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# Mid Upper Arm Circumference in Pregnant Women and Birth Weight in Newborns as Substitute for Skinfold Thickness: Findings from the MAASTHI Cohort Study, India.

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# Abstract

**Background:** Estimating fat deposition in public hospitals using gold-standard measurements such as high-resolution imaging is unaffordable and it is challenging to use skinfold thickness. We aimed to identify the appropriate substitute marker for skinfold thickness to estimate fat deposition in pregnant women and infants.

**Methods:** The study is part of a prospective cohort study titled, MAASTHI in Bengaluru, from 2016-19. Anthropometric measurements such as body weight, head circumference, mid upper arm circumference (MUAC), and skinfold thickness were measured in pregnant women between 14 to 36 weeks of gestational age; while measurements such as birth weight, head, chest, waist, hip, mid upper arm circumference, and skinfold thickness were recorded for newborns. We calculated Kappa statistics to assess agreement between these anthropometric markers with skinfold thickness.

**Results:** We found the highest amount of agreement between total skinfold thickness and MUAC (Kappa statistic, 0.42; 95% CI 0.38-0.46) in pregnant women. For newborns, the highest agreement with total skinfold thickness was with birth weight (0.57; 95% CI 0.52-0.60). Our results indicate that MUAC higher than 29.2 cm can serve as a suitable alternative to total skinfolds-based assessments for obesity screening in pregnancy in public facilities. Similarly, a birth weight cut-off of 3.45 kg can be considered for classifying obesity among the newborns.

**Conclusions**: Mid upper arm circumference and birth weight can be used as markers of skinfold thickness, reflecting fat deposition in pregnant women and the infant, respectively. These two anthropometric measurements could substitute for skinfold thickness in low- and middle-income urban India settings.


# Introduction

The increasing prevalence of overweight and obesity among children is a significant public health issue attributing to immediate and long-term health problems.(1) However, the available estimates of obesity are highly variable in India, suggesting a range of 1 to 29% of children (2–5) and 11.1% in pregnant women.(6) There is an intergenerational cycle of perpetuating association of obesity in mothers with that of children, leading to a myriad of diseases such as type 2 diabetes mellitus (T2DM), dyslipidemia, and cardiovascular disease (CVD). Obesity has increased in adults and children owing to the epidemiological and demographic transition in India. From 2001 to 2005, the prevalence of children with overweight/obese has increased from 16.3 to 19.3%.(7) In order to start effective strategies to reduce adverse outcomes, it is necessary to evaluate pregnant women and children for obesity using reliable markers that can be scaled across the nation.

Lack of clear recommendations adds to the complexities of screening during pregnancy and infancy. First, there is no standard definition of what constitutes obesity in pregnancy and at birth. The available recommendations are mostly for pre-pregnancy measures.(8) Second, there are ambiguities in the

methods for screening obesity, with some using birth weight while others suggesting BMI z-scores or weight-for-length (WFL). The reliability of anthropometric markers in estimating obesity is a substantial challenge. For example, poor sensitivity (47.7%) and positive predictive value (67.7%) are noted for BMI.(9) Studies across different settings have shown that high MUAC has high diagnostic accuracy (sensitivity, specificity and predictive values) for the identification of adiposity (as measured by body composition techniques.(10) Fourth, it is difficult to ensure that trained staff are available to maintain homogeneity and internal validity.(9) Finally, when measured using standard methods, there are high chances of measurement error, often depending on the number of observers, skill and staff turnover.(11)

There are several advanced methods with higher reliability for measuring obesity. These include bioelectrical impedance analysis (BIA), deuterium dilution, dual-energy x-ray absorptiometry (DXA), fluid displacement plethysmography (Pea Pod), ultrasound and magnetic resonance imaging (MRI). Unfortunately, using these instruments is either costly, challenging to implement at the population level and also require considerable expertise.(12, 13) Due to these complexities in measuring the fat deposition, measuring the thickness of two layers of subcutaneous fat pinched using callipers referred to as total skinfold thickness is generally employed in community settings.(14)

It is essential to screen obesity in public facilities using appropriate but realistic methods to assess fat deposition in the body. Hence, using total skinfolds for assessing body composition is a quick, convenient, relatively inexpensive method across all ages. However, this requires rigorous training and expertise. In addition to the possibility of high Intra- and inter-observer variability in using the callipers,(15) multiple readings in at least three sites are necessary to obtain reliable skinfold thickness. This will not be possible in most public facilities, which are otherwise understaffed, overcrowded and offer no privacy. It is difficult to ensure frontline health workers have the necessary training and reduce Intra- and inter-observer variability in millions of health workers. Therefore, we aimed to assess the validity and determine appropriate cut-off levels of several anthropometric markers as alternatives for total skinfolds in pregnant women and newborn infants in a prospective cohort study.

# Methods

# Study design and subjects

Maternal Antecedents of Adiposity Studying the Transgenerational role of Hyperglycemia and Insulin (MAASTHI) is a prospective pregnancy cohort. A detailed protocol and methods are published elsewhere.(16) In brief, we recruited voluntarily consenting eligible pregnant women from public facilities in Bengaluru, Karnataka from 2016–2019. We excluded participants with Diabetes, HIV and Hepatitis or their inability to complete the oral glucose tolerance test (OGTT). The included women were aged 18–45 years, having singleton pregnancy before the gestational age of 36 weeks. We collected the data and measured anthropometry from the voluntarily consenting pregnant women between 14 to 36 weeks. Women were invited for lab tests (glucose and haemoglobin) between 24 to 36 weeks. Follow-up was

conducted in the women who completed the lab tests and we considered infants from birth to five months of age.

# Anthropometric measurements

## Pregnancy

Standing height and weight were measured using the portable stadiometer (SECA 213) and digital weighing scale (Tanita). We recorded weight to the nearest 100 gram with minimal clothing and barefoot. The height was read to the nearest 0.1 cm. Mid upper arm circumference (MUAC) was measured for the left arm using circumference tape (Chasmors WM02). Two readings for each anthropometric measurement were recorded. Head Circumference was measured using Chasmors WM02.

## Newborn anthropometry

For weight measurement, newborns were placed naked on the digital weighing scale (SECA 354), and two readings to the nearest 0.5 grams were taken. The newborn length was measured using Infantometer.

## Total Skinfold thickness

We measured triceps, biceps, and subscapular skinfold thickness in pregnant women between 14 and 36 weeks of pregnancy. For newborns, measurements were done between birth and five months of age. The measurement was conducted on the left side using Holtain Calliper (Holtain, U.K 610ND). Triceps skinfolds were measured over the posterior belly of triceps muscle of the left arm, halfway between the acromion and the olecranon, on a line passing upwards from the olecranon in the axis of the limb, with the arm extended. Biceps skinfold is measured in the anterior midline of the arm over the biceps on the same level as the triceps skinfold. Subscapular skinfold was measured immediately below the angle of the left scapula, with the arm held by the side of the body. Measurements were made on the left side of the body and readings were taken 5 seconds after the application of the calliper's jaws. Three readings to the nearest 0.2 mm were taken.

# Quality control and calibration

All research assistants were trained at the St. Johns Research Institute, Bengaluru for anthropometric measurements as part of their induction. Competencies of research assistants were assessed at the outset, followed by mandatory annual certification. The intra-observer technical error of measurement was below 1.5% for all measurements and inter-observer TEM was below 2%. Calibration of all the equipment was done every month.

# Statistical Analysis

Descriptive statistics, mean and stratum-wise proportions (as applicable) were generated for socio-demographic and anthropometric characteristics of the study participants. For the anthropometric measures for which multiple readings were available, the arithmetic mean of the non-missing values was used in the analysis. Total skinfold thickness was calculated by summing up the values for biceps, triceps and subscapular skinfold thicknesses. Curve estimation was done to assess the linearity of the association between total skinfold and other explanatory anthropometric measures (*Transreg* procedure in SAS that utilized the Box-Cox transformation of the dependent variable). The strength of linear association (and statistical significance) was described using simple linear regression. After the establishment of a linear association between total skinfold and the rest of the anthropometric parameters, Pearson's correlation analysis between these parameters was assessed. Percentile distribution of maternal skinfold thickness was derived and based on 90th percentile cut-off, the participating pregnant women were categorized into *high* (above 90th percentile and *normal* skinfold (up to 90th percentile) groups.(17)

For the newborns, 85th percentile cut-off was used.(18) Receiver operating characteristics (ROC) curve analysis was performed, and separate ROC curves of maternal body weight, head circumference, MUAC and BMI on 90th percentile cut-off of total skinfold were generated. The optimal cut-off point for each of these measures that corresponded to 90th percentile total skinfold cut-off was determined using following three methods – 1) Youden's *J* statistic; 2) minimized distance to (0, 1) point in the ROC curve; and 3) sensitivity-specificity equality.(19–23) In case conflicting cut-off values were obtained from each of the three methods, the results generated by Youden's *J* statistic procedure were persisted with. For the newborns, the same process was repeated to determine optimal cut-off of different anthropometric measures corresponding to 85th percentile cut-off for total skinfolds. Besides the anthropometric parameters used for pregnant women, chest, waist and hip circumferences were additional parameters evaluated for newborns. Further, the predictive accuracy of the cut-off points for different anthropometric parameters was evaluated by calculating the proportion of misclassification that would result from the use of determined cut-offs. We also assessed Cohen's Kappa statistic to determine the agreement between the determined cut-off and standard 90th /85th percentile cut-offs for total skinfolds. SAS version 9.4 was used for statistical analyses.

# Results

Anthropometry was recorded in 3719 pregnant women, and the mean age was 24.2 years. Majority of them had attained middle school education (91.2%), 22.7% had parents with diabetes, 45.1% of them were primiparous, women largely were homemakers (92.6%), and one in nine (11.1%) women were diagnosed with GDM during the current pregnancy. Of the 3719 pregnant women, 2962 completed the lab tests, there were 60 cases of child death, 290 women had not delivered as of the analysis date, and there were 180 cases lost to follow up. Infant anthropometry was measured in 2432 infants. The mean birth weight was 3.07(SD ± .736) kg, and the total skinfold thickness was 14.20 mm. The mean gestational age at delivery was 38.6 weeks. The characteristics of the study population are summarized in Table 1.

Table 1
Demographic characteristics of participants (N = 3719)

| **Characteristics** | **n(%)** |
|---|---|
| Maternal characteristics (n = 3720) | |
| **Maternal age in years (Mean ± SD)** | 24.26 ± 4.08 |
| **Gestational age at recruitment in weeks (Mean ± SD)** | 23.5 ± 6.01 |
| **Religion** | |
| Hinduism | 1876(50.40%) |
| Islam | 1696(45.60%) |
| Other* | 147(4.00) |
| **Education** | |
| Primary School and below | 337(9.00%) |
| Middle School and above | 3382 (91.00%) |
| **Occupation#(N = 3716)** | |
| Homemakers | 3445(92.60%) |
| Unskilled | 146(3.90%) |
| Semi-skilled/ Skilled | 125(3.40%) |
| **Husband's occupation#(N = 3716)** | |
| Unemployed | 13(0.30%) |
| Unskilled | 1767(47.50%) |
| Semi-skilled | 1182(31.80%) |
| Skilled | 754(20.30%) |
| **Gravida** | |
| Primigravida | 1467(39.40%) |
| Multigravida | 2252(60.60%) |
| **Parity** | |
| Nulliparous | 1667(44.80%) |
| Primiparous | 1677(45.10%) |

*SD, standard deviation; *Others: Christian and Jain; #Occupation: Unskilled: labourer, construction labourer, helper, attender; Peon, cleaner, sweeper, Semi-Skilled: Gatekeeper/Security, Asst. Operator, Asst. electrician, waiter, Skilled: Tailor, carpenter, Driver, plumber, electrician*

| Characteristics | n(%) |
|---|---|
| Multiparous | 375(10.10%) |
| **History of abortion** | |
| 0 | 2997(80.60%) |
| 1 | 601(16.20%) |
| > 2 | 121(3.30%) |
| **Current gestational diabetes status during the assessment** | |
| Yes | 417(11.10%) |
| No | 3302(88.80%) |
| **Blood pressure (N = 3688)** | |
| Systolic blood pressure (mm of Hg) | 101 ± 11.0 |
| Diastolic blood pressure (mm of Hg) | 63.4 ± 9.0 |
| **Family history of diabetes** | |
| None | 2874(77.20%) |
| One Parent | 745(20.02%) |
| Both parent | 101(2.71%) |
| **Anthropometry measurements** | |
| Weight (kg) (Mean ± SD) | 58.95 ± 11.72 |
| Height (cm) (Mean ± SD) | 153.9 ± 5.72 |
| Mid-upper arm circumference(cm) (Mean ± SD) | 26.0 ± 3.87 |
| Biceps skinfold thickness (mm) (Mean ± SD) | 10.63 ± 4.90 |
| Triceps skinfold thickness (mm) (Mean ± SD) | 19.56 ± 5.98 |
| Subscapular skinfold thickness (mm) (Mean ± SD) | 17.26 ± 6.00 |
| Sum of skinfold thickness (mm) (Mean ± SD) | 47.45 ± 14.8 |
| **Delivery outcomes (n = 2432)** | |
| **Gestational age at delivery in weeks (Mean ± SD)** | 38.6 ± 1.6 |
| **Delivery type** | |

*SD, standard deviation; *Others: Christian and Jain; #Occupation: Unskilled: labourer, construction labourer, helper, attender; Peon, cleaner, sweeper, Semi-Skilled: Gatekeeper/Security, Asst. Operator, Asst. electrician, waiter, Skilled: Tailor, carpenter, Driver, plumber, electrician*

| Characteristics | n(%) |
|---|---|
| Vaginal delivery | 1341(55.10%) |
| Caesarean delivery | 1092(44.90%) |
| Infant characteristics (n = 2432) | |
| **Sex** | |
| Male | 1257(51.70%) |
| Female | 1175(48.30%) |
| **Age at assessment in days (Mean ± SD)** | 12.1 ± 19.3 |
| **Anthropometry measurements** | |
| Weight (kg) (Mean ± SD) | 3.07 ± .736 |
| Length (cm) (Mean ± SD) | 49.55 ± 3.88 |
| Crown-rump length (cm) (Mean ± SD) | 32.59 ± 3.21 |
| Head circumference (cm) (Mean ± SD) | 33.76 ± 2.16 |
| Chest circumference (cm) (Mean ± SD) | 32.33 ± 2.81 |
| Waist circumference (cm) (Mean ± SD) | 30.75 ± 3.72 |
| Hip circumference (cm) (Mean ± SD) | 29.16 ± 3.72 |
| Mid-upper arm circumference(cm) (Mean ± SD) | 9.89 ± 1.22 |
| Biceps skinfold thickness (mm) (Mean ± SD) | 4.05 ± 1.17 |
| Triceps skinfold thickness (mm) (Mean ± SD) | 5.19 ± 1.48 |
| Subscapular skinfold thickness (mm) (Mean ± SD) | 4.97 ± 1.38 |
| Sum of skinfold thickness (mm) (Mean ± SD) | 14.20 ± 3.69 |

*SD, standard deviation; *Others: Christian and Jain; #Occupation: Unskilled: labourer, construction labourer, helper, attender; Peon, cleaner, sweeper, Semi-Skilled: Gatekeeper/Security, Asst. Operator, Asst. electrician, waiter, Skilled: Tailor, carpenter, Driver, plumber, electrician*

The optimum cut-off values for the various anthropometric measurements corresponding to the 90th percentile cut-off of the total maternal skinfold thickness is shown in Table 2. Although the cut-off values obtained via different ROC curve methods were not identical, they approximated each other. Given the discordance, the cut-offs generated using Youden's *J* statistic method – 66.89 kg for weight, 53.39 cm for HeadC, 29.20 cm while considering MUAC and 27.82 kg/$m^2$ for BMI – were selected as optimal.

Table 2

Cut-offs for different anthropometric measures corresponding to total skinfold thickness cut-off (90th percentile) in pregnant women, by different methods of ROC curve analysis. [N = 3719]

| Anthropometric measure | Cut-off corresponding to 90th percentile of total skinfold thickness from different methods | | |
|---|---|---|---|
| | Youden's *J* statistic** | Minimized distance to (0, 1) point in the ROC curve | Sensitivity-specificity equality |
| Bodyweight (kg) | 66.89 | 66.89 | 64.94 |
| Head circumference (cm) | 53.39 | 53.39 | 53.09 |
| Mid-upper arm circumference (cm) | 29.2 | 28.5 | 28.3 |
| BMI (kg/$m^2$) | 27.82 | 27.37 | 27.49 |

*Sum of Biceps, Triceps and Sub−scapular skinfold thickness

** In case of discrepancy between cut−offs determined by different methods, the cut−off obtained via Youden's *J* statistic was considered as standard

Table 3 depicts the resultant distribution of 90th percentile of total skinfold according to the optimal cut-off values for the four maternal anthropometric measures, derived from the ROC curve analyses. MUAC cut-off had the least amount of misclassification (15%), while HeadC cut-off had the highest (worst) misclassification (32.46%). Highest amount of agreement (as per *Kappa* statistic) with total skinfold was also attributed to MUAC cut-off value (0.42 (95% CI 0.38–0.46)). We found that MUAC cut-off emerged as the best possible substitute for the measurement of total skinfolds in pregnant women (Table 2–3, Figs. 1–2).

Table 3
The magnitude of agreement and the extent of misclassification on using different anthropometric measures instead of total skinfold thickness for measurement of body fat in pregnant women (90th percentile cut off). [N = 3719]

| Anthropometric measure | Cut-off # | Total skin fold thickness percentile | | Total misclassification (%) | Kappa coefficient (95% CI) |
|---|---|---|---|---|---|
| | | < 90th percentile | > 90th percentile | | |
| Body weight (kg) | < 66.89 | 2799 (75.26) | 90 (2.42) | 17.32 | 0.38* (0.34–0.41) |
| | ≥ 66.89 | 554 (14.90) | 276 (7.42) | | |
| Head circumference (cm) | < 53.39 | 2304 (61.95) | 158 (4.25) | 32.46 | 0.12** (0.1–0.15) |
| | ≥ 53.39 | 1049 (28.21) | 208 (5.59) | | |
| Mid-upper Arm Circumference (cm) | < 29.20 | 2885 (77.60) | 90 (2.42) | 15.01 | 0.42*** (0.38–0.46) |
| | ≥ 29.20 | 468 (12.59) | 275 (7.40) | | |
| BMI (kg/m$^2$) | < 27.82 | 2746 (73.84) | 81 (2.18) | 18.5 | 0.36* (0.33–0.40) |
| | ≥ 27.82 | 607 (16.32) | 285 (7.66) | | |

#Cut off corresponding to 90th percentile of total skinfold thickness

*Fair agreement; **Slight agreement; ***Moderate agreement *[Landis & Koch (1977)]*

Each of the seven anthropometric parameters in the newborns was positively correlated with total skinfold thickness with a statistically significant slope. (Figs. 3–4)

Although the cut-off values, for each of the seven anthropometric measures, produced using different ROC curve methods were not identical, they approximated each other. (Figs. 3–4) The optimum cut-off values for the various anthropometric measurements corresponding to the 85th percentile cut-off of the total maternal skinfold thickness for newborns are shown in Table 4. We found that birth weight in babies was a perfect substitute for skinfold thickness. We also found that HeadC, CC, WC and HC were optimally similar concerning the parameters listed in Table 4. The Youden's *J* statistic method revealed the following cut-off values – 3.45 kg for body weight, 35cm for HeadC, 33.7cm for CC, 31.7cm for WC, 30.3cm for HC, 10.30cm for MUAC and 13.22 (kg/m$^2$) for BMI. (Table 4)

Table 4

Cut-offs for different anthropometric measures that correspond to total skinfold thickness cut-off (85th percentile) for children at birth - determined by different methods of ROC curve analysis. [N = 2432]

| Anthropometric measure | Cut-off corresponding to 85th percentile of total skinfold thickness from different methods | | |
|---|---|---|---|
| | Youden's *J* statistic** | Minimized distance to (0, 1) point in the ROC curve | Sensitivity-specificity equality |
| Bodyweight (kg) | 3.45 | 3.40 | 3.26 |
| Head circumference (Cm) | 35.00 | 34.70 | 34.60 |
| Chest circumference (Cm) | 33.70 | 33.70 | 33.40 |
| Waist circumference (Cm) | 31.70 | 32.40 | 32.40 |
| Hip circumference (Cm) | 30.30 | 30.30 | 30.50 |
| Mid-upper arm circumference (Cm) | 10.30 | 10.30 | 10.30 |
| BMI ($kg/m^2$) | 13.22 | 12.87 | 12.88 |

*Sum of Biceps, Triceps and Sub−scapular skinfold thickness

** In case of discrepancy between cut−offs determined by different methods, the cut−off obtained via Youden's *J* statistic was considered as standard.

Table 5 depicts the extent of misclassification that would result from the use of the newly defined cut-offs instead of the accepted standard, i.e. 85th percentile of total skinfold in newborns along with the amount of agreement (expressed by kappa statistic) between each of the seven measures and total skinfolds cut-off. Our results indicate that the birth weight cut-off (3.45 kg) had the least amount of misclassification (13%) against total skinfold thickness, while BMI cut-off had the highest (worst) misclassification (24.11%). The highest value of kappa statistic was also attributed to Birth weight (0.57 (0.52–0.60)] followed by the head and chest circumferences, respectively. The cut-offs for circumferences at the waist, hip and mid upper arm and BMI showed *fair* agreement with total skinfold thickness.

Table 5

The magnitude of agreement and the extent of misclassification on using different anthropometric measures instead of total skinfold thickness for measurement of body fat among children at birth (85th percentile cut-off). [N = 2432]

| Anthropometric measure | Cut-off# | Total skin fold thickness percentile | | Total misclassification (%) | Kappa coefficient (95% CI) |
|---|---|---|---|---|---|
| | | ≤ 85th percentile | > 85th percentile | | |
| Birth weight (kg) [N = 2432] | < 3.45 | 1839 (75.62) | 78 (3.21) | 13.00 | 0.57* (0.52–0.60) |
| | ≥ 3.45 | 238 (9.79) | 277 (11.39) | | |
| Head circumference (cm) [N = 2432] | < 35.00 | 1699 (69.86) | 90 (3.70) | 19.24 | 0.42* (0.38–0.46) |
| | ≥ 35.00 | 378 (15.54) | 265 (10.90) | | |
| Chest circumference (cm) [N = 2432] | < 33.70 | 1718 (70.64) | 85 (3.50) | 18.26 | 0.45* (0.40–0.49) |
| | ≥ 33.70 | 359 (14.76) | 270 (11.10) | | |
| Waist circumference (cm) | < 31.70 | 1469 (60.40) | 52 (2.14) | 27.14 | 0.34** (0.31–0.37) |
| | ≥ 31.70 | 608 (25.00) | 303 (12.46) | | |
| Hip circumference (cm) | < 30.30 | 1609 (66.16) | 74 (3.04) | 22.28 | 0.39** (0.35–0.43) |
| | ≥ 30.30 | 468 (19.24) | 281 (79.15) | | |
| Mid Upper Arm Circumference (Cm) | < 10.30 | 1621 (66.65) | 78 (3.21) | 21.96 | 0.39** (0.35–0.43) |
| | ≥ 10.30 | 456 (18.75) | 277 (11.39) | | |
| BMI (kg/m2) | < 13.22 | 1609 (66.19) | 119 (4.90) | 24.11 | 0.31** (0.27–0.35) |
| | ≥ 13.22 | 467 (19.21) | 236 (9.71) | | |

#Cut off corresponding to 85th percentile of total skinfold thickness

*Moderate agreement; **Fair agreement *[Landis & Koch (1977)]*

# Discussion

There is a need for using feasible and accurate indicators of nutritional status in pregnant women and new-born children to identify adiposity, an independent cardiometabolic risk factor. The burgeoning epidemic of obesity impacts all age groups and has a negative impact across the life-course and generations. Our results indicate that MUAC higher than 29.2 cm can serve as a suitable alternative to total skinfolds based assessments for obesity screening in pregnancy in resource-constrained public health facilities. Similarly, a birth weight cut-off of 3.45 kg can be considered for classifying obesity among the newborns.

Pre-pregnancy measurements are rarely available in most of the Indian setting.(24) As per the national survey,(25) 59% rural and 41% of urban pregnant women avail public facilities for antenatal care, they mostly have their first antenatal visit late in the first trimester (or even later), making the bodyweight an unreliable indicator for assessment of overweight or obesity in pregnancy.(26) Since bodyweight is also integral to the estimation of BMI, this too suffers from the same limitation as a marker for obesity. Therefore, to obtain a reliable marker for obesity at any given point during the gestational period, we attempted to use MUAC measurements. Our results showed concordance with the review by Ververs *et al.*, wherein the reliability of inexpensive MUAC is validated.(27) Measuring MUAC in pregnancy eliminates the need for sophisticated equipment and calculations and is a reliable proxy of pre-pregnancy body fat and nutrition. These reasons also make MUAC a popular and feasible choice in public facilities.(28–30) A recent study conducted among adolescents, lactating and parous non-pregnant women in one of the most impoverished regions in India, reported that MUAC can be a viable marker for assessing the nutritional status of women in community settings.(23) Maternity care guidelines in South Africa, a country with a similar economic profile and maternal health challenges as India, recommends using MUAC greater than 33 cm as indicative of obesity in pregnant women.(29) The evidence from Argentina suggests MUAC cut-off points according to the gestational age.(30)

Birth weight is a reliable predictor of body composition in newborns, explaining up to 84% of body fat in the newborns.(31, 32) Previous studies have shown that Indian babies preserve more subscapular skinfold thickness at birth even though these children had a lower birth weight.(33) However this was not replicated in recent studies, that showed that Skinfold thicknesses in Indian babies were similar to those reported in a Western population with comparable birth weights, some of these studies used more accurate measurements of body composition like deuterium dilution and air displacement plethysmograph.(32, 34, 35) Studies have shown a significant positive correlation between body weight and %BF across the weight range of 2.3–4 kg (35). The available evidence supports our finding that intrauterine growth is best assessed by weight at birth.(36, 37) Similar findings were also found in other LMICs.(31, 38)

In India, measuring MUAC in pregnancy and birth weight to assess obesity can help to plan and prevent potential adverse outcomes. We recently showed that maternal obesity is an independent risk factor for neonatal adiposity.(39) Total skinfold measurement, the preferred method for assessment of obesity is

often impeded by the dearth of trained staff, time, and costly equipment. In comparison, MUAC and birth weight measurements can be incorporated relatively easily in antenatal care services for immediate use in all hospitals. The weighing scales are available in all labour rooms, including rural health centres. Therefore, the measurement of birth weight can be done immediately after birth. This can be further validated in other geographies and settings (such as private hospitals) to arrive at a national consensus for cut-off so that appropriate obesity control measures can be taken in early childhood to prevent the deleterious health consequences in their adult life. Both the anthropometric markers as alternatives for skinfold thickness in our study demonstrated the feasibility for use in the public facilities due to the usability and costs involved.

Some of the limitations are; firstly, the need to ensure adequate training for the healthcare staff for MUAC measurement. However, MUAC is less resource and skill intensive compared to skinfold thickness assessment. Secondly, there could be misclassification resulting from using a substitute measure for total skinfold thickness in obesity measurement; a certain proportion of the population may wrongly get classified obese (or vice versa) when they are not so. Further validation studies in India can establish the reliability and validity to steer policy-level actions to prioritise screening obesity in pregnancy. The third limitation is that this study mostly represents the source population comprising of low-middle income women that attend public facilities in Bengaluru. This needs to be validated in an even larger population to prove its wider applicability. However, we were able to capture the measurements among a large sample size of mother-child dyads and thus have been able to show the use at public facilities for urban populations that can be applied across the country.

## Declarations

# Ethical approval

The study was reviewed and approved by the Institutional ethics committee (IEC) of the Indian Institute of Public Health – Bengaluru campus *vide* IEC no. IIPHHB/TRCIEC/091/2015 dated 13th July 2015 and IEC no. IIPHHB/TRCIEC/121/2017 dated 24th July 2017. The study was conducted in accordance with the Declaration of Helsinki.

# Consent to participate and publish

Written informed consent before participation in the study was obtained from all voluntarily willing participants for participation, follow-ups, and permission to publish anonymous data in any report, journal etc. After delivery infants were measured for anthropometry after obtaining consent from the participant and in the presence of a family member.

# Availability of data and materials

The data that support the findings of this study are not publicly available but applications for data access can be submitted to the corresponding author on reasonable request.

# Competing Interests

The authors declare that they have no competing interests.

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# Contributors

GRB and AD contributed to conception and design. AD analysed the data. EL, DR and DJ drafted the manuscript. PT, SK, SBN and GVS contributed to interpretation and to critically revising the manuscript. All authors gave final approval and agree to be accountable for all aspects ensuring integrity and accuracy.

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# Figures

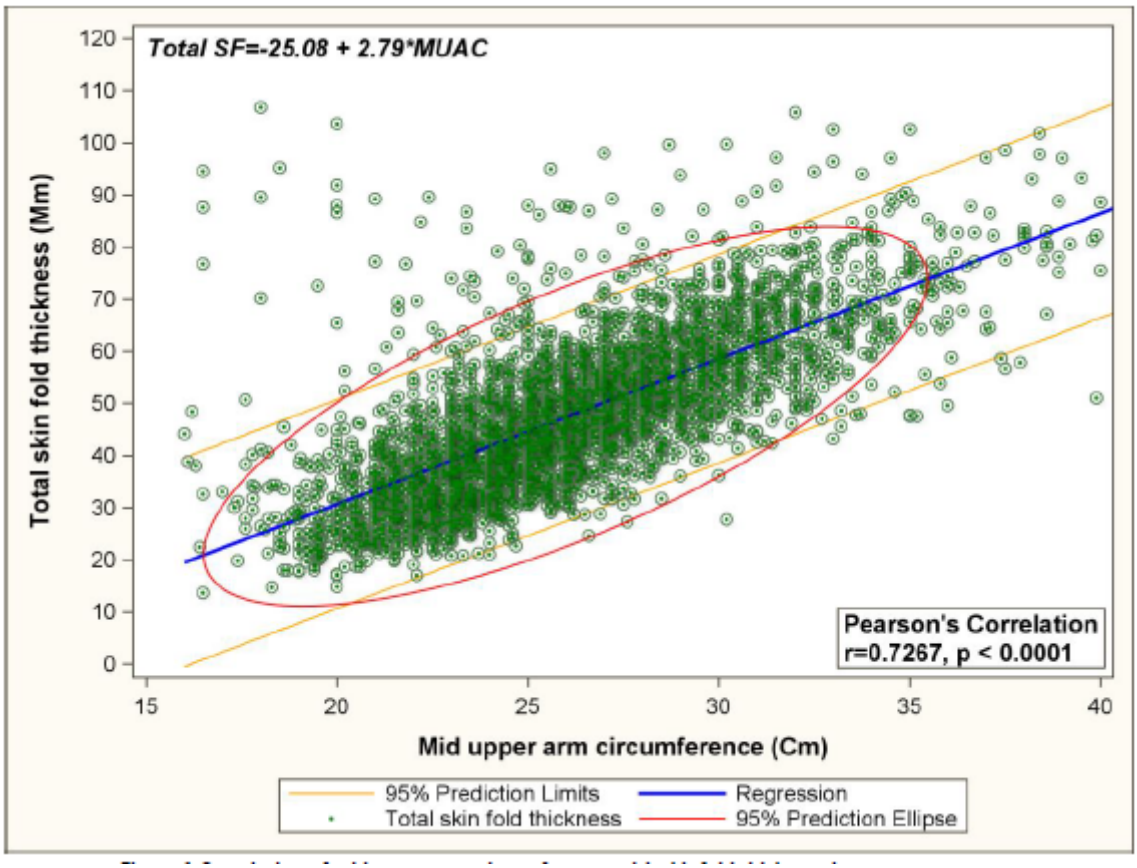
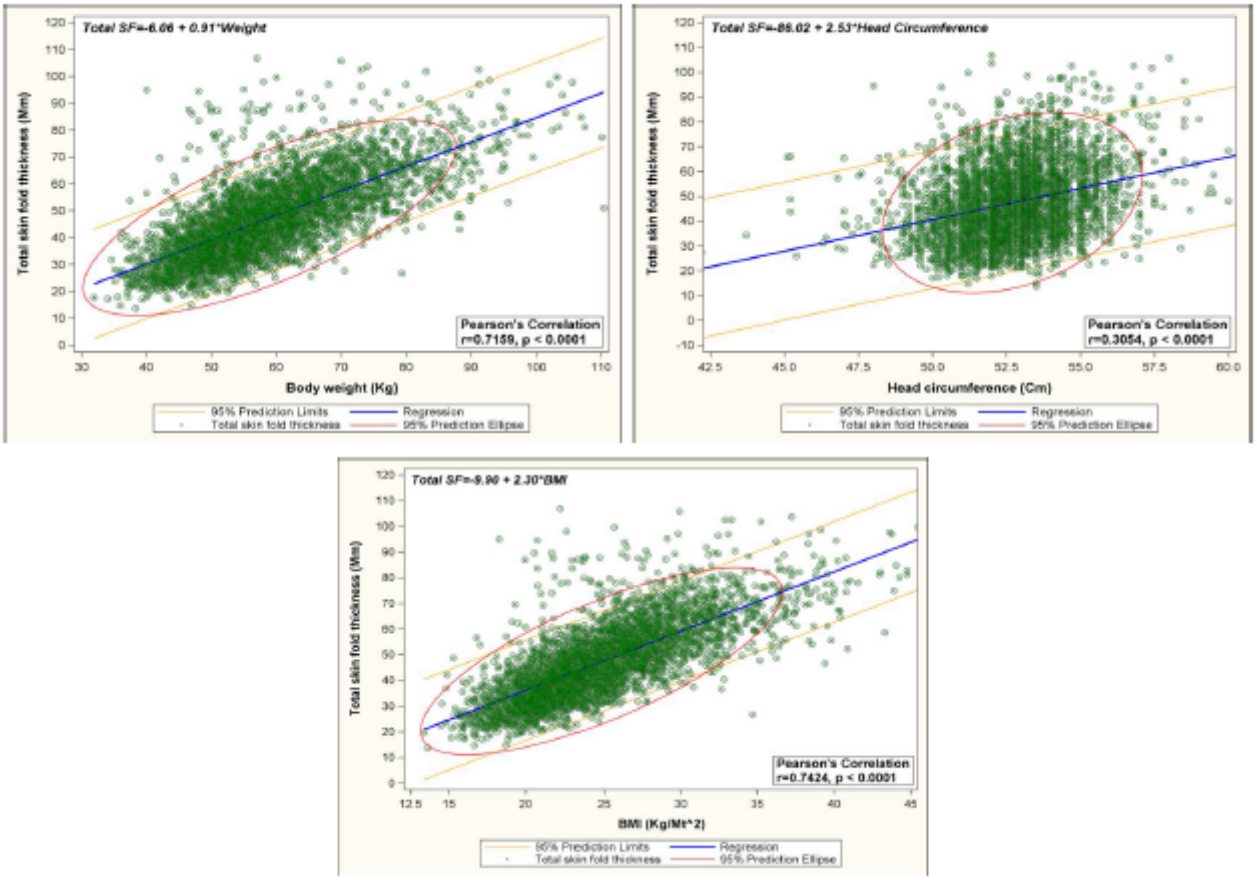


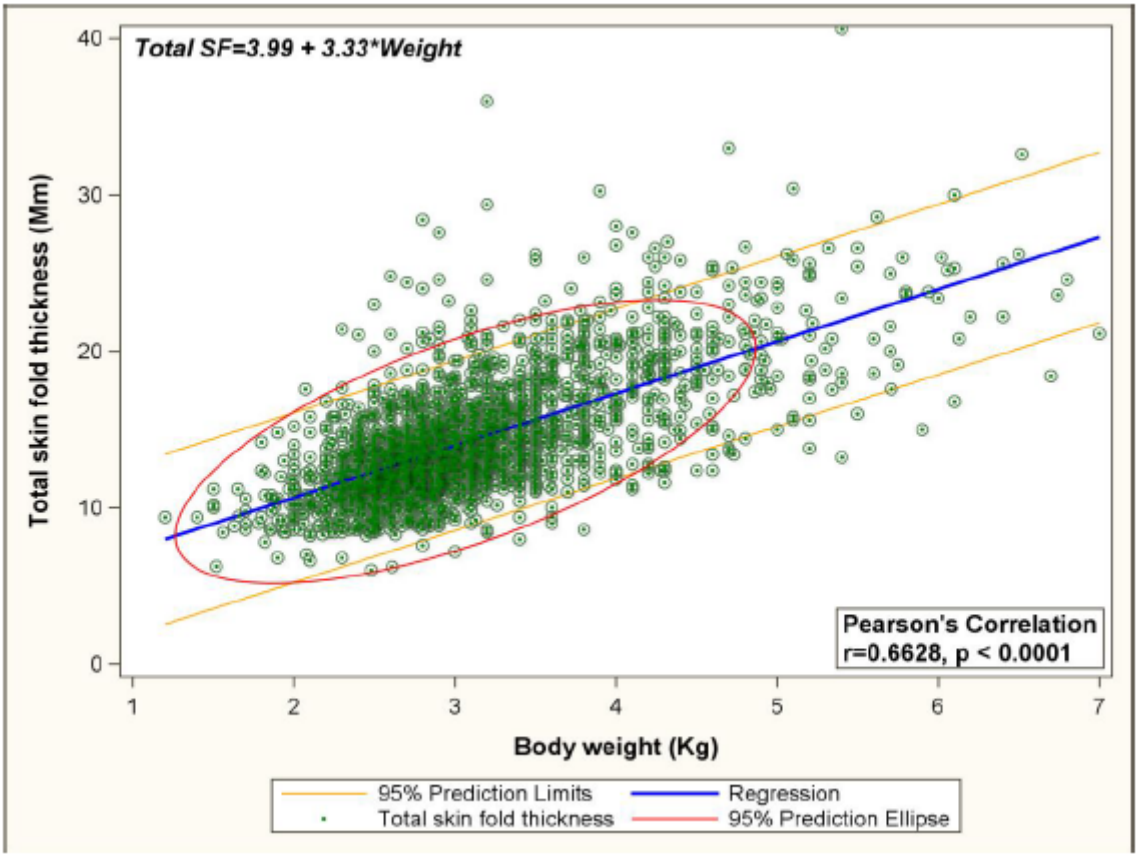

**Figure 1**

Correlation of mid-upper arm circumference with skinfold thickness in pregnant women



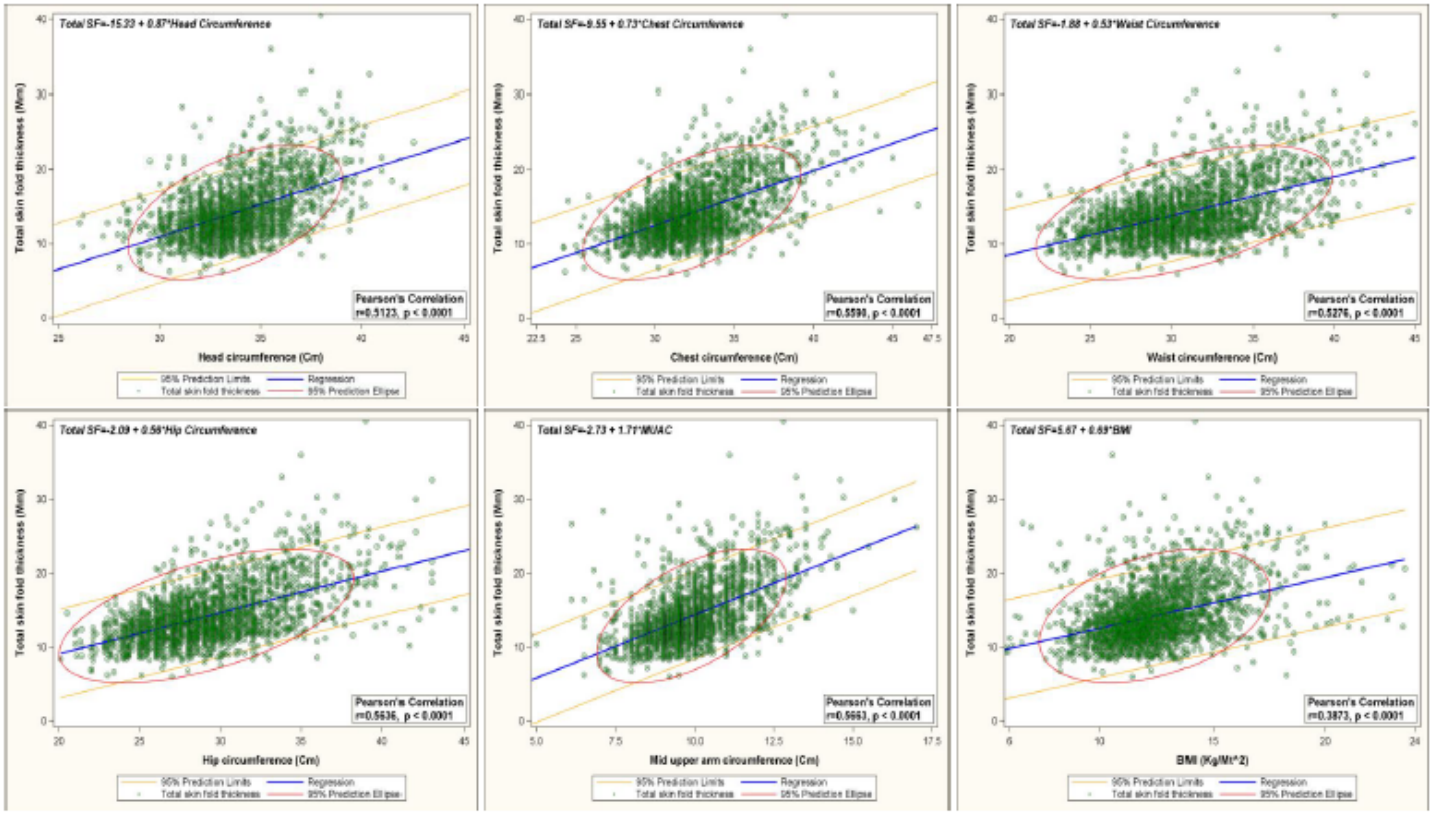

## Figure 2

Correlation of anthropometric markers with skinfold thickness in pregnant women




## Figure 3

Correlation of birth weight with skinfold thickness in infants




## Figure 4

Correlation of anthropometric markers with skinfold thickness at birth in infants