effective method for evaluating nutrition in children (Kalami et al., 2022; Kriemler et al., 2010; Rahman et al., 2024; van Beijsterveldt et al., 2023). Muscularity and adiposity can be indirectly assessed through skinfold thickness, body mass index (BMI), and circumference measurements (Frisancho, 1990; Malik et al., 2023; Sen & Mondal, 2013; Wells, 2010). Research suggests that skinfold measurements in children may be superior to BMI as predictors of obesity and body fat (Kriemler et al., 2010; Nooyens et al., 2007; Puttaswamy et al., 2024; van Beijsterveldt et al., 2023; Zimmermann et al., 2004). Typically, the assessment of muscularity and adiposity is conducted using skinfold thickness and upper arm circumference measurements (Addo et al., 2017; Debnath et al., 2017; Dutta & Sengupta, 2023; Frisancho, 1981; Gibson, 2005; Muñoz Esparza et al., 2019; Nwankwo et al., 2024; Oyhenart et al., 2019; Taylor et al., 2010; Yavuz & Özer, 2020). Frisancho and Tracer (1987) conducted a study on 9,134 American children aged 2–17 years and developed means and percentiles for UMA based on height, using data from the National Health and Nutrition Examination Survey (NHANES 1971–1974 and NHANES 1976–1980). A study conducted on Egyptian children aged 2–17 years developed standards for upper arm muscle area on height (UAMAH) (Monir et al., 2008).

Upper arm anthropometry, including total upper arm area (TUA), UMA, UFA, arm fat index (AFI), and upper arm fat area estimate (UFE), is used to assess body composition. UFA provides a direct estimate of subcutaneous fat in the upper arm, reflecting adiposity. UFA and UFE allow comparison of fat stores across children of varying growth patterns depending on age, sex, and body size. Together with upper arm muscle area estimate (UME), these measurements are derived from mid-upper arm circumference (MUAC) and triceps skinfold (TSF) (Debnath et al., 2017; Frisancho, 1990; Wells, 2010).

Upper arm anthropometry has gained considerable attention over recent decades compared to traditional measurements (e.g., (Basu et al., 2010; Bolzan et al., 1999; Chowdhury & Ghosh, 2009; Dutta & Sengupta, 2023; Gültekin et al., 2006; Lipsberga & Kažoka, 2016; Monir et al., 2008; Nwankwo et al., 2024; Ozturk et al., 2009; Sen et al., 2011, 2015; Senbanjo et al., 2014; Singh & Mondal, 2014; Yavuz & Özer, 2020)), though it has not yet been routinely adopted to assess body composition and nutritional status. UMA and UFA were introduced as reliable measures of nutritional status for children in various community settings. Research has subsequently employed UMA and UFA to assess body composition and nutritional status of children (e.g., (Arps, 2023; Basu et al., 2010; Chowdhury & Ghosh, 2009; Çiçek et al., 2009; Erfan et al., 2003; Oyhenart et al., 2019; Sen et al., 2011, 2015; Sikdar, 2012; Singh & Mondal, 2014; Yavuz & Özer, 2020)).

Few studies exist regarding standard growth references for children concerning upper arm composition (Addo et al., 2017; Gültekin et al., 2006; Monir et al., 2008; Nwankwo et al., 2024; Oyhenart et al., 2019). UAMAH has been recognised as a relatively better and more reliable indicator for assessment of child nutritional status (Frisancho & Tracer, 1987) based on body composition compared to conventional indices such as BMI for age, because UAMAH is derived from MUAC and TSF, which reflect muscle mass and body composition, whereas BMI only reflects body weight relative to height (Debnath et al., 2017; Dutta & Sengupta, 2023). Some studies have reported on UAMAH-based nutritional assessments (Arps, 2023; Debnath et al., 2017; Dutta & Sengupta, 2023; Lipsberga & Kažoka, 2016; Singh & Mondal, 2014). Using these anthropometric measurements, several investigations have been conducted to assess body composition and undernutrition among children (Arps, 2023; Basu et al., 2010; Çiçek et al., 2014; Debnath et al., 2017; Dutta & Sengupta, 2023; Erfan et al., 2003; Gültekin et al., 2006; Lipsberga & Kažoka, 2016; Ozturk et al., 2009; Sen et al., 2015; Sikdar, 2012; Singh & Mondal, 2014).

Upper arm anthropometry is becoming increasingly used for nutritional assessment and body composition analysis. Traditionally, height, weight, MUAC, BMI, and skinfolds were utilized to assess nutritional status and body composition; however, Frisancho (1981) emphasized the importance of upper arm measurements. Body composition indicates muscle mass and adiposity variations caused by genetic or ethnic and environmental factors (Dutta & Sengupta, 2023; Kang et al., 2021; Paciência et al., 2021). Several studies reported the relationships of socio-economic and demographic factors with the prevalence of wasting (Harding et al., 2018; P. Khanra et al., 2020; Mishra & Bera, 2024; Mutua et al., 2017; Mutunga et al., 2020; Patil et al., 2017; Sen et al., 2011, 2020; Tigga et al., 2015; Wali et al., 2021). Few studies have been conducted on age- and sex-specific changes in body composition and standard growth references for preschool-age children based on upper arm anthropometry. Therefore, the aim and objective of this study was to evaluate age- and sex-specific body composition and nutritional status and their association with socio-economic and demographic factors among preschool children aged 2–5 years in Jalpaiguri, West Bengal, India, using upper arm composition.

2 Material and methods

The present cross-sectional study has been carried out among 1122 preschool children (570 boys and 552 girls) of three ethnicities, including Rajbanshi, Namasudra, and Nashyaseikh, aged 2–5 years. Data was collected from 48 Integrated Child Development Centers of the Maynaguri block, Jalpaiguri district, West Bengal, India. Children were selected by age, sex, and ethnicity based on the stratified sampling method. The study was conducted from 5^{th} August 2023 to 5^{th} April 2024. The participants were free from any physical deformities and not suffering from any disease at the time of examination.

The Rajbanshi, Namasudra, and Nashyaseikh communities constitute the predominant resident populations in the study area. Rajbanshis are an indigenous agrarian community traditionally engaged in agriculture and allied occupations. Namasudras are a Scheduled Caste community with diverse occupations, including agriculture, wage labour, and small-scale business. Nashyaseikhs are a socioeconomically disadvantaged Muslim community, primarily involved in agriculture, daily wage labour, and other informal occupations. These three communities together represent the majority of preschool children enrolled in the selected ICDS centres and therefore were considered appropriate for investigating body composition and nutritional status in the study area.

2.1 Data collection

All the necessary study approval was taken from the Child Development Project Officer (CDPO) of Maynaguri, and research permission was obtained from the University of North Bengal. All types of data were collected by the first author, AB.

Anthropometric measurements

The anthropometric measurements used in the present study were height, body weight, mid-upper arm circumference (MUAC), and triceps skinfold (TSF) measurements. All anthropometric measurements were taken following standard anthropometric techniques as proposed by Lohman et al. (1988). The heights of the subjects were recorded with the help of an anthropometer to the nearest 0.10 cm. The weight of the children wearing minimal clothing and with bare feet was recorded using a portable digital scale to the nearest 0.1 kg. MUAC was taken at the point midway between the acromion and the radial of the upper arm using a non-stretchable measuring tape on the left side to the nearest 0.10 cm. The skinfold measurement was done using a Holtain skinfold calliper calibrated on the left side of each subject to the nearest 0.2 mm.

Socio-economic and demographic data

Various socio-economic and demographic data, such as children's sex (boys & girls), age (2 years, 3 years, 4 years & 5 years), ethnicity (Rajbanshi, Namasudra & Nashyaseikh), type of delivery (vaginal – caesarean), birth weight (<2500 gm – $\geq$2500 gm), number of rooms in the household (1, 2, $\geq$3), fuel for cooking (wood, crop residue, LPG), house type (non-brick – brick), bathing place (open – closed), monthly family income (INR <7500, INR 7500-15000, INR >15000) and maternal BMI (<18.5 kg/m^2, 18.5-22.99 kg/m^2, >23 kg/m^2), were collected by a pre-tested questionnaire.

2.2 Data management and statistical analysis

Assessment of upper arm composition

Upper arm body composition was assessed utilizing the standard equations developed by Frisancho (1981, 1990) using MUAC and TSF.

$$TUA\ cm^2 = (MUAC)^2 / (4\times \pi)$$

$$UMA\ cm^2 = \{MUAC - (TSF\times\pi)\}^2/(4\times n)$$

$$UFA\ cm^2 = \{(MUAC)^2 / (4\times\pi)\} - UMA$$

$$AFI = UFA / \{(MUAC)^2 / (4\times\pi)\} \times 100$$

Using the anthropometric indices of the upper arm, anthropometric body composition was calculated using the formula developed by Rolland-Cachera et al. (1997).

$$UFE = MUAC \times (TSF/2)$$

$$UME = \{(MUAC)^2 / (4\times\pi)\} - UFE$$

Assessment of nutritional status

The prevalence of undernutrition was evaluated in terms of UAMAH using the classification based on Z-scores for UAMAH as developed by Frisancho and Tracer (1987) (Table 1).

Table 1: Classification of nutritional status based on UAMAH

Nutritional Status	UAMAH Percentile	UAMAH Category	Z-Score
Wasted	0–5.0	Category I	< -1.60
Below Average	5.1–15.0	Category II	-1.60 to -1.00
Average	15.1–85.0	Category III	-1.00 to +1.00
Above Average	85.1–95	Category IV	+1.00 to +1.60
High Muscle	95.1–100	Category V	$\geq$ +1.60

Statistical analysis

All statistical analyses were done on the Statistical Package for the Social Sciences (SPSS v. 18). One-way analysis of variance (ANOVA) was utilized to observe significant age variations. A t-test was performed between low birth weight (LBW) and normal birth weight child groups to observe sex- and age-specific differences based on birth weight. The Chi-square (χ^2) analysis, binary logistic regression (BLR), and multiple linear regression were performed to observe the associations of socio-economic and demographic variables with wasting measured as low UAMAH. The χ^2 analysis was employed to examine the unadjusted association between categorical socioeconomic and demographic variables and the prevalence of wasting (low UAMAH). The BLR was subsequently performed to estimate the independent effects of these variables on wasting (low UAMAH) while simultaneously controlling for the influence of other covariates. Multiple linear regression analysis was additionally conducted to evaluate the relative contribution of socioeconomic and demographic variables to UMA among studied children. A p-value of <0.05 was considered to be statistically significant.

3 Results

Table 2 shows the age- and sex-specific sample size, mean, and standard deviation (SD) values of height, weight, BMI, MUAC, and TSF and the derived body composition measurements of TUA, UMA, UFA, AFI, UFE, and UME among 24-71-month-old children. The mean height and weight of boys are significantly higher than those of girls. The mean height shows significant sex differences at all ages. TSF is slightly higher among girls than boys in most of the age groups. Mean weight, UMA, and UME show statistically significant sex differences in the age groups of 36-47 months and 48-59 months. The mean TSF, UFA, and UFE show significant sex differences only in the age group of 36-47 months. The mean BMI, MUAC, and TUA show significant sex differences only in the age group of 48-59 months, whereas AFI shows significant sex differences in the age groups of 36-47 and 60-71 months. F-tests showed that significant age variation was found in all anthropometric and body composition variables among boys and girls except for TSF and AFI, which show significant age variation only in the case of boys, but BMI shows significant age variation only in girls.

Table 3 presents age- and sex-specific descriptive statistics of anthropometric and body composition variables among children who have LBW. The t-test shows significant sex differences in mean height only in children aged 36-47 months. UMA shows sex differences at the age of 48-59 months in children. TSF, UFA, and UFE show significant sex differences in children aged 60-71 months. UME shows statistically significant sex differences in the age groups of 36-47 months and 48-59 months of children. The F-test shows that height, weight, and BMI show significant age variation among both sexes. MUAC, TUA, UMA, UFA, UFE, and UME signify the age variation only in girls. TSF and AFI show no significant age variation in both sexes.

Table 4 depicts the age- and sex-specific prevalence of wasting among children categorized by Frisancho and Tracer's (Frisancho & Tracer, 1987) classification based on UAMAH. The proportion of children belonging to the wasted category was found to be higher among boys than girls (<-1.60 z-score; 52.63% vs. 43.48%). However, the below-average category had about the same percentage of boys as girls (-1.60 to -1.00 z-score; 26.14% vs. 26.27%); the average category was more frequent among girls (-1.00 to

Table 2: Age- and sex-specific descriptive statistics (mean ± SD) of anthropometric and body composition variables among the studied preschool children

Variable	Sex	N	24-35 months	36-47 months	48-59 months	60-71 months	*F*-value
			B-105; G-90	B-153; G-157	B-167; G-191	B-145; G-114	
Height (cm)	Boys	570	89.42 (3.72)	94.19 (4.28)	101.65 (4.96)	108.57 (5.26)	422.59***
	Girls	552	88.15 (2.87)	92.28 (4.37)	99.98 (5.05)	106.73 (6.33)	320.51***
	t-value		2.69*	3.89***	3.14**	2.49*	
Weight (kg)	Boys	570	12.08 (1.70)	13.09 (1.65)	15.24 (2.94)	17.36 (3.36)	108.80***
	Girls	552	12.02 (1.70)	12.51 (1.77)	14.29 (2.26)	16.78 (3.57)	92.21***
	t-value		0.27	2.98**	3.39***	1.32	
BMI (kg/m^2)	Boys	570	15.08 (1.56)	14.74 (1.46)	14.67 (1.89)	14.62 (1.89)	1.61
	Girls	552	14.43 (1.78)	14.67 (1.65)	14.25 (1.57)	14.61 (1.87)	9.91***
	t-value		-1.48	0.39	2.27*	0.69	243.68
TSF (mm)	Boys	570	7.43 (1.57)	7.31 (1.57)	8.14 (3.19)	7.56 (2.74)	3.55*
	Girls	552	7.82 (2.42)	7.88 (2.24)	8.05 (2.14)	8.17 (2.64)	0.54
	t-value		-1.29	-2.61*	0.30	-1.80	
MUAC (cm)	Boys	570	14.01 (1.16)	14.09 (0.93)	14.80 (5.59)	15.14 (1.69)	21.08***
	Girls	552	14.07 (1.16)	14.04 (1.26)	14.40 (1.20)	15.17 (1.71)	17.96***
	t-value		-0.37	0.33	2.63*	-0.15	
TUA (cm^2)	Boys	570	15.74 (2.70)	15.86 (2.10)	17.64 (4.22)	18.47 (4.54)	19.07***
	Girls	552	15.88 (2.75)	15.83 (2.94)	16.63 (2.90)	18.55 (4.63)	17.18***
	t-value		-0.36	0.12	2.60**	-0.142	
UMA (cm^2)	Boys	570	10.92 (1.69)	11.10 (1.26)	11.99 (1.72)	13.05 (2.34)	40.36***
	Girls	552	10.79 (1.48)	10.71 (1.69)	11.29 (1.80)	12.74 (2.35)	30.06***
	t-value		0.53	2.25*	3.75***	1.10	
UFA (cm^2)	Boys	570	4.81 (1.34)	4.76 (1.21)	5.34 (2.98)	5.41 (2.64)	5.49***
	Girls	552	5.08 (1.90)	5.11 (1.81)	5.60 (1.77)	5.81 (2.62)	3.23*
	t-value		-1.09	-1.98*	1.18	-1.21	
AFI	Boys	570	30.36 (4.34)	29.73 (4.62)	30.82 (7.02)	28.34 (6.19)	5.14**
	Girls	552	31.38 (6.78)	31.77 (5.98)	31.76 (5.69)	30.43 (5.83)	1.41
	t-value		-1.23	-3.36***	-1.38	-2.80*	
UFE (cm^2)	Boys	570	5.27 (1.66)	5.20 (1.41)	6.25 (3.61)	5.92 (3.10)	5.24***
	Girls	552	5.60 (2.28)	5.64 (2.16)	5.88 (2.14)	6.39 (3.06)	2.63*
	t-value		-1.17	-2.12*	1.14	-1.22	
UME (cm^2)	Boys	570	10.46 (1.62)	10.66 (1.23)	11.39 (1.50)	12.54 (2.14)	44.39***
	Girls	552	10.27 (1.47)	10.18 (1.64)	10.74 (1.79)	12.16 (2.10)	31.17***
	t-value		0.87	2.85***	3.69***	1.464	

* $p < .05$, ** $p < .01$, *** $p < .001$

Note. BMI = body mass index; TSF = triceps skin fold; MUAC = mid upper arm circumference; TUA = total upper arm area; UMA = upper arm muscle area; UFA = upper arm fat area; AFI = arm fat index; UFE = upper arm fat estimate; UME = upper arm muscle estimates.

Table 3: Age- and sex-specific descriptive statistics (mean ± SD) of anthropometric and body composition variables among children having LBW (<2.50 kg).

Variables	Sex	N	24-35 months B- 23; G- 17	36-47 months B- 44; G- 49	48-59 months B- 29; G- 56	60-71 months B- 16; G- 21	F
Height (cm)	Boys	112	89.46 (3.91)	92.38 (4.02)	99.33 (5.66)	104.13 (6.02)	41.79***
	Girls	143	88.60 (3.18)	90.06 (4.41)	97.18 (4.91)	107.45 (7.99)	67.63***
	t-value		0.77	2.65**	1.73	-1.44	
Weight (kg)	Boys	112	11.99 (1.64)	12.67 (1.43)	13.86 (1.90)	15.03 (2.61)	11.49***
	Girls	143	12.13 (1.37)	12.25 (1.81)	13.13 (1.47)	17.57 (5.57)	22.95***
	t-value		-0.29	1.23	1.79	-1.84	
BMI (kg/m^2)	Boys	112	14.98 (1.93)	14.87 (1.64)	14.00 (1.13)	13.73 (1.07)	3.95*
	Girls	143	15.44 (1.55)	15.07 (1.56)	13.92 (1.44)	14.88 (2.56)	5.72***
	t-value		-0.84	-0.60	0.28	-1.85	
TSF (mm)	Boys	112	7.45 (1.07)	7.80 (1.88)	7.50 (2.29)	7.30 (1.53)	0.41
	Girls	143	7.97 (1.76)	8.28 (2.29)	7.89 (1.43)	9.06 (3.48)	1.56
	t-value		-1.09	-1.10	-0.85	-2.08*	
MUAC (cm)	Boys	112	13.82 (0.91)	14.19 (0.96)	14.20 (1.11)	14.38 (1.03)	1.17
	Girls	143	14.04 (0.80)	14.08 (1.27)	13.81 (0.77)	15.24 (2.08)	7.09***
	t-value		-0.82	0.46	1.69	-1.64	
TUA (cm^2)	Boys	112	15.26 (1.99)	16.09 (2.26)	16.15 (2.60)	16.55 (2.39)	1.14
	Girls	143	15.75 (1.83)	15.91 (3.00)	15.24 (1.75)	18.83 (5.39)	7.55***
	t-value		-0.80	0.34	1.71	-1.73	
UMA (cm^2)	Boys	112	10.53 (1.42)	10.99 (1.21)	11.22 (1.52)	11.70 (1.69)	2.32
	Girls	143	10.64 (1.44)	10.53 (1.38)	10.28 (1.53)	12.33 (2.26)	8.71***
	t-value		-0.24	1.72	2.71*	-0.97	
UFA (cm^2)	Boys	112	4.73 (0.82)	5.10 (1.48)	4.93 (1.80)	4.85 (1.18)	0.37
	Girls	143	5.10 (1.22)	5.37 (1.94)	4.96 (0.92)	6.50 (3.32)	3.65*
	t-value		-1.09	-0.77	-0.08	-2.10*	
AFI	Boys	112	30.93 (3.37)	31.27 (5.35)	30.03 (6.08)	29.21 (5.04)	0.78
	Girls	143	32.33 (6.00)	33.09 (5.40)	32.60 (5.20)	32.87 (7.39)	0.10
	t-value		-0.86	-1.63	-1.94	-1.79	
UFE (cm^2)	Boys	112	5.17 (0.94)	5.60 (1.74)	5.41 (2.18)	5.28 (1.36)	0.37
	Girls	143	5.62 (1.43)	5.95 (2.32)	5.46 (1.09)	7.23 (3.89)	3.46*
	t-value		-1.13	-0.82	-0.12	-2.13*	
UME (cm^2)	Boys	112	10.09 (1.40)	10.48 (1.16)	10.74 (1.54)	11.26 (1.68)	2.41
	Girls	143	10.12 (1.51)	9.95 (1.24)	9.77 (1.60)	11.59 (1.81)	7.79***
	t-value		-0.07	2.14*	2.71*	-0.57	

* $p < .05$, ** $p < .01$, *** $p < .001$

Note. Abbreviations: BMI = body mass index; TSF = triceps skinfold; MUAC = mid-upper arm circumference; TUA = total upper arm area; UMA = upper arm muscle area; UFA = upper arm fat area; AFI = arm fat index; UFE = upper arm fat estimate; UME = upper arm muscle estimate.

1.00 z-score; 20.88% vs. 29.89%); and very few boys and girls (1.00 to 1.60 z-score; 0.35% vs. 0.36%) were in the above-average category. The prevalence of wasting was highest (62.07%) at 60-71 months and lowest (30.48%) at 24-35 months among boys. Among girls, however, the prevalence of wasting was the highest (50.78%) at 48-59 months and lowest (26.67%) at 24-35 months. Chi-square analysis shows significant categorical variation in prevalence or distribution of wasting across different age groups among boys (χ^2=37.47; p<0.001) as well as girls (χ^2=22.54; p<0.01).

Table 4: Prevalence of undernutrition (wasting) using UAMAH among studied children

Age (months)	N	Wasted (< -1.60 z-score)	Below average (-1.60 to -1.00)	Average (-1.00 to 1.00)	Above average (1.00 to 1.60)
	Boys				
24–35	105	32 (30.48)	41 (39.04)	32 (30.48)	0
36–47	153	77 (50.33)	44 (28.76)	32 (20.91)	0
48–59	167	101 (60.49)	36 (21.55)	30 (17.96)	0
60–71	145	90 (62.07)	28 (19.31)	25 (17.24)	2 (1.38)
24–71	570	300 (52.63)	149 (26.14)	119 (20.88)	2 (0.35)
χ^2	37.47*** d.f., 9				
	Girls				
24–35	90	24 (26.67)	31 (34.44)	35 (38.89)	0
36–47	157	70 (44.59)	42 (26.75)	45 (28.66)	0
48–59	191	97 (50.78)	44 (23.04)	50 (26.18)	0
60–71	114	49 (42.98)	28 (24.57)	35 (30.70)	2 (1.75)
24–71	552	240 (43.48)	145 (26.27)	165 (29.89)	2 (0.36)
χ^2	22.54** d.f., 9				

** $p < .01$, *** $p < .001$

Table 5 depicts age- and sex-specific bivariate correlations in all the anthropometric and body composition variables that are statistically significantly correlated. There is no statistically significant correlation of height with BMI and AFI among boys, and of height with BMI and AFI, as well as AFI with UMA, in girls.

Table 7 presents multiple linear regression analysis in which UMA, a continuous dependent variable, was predicted from selected socioeconomic and demographic variables. Factors like sex, age, ethnicity, type of delivery, birth weight of child, fuel for cooking, house type, monthly family income, and maternal BMI showed significant association with UMA. Among these, age showed the strongest positive association (β = 0.403), followed by birth weight (β = 0.171) and monthly family income (β = 0.134). Whereas the number of living rooms and bath places was found as a not significant factor of UMA among studied children.

Table 5: Age and sex combined bivariate correlation of all anthropometric and body composition variables

Variables	HT	WT	BMI	TSF	MUAC	TUA	UMA	UFA	AFI	UFE	UME
Boys											
HT	1	.803**	-.035	.150**	.472**	.461**	.583**	.256**	-.064	.246**	.583**
WT	.803**	1	.612**	.563**	.829**	.833**	.806**	.678**	.301**	.668**	.724**
BMI	.035	.612**	1	.714**	.759**	.768**	.585**	.761**	.563**	.755**	.460**
TSF	.150**	.563**	.714**	1	.791**	.808**	.411**	.978**	.932**	.979**	.209**
MUAC	.472**	.829**	.759**	.791**	1	.995**	.881**	.879**	.548**	.866**	.761**
TUA	.461**	.833**	.768**	.808**	.995**	1	.865**	.902**	.561**	.891**	.738**
UMA	.583**	.806**	.585**	.411**	.881**	.865**	1	.563**	-.100*	.543**	.976**
UFA	.256**	.678**	.761**	.978**	.879**	.902**	.563**	1	.837**	.999**	.371**
AFI	-.064	.301**	.563**	.932**	.548**	.561**	.100*	.837**	1	.841**	-.096*
UFE	.246**	.668**	.755**	.979**	.866*	.891**	.543**	.999**	.841**	1	.347**
UME	.583**	.724**	.460**	.139**	.759**	.736**	.976**	.371**	-.096*	.347**	1
Girls											
HT	1	.793**	-.055	.147**	.441**	.432**	.500**	.247**	-.021	.232**	.491**
WT	.793**	1	.550**	.532**	.815**	.819**	.747**	.666**	.266**	.651**	.666**
BMI	-.055	.550**	1	.673**	.743**	.749**	.544**	.746**	.469**	.742**	.426**
TSF	.147**	.532**	.673**	1	.711**	.724**	.276**	.968**	.926**	.974**	.091*
MUAC	.441**	.815**	.743**	.711**	1	.995**	.870**	.846**	.418**	.829**	.762**
TUA	.432**	.819**	.749**	.724**	.995**	1	.860**	.864**	.428**	.848**	.747**
UMA	.500**	.747**	.544**	.276**	.870**	.860**	1	.486**	-.074	.458**	.981**
UFA	.247**	.666**	.746**	.968**	.846**	.864**	.486**	1	.806**	.999**	.311**
AFI	-.021	.266**	.469**	.926**	.418**	.428**	-.074	.806**	1	.818**	-.250**
UFE	.232**	.651**	.742**	.974**	.829**	.848**	.458**	.999**	.818**	1	.281**
UME	.491**	.666**	.426**	.091*	.762**	.747**	.981**	.311**	-.250**	.281**	1

* $p < .05$, ** $p < .01$, *** $p < .001$

Note. For abbreviations see Table 2.

Table 6: Association of socio-economic and demographic factors with prevalence of wasting (low UAMAH).

Variables	$<5^{th}$ percentile (Wasted)	$>5^{th}$ percentile (Normal)	Exp (B)	95% CI	χ^2
Sex					
Boys	300	270	0.633***	0.49–0.82	9.41**
Girls	240	312	1		
Age					
2 years	56	139	1		40.06***
3 years	147	163	0.428***	0.28–0.64	
4 years	198	160	0.274***	0.18–0.41	
5 years	139	120	0.287***	0.19–0.44	
Ethnicity					
Rajbanshi	185	198	1.274	0.96–1.70	11.69**
Namasudra	155	216	1.659***	1.24–2.22	
Nashyaseikh	200	168	1		
Delivery					
Vaginal	394	330	0.557***	0.42–0.73	32.36***
Caesarean	146	252	1		
Birth weight of child					
$<$2500 gm	144	111	0.554***	0.41–0.76	9.20**
$\geq$2500 gm	396	471	1		
Number of living rooms					
1	126	115	1.410	0.97–2.04	7.91*
2	213	278	1.802***	1.33–2.43	
$\geq$3	201	189	1		
Fuel for cooking					
Wood	415	410	0.712*	0.52–0.98	11.77*
Crop residue	12	5	0.231*	0.07–0.74	
LPG	113	167	1		
House type					
Non-brick	409	457	1.264	0.95–1.68	1.23
Brick	131	125	1		
Bath place					
Open	219	186	0.666***	0.52–0.85	8.97**
Closed	321	396	1		
Monthly Family Income					
INR $<$7500	155	129	0.537**	0.36–0.79	14.10***
INR 7500–15000	318	338	0.664*	0.47–0.93	
INR $>$15000	67	115	1		
Maternal BMI					
$<$18.5 kg/m^2	66	59	1.190	0.78–1.81	12.25**
18.5–22.99 kg/m^2	280	254	1		
$>$23 kg/m^2	194	269	1.388*	1.05–1.83	

* $p < .05$, ** $p < .01$, *** $p < .001$
Note. For abbreviations see Table 2.

Table 7: Multiple regression predicting upper arm muscle area (dependent variable) from socioeconomic and demographic factors

Variables	B	Std Error	Beta	t	95% CI		Sig
					Lower	Upper	
Constant	6.957	0.459		15.172	6.057	7.857	0.000
Sex	-0.417	0.098	-0.101	-4.251	-0.610	-0.225	0.000
Age	0.775	0.047	0.403	16.398	0.682	0.868	0.000
Ethnicity	-0.213	0.061	-0.085	-3.506	-0.333	-0.094	0.000
Delivery	0.558	0.104	0.130	5.360	0.354	0.763	0.000
Birth weight of child	0.802	0.114	0.171	7.029	0.578	1.025	0.000
Number of living rooms	-0.028	0.070	-0.010	-0.398	-0.166	0.110	0.691
Fuel for cooking	0.142	0.062	0.058	2.266	0.019	0.264	0.024
House Type	-0.330	0.123	-0.066	-2.683	-0.571	-0.089	0.007
Bath Place	0.208	0.108	0.049	1.916	-0.005	0.420	0.056
Monthly Family Income	0.431	0.086	0.134	5.014	0.262	0.599	0.000
Maternal BMI	-0.089	0.044	-0.049	-2.012	-0.175	-0.002	0.044

Note. $p < .05$*, $p < .01$**, $p < .001$***

4 Discussion

Nutritional assessment by upper arm composition has received considerable attention in epidemiological research and clinical investigations among populations due to its universality, reliability, low cost, simplicity, and non-invasive technique. Combining upper arm composition and conventional anthropometric indices is useful for body composition and nutritional assessment (Addo et al., 2017; Arps, 2023; Chowdhury & Ghosh, 2009; Debnath et al., 2017; Dutta & Sengupta, 2023; Monir et al., 2008; Muñoz Esparza et al., 2019; Nwankwo et al., 2024; Oyhenart et al., 2019; Puttaswamy et al., 2024; Yavuz & Özer, 2020). In developing countries, when age is not known or is unreliable, UAMAH may be an interesting index to predict growth when synchronized with weight-for-height indexes (Bolzan et al., 1999; Monir et al., 2008). The UAMAH is an important tool in combination with recommended nutritional measures (e.g., BMI, stunting, MUAC, and underweight) in children. The present investigation reports an assessment of inferred body composition and nutritional status to improve screening of undernutrition by utilizing upper arm composition, especially in community settings and clinical examination among Integrated Child Development Scheme beneficiaries, to identify adiposity as well as low UAMAH (e.g., wasting) among children. It is an important tool to improve health quality through regular monitoring, which can provide a good assessment of muscularity and adiposity compared to conventional anthropometric measures (Debnath et al., 2017; Dutta & Sengupta, 2023; Lipsberga & Kažoka, 2016; Sen & Mondal, 2013; Singh & Mondal, 2014).

The UAMAH is proposed as a conventional upper arm-based anthropometric measure to identify nutritional status in populations with chronic undernutrition where both muscle and fat mass remain depleted (Bolzan et al., 1999; Debnath et al., 2017; Dutta & Sengupta, 2023; Lipsberga & Kažoka, 2016; Singh & Mondal, 2014). The majority of the children in the present study were observed to be lower than the 5^{th} percentile of the reference values (Frisancho & Tracer, 1987). Greater muscularity would reflect a greater protein reserve, and the low arm musculature is related to low height in children (Frisancho, 1981, 1990; Frisancho & Tracer, 1987). Researchers are advised to use BMI and UAMAH in conjunction for a more complete evaluation of body composition (Frisancho & Tracer, 1987). BMI is widely used to assess nutritional status but does not differentiate between fat mass and lean body mass. BMI is unable to measure body composition; therefore, arm anthropometry is recommended, as it provides additional information that helps to distinguish between fat mass and muscle mass. The present study indicates poor physical growth attainment of children, with low protein reserves and a high prevalence of wasting. The existing reference percentiles for MUAC, AMA, and AFA of well-nourished children up to 20 years are available to researchers around the world (Addo et al., 2017). That study also reported an age-dependent association between height-for-age z-score (HAZ) and the arm z-score measures that varied across sexes, whereas height-adjusted MUAC and AFA may be more sensitive than unadjusted measures of fatness (Addo et al., 2017).

Several studies have been done among different populations for establishing population-specific reference values related to upper arm composition among children and adolescents (e.g., (Arps, 2023; Basu et al., 2010; Bolzan et al., 1999; Çiçek et al., 2014; Frisancho & Tracer, 1987; Gültekin et al., 2006; Monir et al., 2008; Muñoz Esparza et al., 2019; Nwankwo et al., 2024; Oyhenart et al., 2019; Sen et al., 2015; Senbanjo et al., 2014; Sikdar, 2012; Singh & Mondal, 2014)). Frisancho and Tracer (1987), Monir (2008), and Addo et al. (2017) studied UMA and UFA. The present findings can be utilized for further investigations among Indian children aged 24-71 months. Research workers and clinicians can utilise these tables for age- and sex-group-specific comparisons. The present study utilized the age range of 24 months to 71 months, and age-sex-specific mean values of the present study can be compared to those reported by Frisancho and Tracer (1987) and Monir et al. (2008). The UAMAH was lower among the children of the present study than in the American and Egyptian samples, indicating poor nutrition (Figures 1 & 2).

The mean UMA for age in the present investigation is much lower than the 50^{th} percentile value of U.S. children of both sexes, being close to the 5^{th} percentile of U.S. children across age and gender. Also, the age-specific mean UFA in our study was distinctly lower than the 50^{th} percentile value of U.S. children in both sexes but slightly higher than the 5^{th} percentile value of U.S. children (Figures 3 & 4).

The present study concludes that poor caloric and protein reserves indicate wasting among the

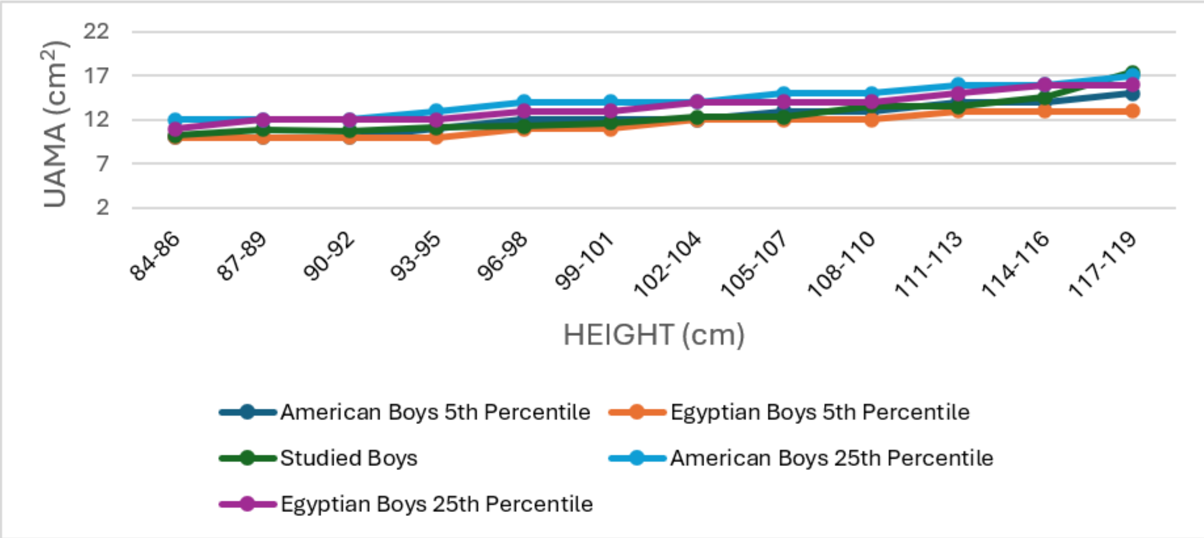

Figure 1: Comparison of UAMAH (cm^2) among Boys with International Standards.

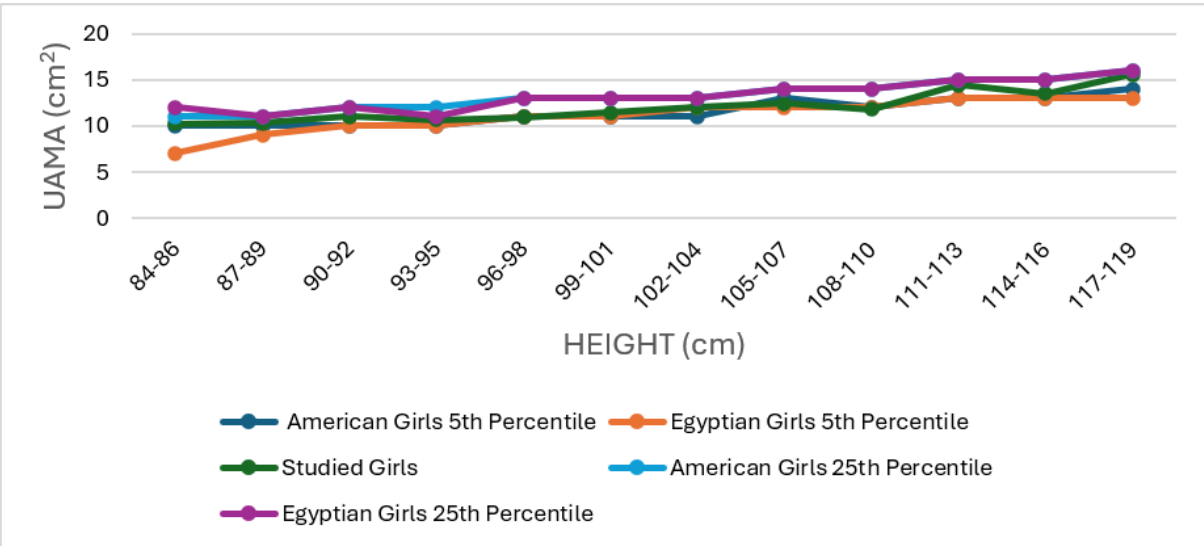

Figure 2: Comparison of UAMAH (cm^2) among Girls with International Standards.

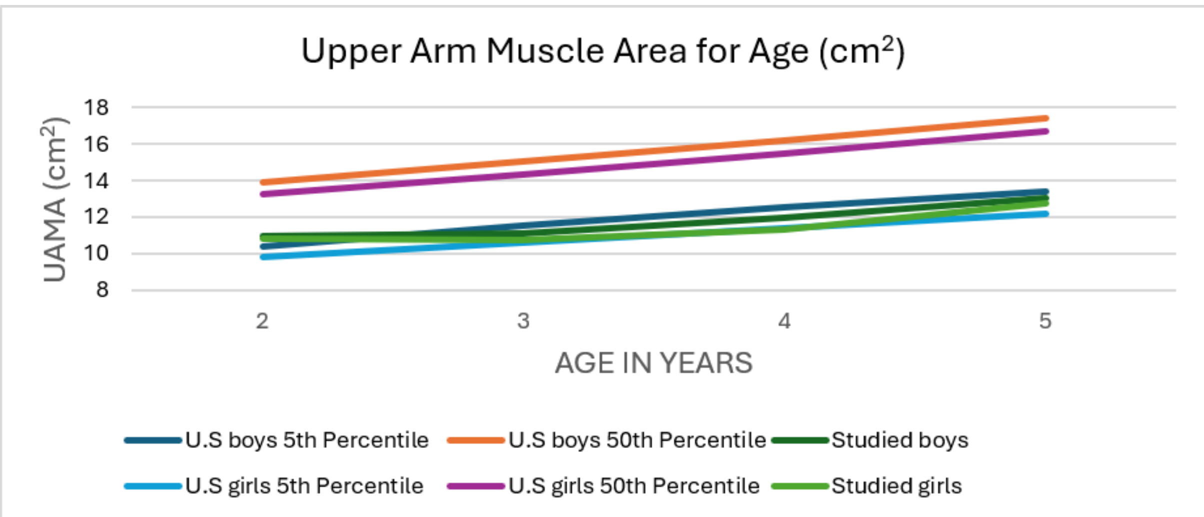

Figure 3: Comparison of upper arm muscle area (cm^2) for age with an international study.

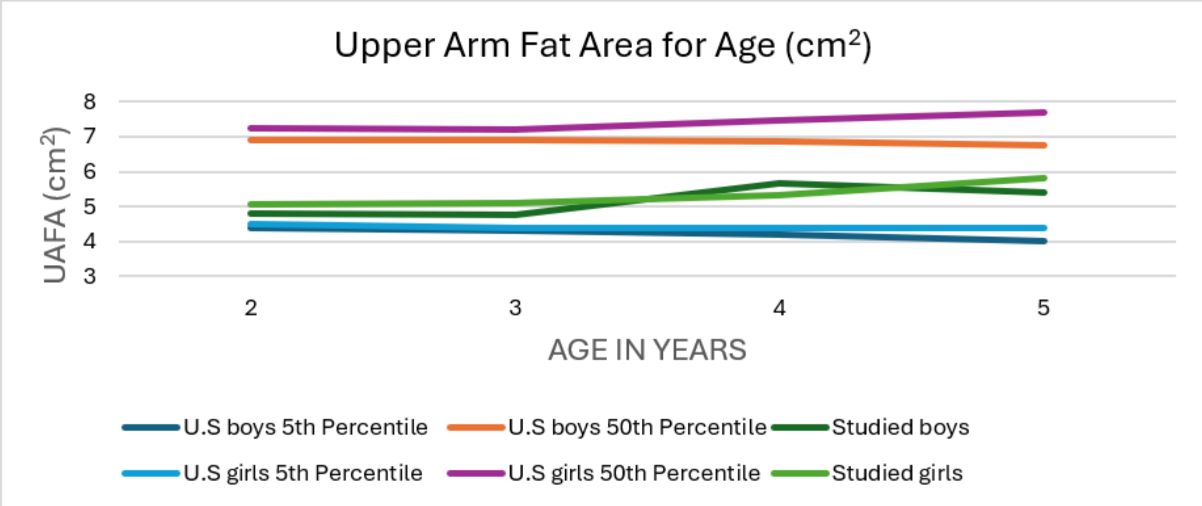

Figure 4: Comparison of upper arm fat area (cm^2) for age with an international study.

preschool children in the present study. The assessment of body composition allows a quantitative appraisal of muscle mass and adiposity that reflects nutritional intake, losses, and energy expenditure over time. The present study found evidence of poor caloric and protein reserve among the children, similar to previous studies (Wells, 2010; Thibault, 2012; Sen et al., 2015; Debnath et al., 2017; Dutta and Sengupta, 2023). The environmental conditions were more or less similar for all children in the present study, as they all were from the same ecological background. Published research studies have found that boys have a greater muscle area than girls, whereas girls have a greater amount of fat mass even before puberty (B. Khanra et al., 2024; Nuzzo, 2025; Olivieri et al., 2008; Ozturk et al., 2009; Rahman et al., 2024; Senbanjo et al., 2014), which is consistent with this study. Furthermore, our findings of gender differences in fat area are consistent with previous studies of prepubertal children (He et al., 2002). The mean of anthropometric variables such as height, weight, and BMI in both sexes at each age group of the present study was distinctly lower than the National Health Statistics Report, 2015-18, which represents the American children described by Fryar et al. (2021) (Figures 5, 6, and 7).

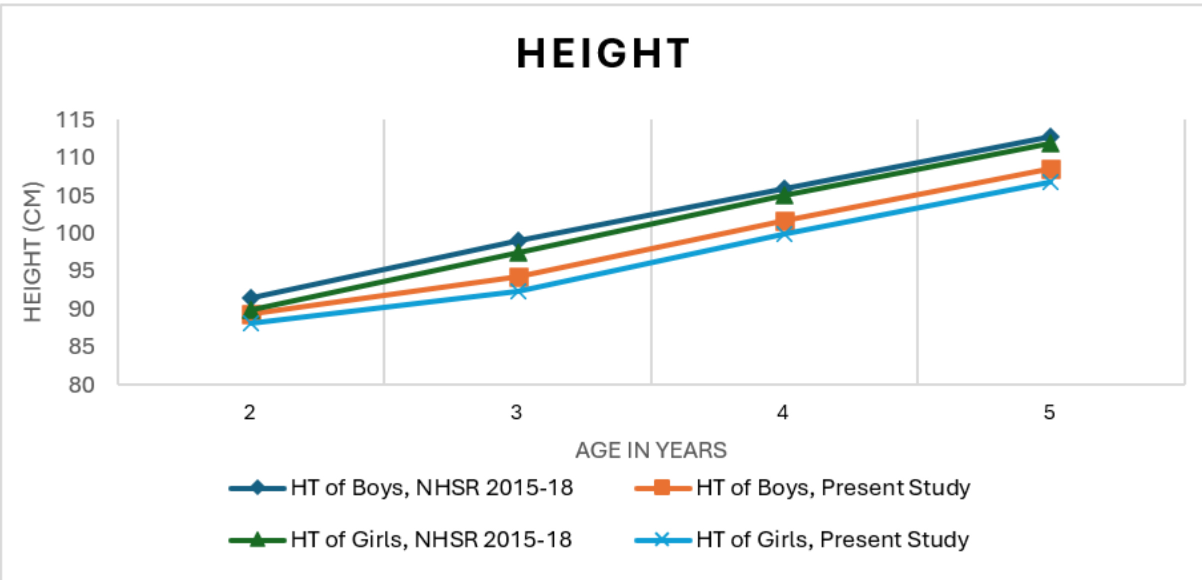

Figure 5: Comparison of mean height (cm) in the present study with the National Health Statistics Report Reference among both sexes.

Skeletal growth is reflected by height measurement, whereas UAMAH is a predictor of muscle mass.

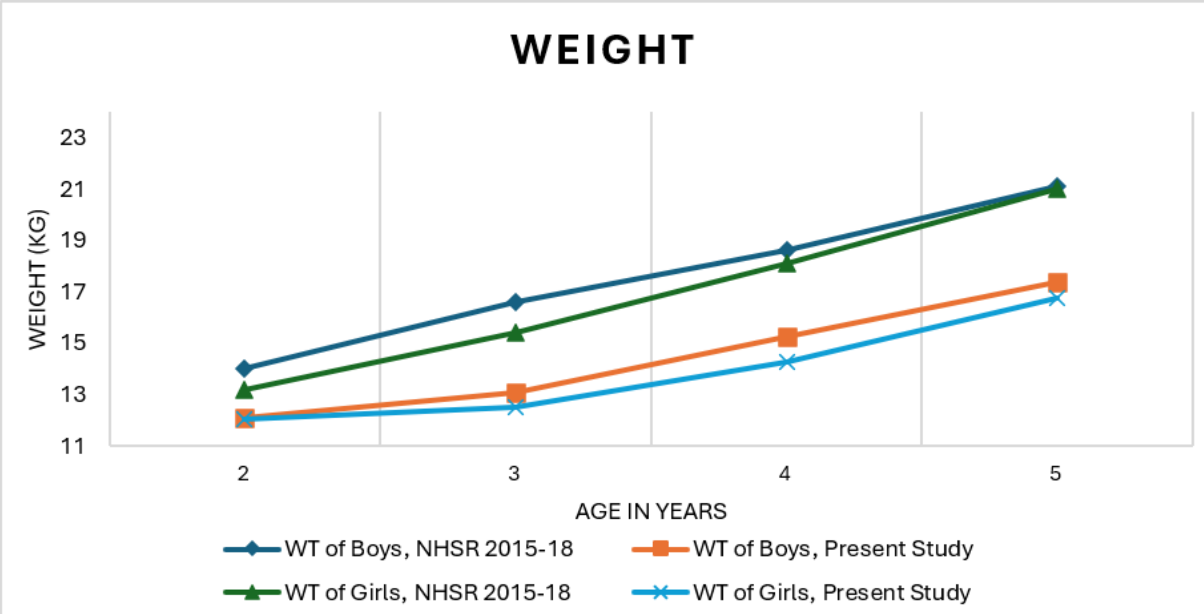

Figure 6: Comparison of mean weight (kg) in the present study with the National Health Statistics Report Reference among both sexes.

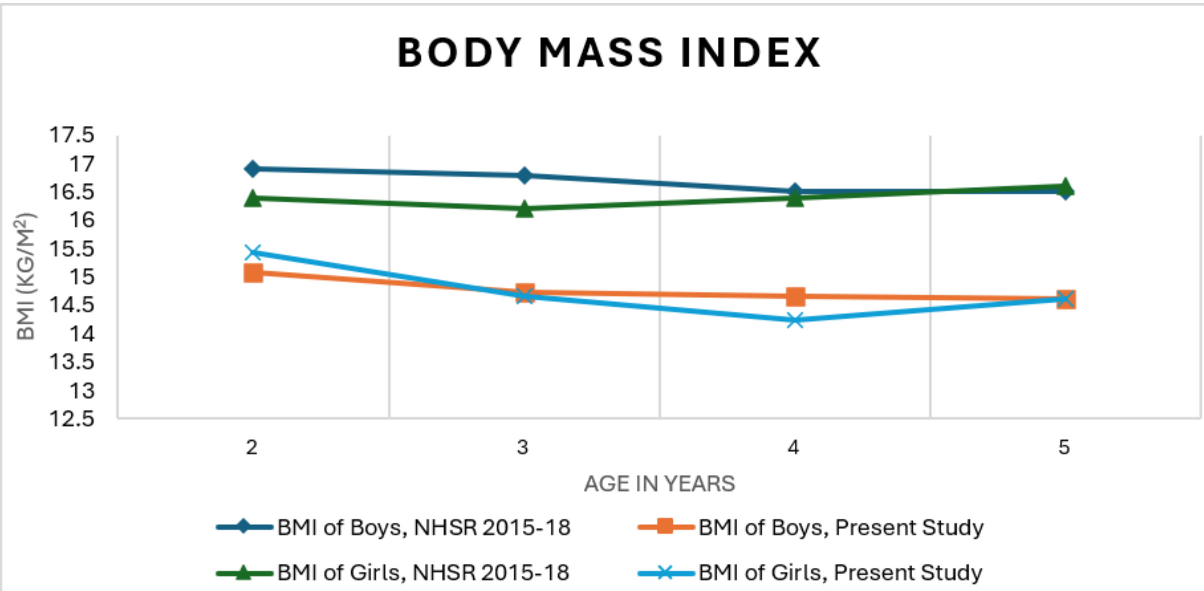

Figure 7: Comparison of mean BMI (kg/m^2) in the present study with the National Health Statistics Report Reference among both sexes.

It is a valuable index to identify the risk factors for undernutrition. The UAMAH shows that 48.13 per cent of both sexes combined come under the UAMAH category I, with a Z score value −1.60. Only 0.36 per cent fall into the UAMAH category IV with a Z score of +1.00 to +1.60 (Table 4). This study highlights the large differences in muscularity and body fat of preschool children in West Bengal when compared with children from other parts of the world. In the category of low-birth-weight children, most body composition variables showed significant age variations only among girls. These low-birth-weight girls have significant age variation of MUAC, TUA, UMA, UFA, UFE, and UME, but no age variation was found among boys.

The present study findings indicated that MUAC was highly correlated with TUA in both sexes because TUA is calculated using MUAC as a key component in the formula for arm area and because TSF is highly correlated with UFA and UFE in both sexes. The present study also reports that girls have higher adiposity than boys in all age groups related to UFA and AFI. The present findings show that girls have higher fat mass scores than boys, and boys have greater muscle mass scores, supporting the results of previous studies (Basu et al., 2010; Debnath et al., 2017; B. Khanra et al., 2024; Lipsberga & Kažoka, 2016; Sen et al., 2011; Yavuz & Özer, 2020) (Table 2). Girls have higher fat patterns than boys in terms of UFA, AFI, and UFE in all age groups (Table 3). The finding suggests that age, sex, birth weight, and catch-up growth have an impact on body composition in childhood (Wells, 2010). Most of the body composition measurements are extremely consistent with a prior study conducted on preschool children (Muñoz Esparza et al., 2019). Argentine preschoolers exhibited low and high protein and caloric reserves. The UAMAH reflects muscle mass relative to height, which is a proxy for protein reserves, whereas UFA reflects fat stores, which are proxies for caloric reserves indicated by upper arm composition (Agüero et al., 2023). The present research found a correlation between BMI, MUAC, and UMA in both sexes. This is consistent with previous research on children in Bahrain (Gharib & Rasheed, 2009), primary school children in China (Ma et al., 2015), Latvian children (Lipsberga & Kažoka, 2016), hospitalised children (Muñoz Esparza et al., 2019), and children of West Bengal (B. Khanra et al., 2024). A substantial association was identified between BMI and AFI, which contrasts with the previous consensus (Lipsberga & Kažoka, 2016) (Table 5). Previous research studies have found associations between BMI, UMA, and UFA (Gharib & Rasheed, 2009; Muñoz Esparza et al., 2019; Yavuz & Özer, 2020). Previous studies revealed that age changes in MUAC, UMA, and UFA indicate changes in upper arm composition in both sexes (Addo et al., 2017; Nwankwo et al., 2024; Oyhenart et al., 2019).

The hypothesis is that upper arm composition is a valuable tool for malnutrition, especially severe malnutrition, regardless of age group and clinical context (Muñoz Esparza et al., 2019; Ngaboyeka et al., 2025). The measurement of upper arm areas is beneficial in detecting both chronic and acute malnutrition, whereas BMI only indicates an acute deficit in hospitalised paediatric patients (Grellety & Golden, 2018; Lambebo et al., 2023; Muñoz Esparza et al., 2019), but UAMAH is a useful measure of undernutrition and as such is related to morbidity and mortality (Arps, 2023; Dutta & Sengupta, 2023; Nwankwo et al., 2024; Oyhenart et al., 2019). The upper arm anthropometric indices should be utilised by academicians and physicians to assess the prevalence of population-specific malnutrition (Debnath et al., 2017; Dutta & Sengupta, 2023; Sikdar, 2012). The measurement of arm anthropometry is a viable alternative method for determining nutritional status. As a result, UMA and UFA should be measured in conjunction with other anthropometric indices to provide a comprehensive assessment of nutritional health among preschool children. Upper arm anthropometric measurements derived from mid-upper arm circumference, arm muscle, and arm fat areas offer several advantages compared with advanced techniques like Dual-Energy X-ray Absorptiometry (DXA) and the Total Body Water Method (TBW). They are simple, rapid, and inexpensive and require minimal equipment, making them suitable for large field surveys and resource-limited settings. These measures can also provide indirect estimates of muscle and fat reserves. However, upper arm measurements are less precise than DXA or TBW, which directly assess body composition. Their accuracy can be influenced by factors like age, sex, and ethnic variation, and they provide only regional rather than whole-body estimates of fat and lean mass, which can affect the assessment of nutritional condition.

Further, the multiple linear regression analysis demonstrated that UMA was significantly associated with several socioeconomic and demographic factors (Table 7). Among the demographic variables, sex of the child showed a significant negative association with UMA (B = -0.417, $p<0.001$), indicating gender differences in muscle area (i.e., boys > girls). Age exhibited the strongest positive association with UMA (B = 0.775, $p<0.001$), suggesting that UMA increased progressively with advancing age. Ethnicity also emerged as a significant predictor (B = -0.213, $p < 0.001$), indicating ethnic disparities in muscle development among the studied children. Type of delivery showed a significant positive association with UMA (B = 0.558, $p<0.001$), while birth weight demonstrated a strong positive relationship (B = 0.802, $p<0.001$), suggesting that children with a higher birth weight had greater UMA. Among the household characteristics, the use of cleaner cooking fuel was positively associated with UMA (B = 0.142, $p<0.05$), whereas poorer house type showed a significant negative association (B = -0.330, $p<0.01$). Monthly family income was positively associated with UMA (B = 0.431, $p<0.001$), indicating that children from economically better-off households had greater muscle area, possibly due to better healthcare access. Maternal BMI also showed a significant negative association with UMA (B = -0.089, $p<0.05$), suggesting that maternal nutritional status may influence the child's muscle development. However, the number of living rooms and bath places was not significantly associated with UMA ($p>0.05$) (Table 7).

Age, sex, birth order, maternal education and maternal BMI have been significantly associated with wasting in a previous study (Harding et al., 2018; Mutua et al., 2017; Pandey et al., 2024; Patil et al., 2017; Tigga et al., 2015). Low family income increased the prevalence of wasting among preschool children, similar to previous research (Tigga et al., 2015). Also, LBW has been reported as an independent risk factor for child undernutrition (Khaing et al., 2019; Nshimyiryo et al., 2019). An association of the number of living rooms with child undernutrition has also been reported by previous studies (Biswas & Bose, 2011; P. Khanra et al., 2020). Also, monthly family income has been described repeatedly as an influence on child undernutrition (P. Khanra et al., 2020; Sen et al., 2020). Unlike earlier studies (Sen et al., 2020), the present results show no association of house type with wasting. The type of fuel for cooking (smoked or smokeless) has a significant relationship with child undernutrition (P. Khanra et al., 2020; Mishra & Bera, 2024). Mode of delivery showed a significant association with child wasting, also revealed in the NFHS-5 (Pandey et al., 2024). The observed association between mode of delivery and child wasting likely reflects a combination of maternal health complications, neonatal risk, and poor economic background.

The present study has several limitations that should be considered while interpreting the findings. The small sample size and cross-sectional design cannot establish causal relationships between socioeconomic factors and UAMAH-based nutritional status. Although upper arm anthropometric indices were interpreted using the widely accepted Frisancho and Tracer (1987) reference standards derived from NHANES I and II, ethnic and environmental differences may influence the applicability of these reference standards. In the absence of validated population-specific reference standards for Indian preschool children, these international references were used to facilitate comparison with previous studies. A limitation of the present study is that dietary intake data and other indicators of nutritional status were not assessed.

5 Conclusion

Upper arm anthropometry seems to be an important technique, and its utilization with height by UAMAH can determine body composition and nutritional status. The present study suggests a high prevalence of insufficient protein and calorie reserves; it also provides more insight and further comparison with other studies. Upper arm anthropometry can identify adiposity, or the depletion of fat stores. In preschool children, BMI combined with upper arm anthropometry and UAMAH may be the most productive tool for the assessment of undernutrition as a screening tool. The present study recommends assessment of body composition and nutritional status to improve screening of undernutrition (e.g., wasting) using upper arm composition and/or UAMAH, especially in community or epidemiological settings and clinical checkups, research, and investigation among children. The estimates are reasonably accurate at the population or community level, especially for identifying children at risk of wasting or low protein reserves, but the accuracy depends on proper technique and sex-specific reference standards. Therefore, the improvement of health quality is necessary by evaluating various intervention schemes and supplementary programmes among the studied children.

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Conflict of interest

There is no conflict of interest.

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