Original Article

DOI: 10.7860/IJNMR/2023/58624.2378

Paediatrics Section

Mid Upper Arm Circumference as the Best Surrogate Marker for Identification of Low Birth Weight in Newborns within the First 24 Hours of Life- A Cross-sectional Study

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ABSTRACT

Introduction: Birth weight is a very important determinant factor regarding perinatal morbidity and mortality. However, in developing countries like India weighing facility may not be available in rural areas where an alternative anthropometric parameter like Mid Upper Arm Circumference (MUAC) may be considered alternative to birth weight.

Aim: To determine the accuracy of MUAC by comparing it with different anthropometric parameters for identification of LBW in neonates within the first 24 hours of life.

Materials and Methods: The present study was a hospital based cross-sectional study conducted in labour ward, Postnatal Care (PNC) wards and Neonatal Intensive Care Unit (NICU) of Indira Gandhi Medical College, Nagpur. Total 640 babies were enrolled over a period of 2 years from September 2018 to September 2020. Anthropometric parameters like weight, length, head circumference, Chest Circumference (CC), MUAC, ponderal index were taken by a researcher using standard techniques within first 24 hours of life and correlated with birth weight by using Pearson's correlation coefficient. The comparison of the quantitative and qualitative variables was analysed using independent t-test and chi-square test, respectively. Receiver Operating Characteristic (ROC) curve was used to find out cut-off point of anthropometric parameters for predicting birth weight (<2000 gm, <1500 gm, <1000 gm). DeLong test was used for comparison of area under curve between different anthropometric parameters for predicting birth weight (<2000 gm, <1500 gm, <1000 gm). Univariate linear regression was used to assess the effect of anthropometric parameters on birth weight. The data entry was done in the Microsoft EXCEL spreadsheet and final analysis was done with the use of Statistical Package for Social Sciences (SPSS) software version 21.0.

Results: Among 640 newborns, 334 (59.19%) were females and 306 (47.81%) were males. The mean birth weight was 1903.93 grams and MUAC of 8.3cm. All the chosen parameters showed significant correlation with birth weight (p<0.001). However, MUAC showed strongest correlation (r=0.890) with birth weight and easy to measure. Cut-offs of MUAC ≤8.45 cm, ≤7.5 cm, ≤6.8 cm predict birth weight of <2000gm, <1500gm, <1000gm with sensitivity of 91.22%, 92.81%, 100% and specificity of 88.95%, 89.12%, 89.35%, respectively.

Conclusion: MUAC is the most simple and best surrogate measure that can be used in domiciliary outreach when it is impossible to record weight of baby at birth.

Keywords: Gestational age, Neonatal intensive care unit, Sensitivity and Specificity, Surrogate markers

INTRODUCTION

Birth weight is the most sensitive and reliable indicator of the health in a community and an important indicator of infant growth and survival [1]. Neonatal death is more likely among Low Birth Weight (LBW) babies especially in developing countries [2]. Globally, one in seven live births (20.5 million infants) fell in the LBW category and almost half of them are from South Asia. Moreover, around 40% of LBW infants are from India [3].

LBW is associated with high risk of infections, difficulty in breathing, hypothermia and feeding problems. Therefore, LBW should be detected early to allow newborns to receive appropriate care soon after delivery [4].

However, in some developing countries like India where home delivery is fairly common especially in rural areas, despite the high prevalence of LBW, only about half of the newborns are weighed at birth because of inadequate equipment and a lack of trained health staff and smaller proportion of them gestational age is known. In addition several deliveries are conducted in health care facilities where digital weighing machines are not available. Standardisation of machines is not available at outreach areas. In these circumstances surrogate markers for birth weight need to be identified. Such an anthropometric parameter should be cheap, simple to use even for illiterate people, valid, should identify LBW babies correctly, facilitating early referral to health facilities [5].

Many studies have reported a high correlation between birth weight and various anthropometric parameters (such as mid-arm circumference, mid-thigh circumference, calf circumference, head circumference, CC, foot length etc.,) in newborns [6-8].

MUAC has been found to be an alternative to birth weight in identification of LBW babies [9-11]. MUAC reflects the muscular and fat compartments. The muscular compartment provides an indirect reflection of the protein reserves, while the fat compartment estimates the energy reserves. A low MUAC may be an indication of a decrease in muscle mass, a decrease in subcutaneous fat tissue or both which correlates positively with changes in weight [12].

The aim of the present study was to reaffirm the suggestion given by the WHO of choosing a surrogate anthropometric parameter which could replace measurement of birth weight in a resource poor setting of rural areas of a developing country like India. This anthropometric parameter needs to be highly sensitive so that good proportion of at risk neonates will be referred to a higher center. At the same time, greater specificity is required so that unnecessary referrals do not burden the referral centers.

The present study was conducted to determine the diagnostic accuracy of various anthropometric parameters for predicting different categories of LBW. In the present study, the accuracy of MUAC was determined by comparing it with different anthropometric parameters and its cut-offs that are correlated with birth weight of <2000 gm, <1500 gm, <1000 gm. No similar study was done previously in Nagpur.

MATERIALS AND METHODS

This hospital based cross-sectional study over a period of 2 years from September 2018 to September 2020 was conducted at NICU, labour ward and PNC wards in Indira Gandhi Government Medical College, Nagpur. As per the study done by Sood SL et al., considering the proportion (p) of LBW babies with MUAC <9cm is 13.12% sample size was calculated by using formula [13]:

$n=3.84 \times pq/r^2$ (here r=20% of 13.12=2.624; r^2=6.88) q=1-p (considering 95% Confidence Interval (CL) and relative error being 20%)

$3.84 \times 13.12 \times 86.88/6.88=636$

A total of 640 newborns within 24 hours with birth weight <2.5 kg whether term, postterm or preterm irrespective of gestational age were included. Newborns with major congenital anomalies and/or birth injuries (including upper limb anomalies and with upper limb birth injury) and those who were sick excluded from study.

A written informed consent was obtained from parents or guardians. Ethical clearance for conducting the study was obtained from the Institutional Ethics Committee (Reference No.IGGMC/Pharm/IEC/222/2018). To avoid inter-observer bias, all measurements were taken by a researcher. Weight was recorded using electronic infant weighing machine (Phoenix Nitiraj Engineers Pvt., Ltd., CGMS-20 IND/09/11/210) after removing all the clothes including diaper. They were categorised into LBW (<2500 gm), VLBW (<1500 gm) and ELBW (<1000gm) [14].

MUAC measuring tape (Ibis Medical MUAC tape, IBIS Medical Equipment & Systems Pvt., Ltd., part no 0478) from UNICEF Supply Division was used to measure MUAC at midpoint between olecranon and acromion process [15]. Length of newborn was recorded on an infantometer (IS Indosurgicals Acrylic infantometer) with baby supine, knees fully extended and soles of the feet held firmly against the foot board and head touching fixed board. Head Circumference (HC) was measured by using a non stretchable non distensible plastic tape (Fargo measuring tape), the maximum circumference of the head from occipital protuberance to the supraorbital ridges on the forehead was recorded. CC was measured by non stretchable non distensible plastic tape (Fargo measuring tape) at the level of nipples, midway between inspiration and expiration [Table/Fig-1-3].

Ponderal index was calculated by using formula= weight (g)×100 / length (cm^3) [16].

[Table/Fig-1]: Measuring Chest Circumference (CC). **[Table/Fig-2]:** Measuring head circumference. (Images from left to right)

[Table/Fig-3]: Measuring MUAC.

STATISTICAL ANALYSIS

The comparison of the variables which were quantitative in nature was analysed using Independent t-test (for two groups). The comparison of the variables which were qualitative in nature was analysed using chi-square test. Pearson correlation coefficient was used to find out the correlation of MUAC with birth weight. Sensitivity, specificity, positive and negative predictive values for various MUAC were calculated and ROC curve was used to find out optimum cut-off point of MUAC for predicting LBW (<2000 gm, <1500 gm, <1000 gm). DeLong test was used for comparison of area under curve between different anthropometric parameters for predicting birth weight (<2000 gm, <1500 gm, <1000 gm). A simple linear regression model was fitted to predict birth weight from MUAC values and 95% Prediction Intervals (95% PI) constructed to examine the range of error in prediction on account of sampling variation. Univariate linear regression was used to assess effect of MUAC on birth weight. Data were entered in Microsoft excel spreadsheet and final analysis was done by using SPSS software version 21.0. Probability (p) value less than 0.05 was considered statistically significant.

RESULTS

Out of 640 newborns, 334 (52.19%) were females and 306 (47.81%) were males. Twenty (3.13%) newborns were Extremely LBW (ELBW) i.e., birth weight less than 1 kg, 133 (20.78%) newborns were having birth weight between 1-<1.5 kg while 487 (76.09%) newborns were having birth weight between 1.5 -<2.5 kg [Table/Fig-4].

A total of 444 (69.38%) newborns were delivered by vaginal route while 196 (30.63%) newborns were delivered by lower segment cesarean section.

[Table/Fig-4] shows mean birth weight of female newborns is 1918.75±488.15 grams and mean birth weight of male newborns is 1887.76±495.89 grams and p-value of 0.775 (which is >0.05, statistically not significant) hence there was no significant difference observed between birth weight and gender.

Birth weight (grams)	Female (n=334)	Male (n=306)	Total	p-value	Test performed
ELBW	10 (2.99%)	10 (3.27%)	20 (3.13%)	p=0.775	Chi-square test; 0.51
VLBW	66 (19.76%)	67 (21.90%)	133 (20.78%)		
LBW	258 (77.25%)	229 (74.84%)	487 (76.09%)		
Mean±SD	1918.75± 488.15	1887.76± 495.89	1903.93± 491.73	p=0.426	t-test; 0.796
Median (25th-75th percentile)	2000 (1500-2400)	2000 (1485-2370)	2000 (1500-2400)		
Range	600-2499	800-2490	600-2499		

[Table/Fig-4]: Comparison of birth weight (grams) between gender.

In the present study, birth weight ranged from 600-2499 gm with mean 1903.93±491.73 and median 2000 gm. Length of newborns ranges from 28-51cm with mean 41.68±3.97 cm and median 42.5 cm. MUAC ranges from 4.5-11.5 cm with mean 8.33±1.24 cm and median 8.5 cm. HC ranges from 11.8-35.5 cm with mean 30.94±3.26cm and median 31.5 cm. CC ranges from 11-35 cm with mean 29.81±3.43 cm and median 30 cm. Ponderal index ranges from 1.23-3.97 gm/cm³ with mean 2.6±0.43 gm/cm³ and median 2.69 gm/cm³ as shown in [Table/Fig-5] [17].

Anthropometric parameters	Mean±SD	Median (25th-75th percentile)	Range
Birth weight (grams)	1903.93±491.73	2000 (1500-2400)	600-2499
Length (cm)	41.68±3.97	42.5(39-44.5)	28-51
MUAC (cm)	8.33±1.24	8.5(7.4-9.4)	4.5-11.5
Head circumference (HC) (cm)	30.94±3.26	31.5 (29-33.5)	11.8-35.5
Chest circumference (CC) (cm)	29.81±3.43	30 (28-32)	11-35
Ponderal index(gm/cm³) [17]	2.6±0.43	2.69 (2.326-2.876)	1.23-3.97

[Table/Fig-5]: Descriptive statistics of anthropometric parameters of study subjects [17].

Variables	Length (cm)	MUAC (cm)	Head Circumference (HC) (cm)	Chest Circumference (CC) (cm)	Ponderal index
Birth weight (grams)					
Correlation coefficient (r-value)	0.811	0.890	0.788	0.803	0.254
p-value	p<0.001	p<0.001	p<0.001	p<0.001**	p<0.001**

[Table/Fig-6]: Correlation of anthropometric parameters with birth weight.
Pearson correlation coefficient

[Table/Fig-6] shows the correlation coefficient between anthropometric parameters and birth weight where birth weight was significantly correlated (p<0.001**) with anthropometric parameters like MUAC, length, head circumference, CC and ponderal index. Among all MUAC showed strongest correlation with birth weight with correlation coefficient (r-value) of 0.890 and ponderal index weakest (r=0.254).

Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <2000 gm were ≤41.8 cm, ≤8.45 cm, ≤30 cm, ≤29.5 cm, ≤2.68 gm/cm³ with sensitivity 80.41%, 91.22%, 73.65%, 76.01%, 64.19% and specificity 87.21%, 88.95%, 95.35%, 94.48%, 66.57%, respectively [Table/Fig-7].

[Table/Fig-8,9] depict comparison of area under ROC curve between different anthropometric parameters for predicting birth weight <2000 grams.

Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <1500 gm were ≤40 cm, ≤7.5 cm, ≤28.3 cm, ≤28 cm, ≤2.33 gm/cm³ with sensitivity 88.89%, 92.81%, 60.78%, 73.86%, 49.02% and specificity 82.96%, 89.12%, 92.61%, 83.98%, 81.52, respectively [Table/Fig-10].

[Table/Fig-11,12] depict comparison of area under ROC curve between different anthropometric parameters for predicting birth weight <1500 grams.

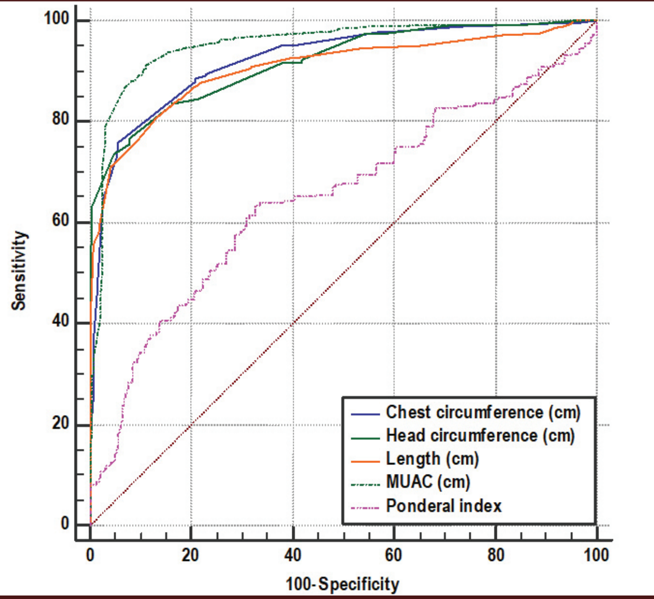
Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <1000 gm were ≤39 cm, ≤6.8 cm, ≤27 cm, ≤25 cm, ≤1.83 gm/cm³ with sensitivity 95%, 100%, 75%, 85%, 35% and specificity 76.29%, 89.35%, 90.32%, 90.32%, 97.42%, respectively [Table/Fig-13].

[Table/Fig-14,15] depict comparison of area under ROC curve between different anthropometric parameters for predicting birth weight <1000 grams.

As shown in [Table/Fig-14], the ROC curves for predicting BW <1000 grams showed that MUAC (AUC=0.97, 95%CI: 0.95-0.98) provided a better AUC than other parameters like length (AUC =0.94, 95% CI: 0.92-0.96), HC(AUC=0.88, 95% CI: 0.86-0.91), CC (AUC=0.93, 95% CI: 0.91-0.95), PI (AUC=0.59, 95% CI: 0.55-0.62) although the difference was not significant. Similarly, MUAC was more superior than other parameters for predicting birth weight <1500 grams and <2000 grams as shown in [Table/Fig-8,11], respectively.

Birth weight (grams) (<2000)	Length (cm)	MUAC (cm)	Head Circumference (HC) (cm)	Chest Circumference (CC) (cm)	Ponderal index (gm/cm³)
Area under ROC curve (AUC)	0.907	0.954	0.918	0.924	0.65
Standard error	0.0126	0.00844	0.0108	0.0104	0.0223
95% confidence interval	0.881-0.928	0.934-0.969	0.894-0.938	0.901-0.944	0.611- 0.687
p-value	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Cut-off	≤41.8	≤8.45	≤30	≤29.5	≤2.681
Sensitivity (95% CI)	80.41% (75.4-84.8)	91.22% (87.4-94.2%)	73.65% (68.2-78.6%)	76.01% (70.7-80.8%)	64.19% (58.4-69.7%)
Specificity (95% CI)	87.21% (83.2-90.6%)	88.95% (85.2-92.1%)	95.35% (92.6-97.3%)	94.48% (91.5-96.6%)	66.57% (61.3-71.5%)
PPV (95% CI)	84.4% (79.6-88.4%)	87.7% (83.5-91.1%)	93.2% (89.1-96.0%)	92.2% (88.1-95.2%)	62.3% (56.6-67.8%)
NPV (95% CI)	83.8% (79.6-87.5%)	92.2% (88.7-94.8%)	80.8% (76.6-84.5%)	82.1% (77.9-85.7%)	68.4% (63.1-73.3%)
Diagnostic accuracy	84.06%	90.00%	85.31%	85.94%	65.47%

[Table/Fig-7]: Receiver Operating Characteristic (ROC) curve to find out cut-off point of anthropometric parameters for predicting birth weight <2000 gm.



[Table/Fig-8]: ROC curve showing comparison of area under curve between different anthropometric parameters for predicting birth weight <2000 grams.
MUAC (AUC=0.95) CC(AUC=0.92) HC(AUC=0.91) Length (AUC=0.90) PI (AUC=0.65)

Birth weight (grams) (<2000)	Difference between areas	Standard error	95% Confidence interval	p-value
Chest Circumference (CC) (cm) vs. Head Circumference (HC) (cm)	0.00599	0.00858	-0.0108-0.0228	0.4851
Chest Circumference (CC) (cm) vs. Length (cm)	0.0176	0.0153	-0.0123-0.0475	0.2493
Chest Circumference (CC) (cm) vs. MUAC (cm)	0.0293	0.0112	0.00731-0.0513	0.009
Chest Circumference (CC) (cm) vs. Ponderal index	0.275	0.0256	0.224-0.325	<0.001**
Head Circumference (HC) (cm) vs. Length (cm)	0.0116	0.014	-0.0158-0.0390	0.407
Head Circumference (HC) (cm) vs. MUAC (cm)	0.0353	0.0121	0.0116 -0.0590	0.0035*
Head Circumference (HC) (cm) vs. Ponderal index	0.269	0.0272	0.215-0.322	<0.001**
Length (cm) vs. MUAC (cm)	0.0469	0.0136	0.0202-0.0736	<0.001**
Length (cm) vs. Ponderal index	0.257	0.0302	0.198-0.316	<0.001**
MUAC (cm) vs. Ponderal index	0.304	0.0236	0.258-0.350	<0.001**

[Table/Fig-9]: Comparison of area under curve between different anthropometric parameters for predicting birth weight <2000 grams.

[Table/Fig-7,10,13] shows cut-offs of MUAC ≤8.45, ≤7.5 cm, ≤6.8 cm predict birth weight of <2000 gm, <1500 gm, <1000 gm, respectively using ROC curve with sensitivity of 100%, 92.81%, 91.22% and specificity of 89.35%, 89.12%, 88.95%, respectively.

A simple linear regression was fitted with birth weight as independent variable and MUAC as dependent variable. The regression coefficient 'b' (slope) was 354.1 (95% CI of b=340.026, 368.173); p <0.001 as shown in [Table/Fig-16].

[Table/Fig-17] shows relationship between MUAC and birth weight. MUAC is significantly correlated with birth weight with correlation coefficient of 0.890 and p-value < 0.001**.

DISCUSSION

Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <2000 gm were ≤41.8 cm, ≤8.45cm, ≤30 cm, ≤ 29.5 cm, ≤2.68 gm/cm^3 with sensitivity 80.41%, 91.22%, 73.65%, 76.01%, 64.19% and specificity 87.21%, 88.95%, 95.35%, 94.48%, 66.57%, respectively.

Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <1500 gm were ≤40 cm, ≤7.5 cm, ≤28.3cm, ≤28cm, ≤2.33gm/cm^3 with sensitivity 88.89%, 92.81%, 60.78%, 73.86%, 49.02% and specificity 82.96%, 89.12%, 92.61%, 83.98%, 81.52%, respectively.

Cut-offs of length, MUAC, HC, CC and ponderal index for determining BW <1000 gm were ≤39 cm, ≤6.8 cm, ≤27 cm, ≤ 25 cm, ≤1.83 gm/cm^3 with sensitivity 95%, 100%, 75%, 85%, 35% and specificity 76.29%, 89.35%, 90.32%, 90.32%, 97.42%, respectively [Table/Fig-18].

In other studies done outside India like in Nigeria, Bangladesh and Indonesia, MUAC cut-off were 9.6cm, 9cm and 10.5 cm for predicting birth weight <2500 gm [18-20]. Thus, the cut-off point for MUAC that would identify newborns with a birth weight <2500 gm was between 9 cm to 10.5 cm.

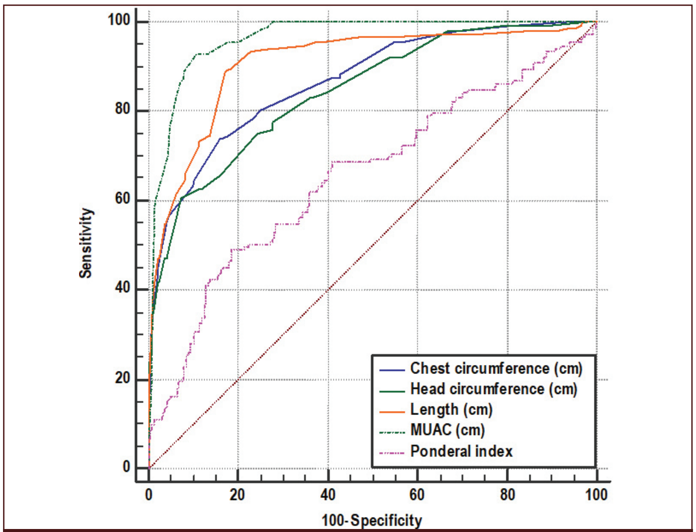
Cut-off of MUAC according to present study is ≤8.45 cm for predicting birth weight of <2000 gm. while Das JC et al., found cut-off of 8cm of MUAC for <2000 gm [19]. Jyothi SD and Gopal K found MUAC cut-off of ≤9.03 cm for <2000 gm [22]. [Table/Fig-19] of cut-off values from similar studies using MUAC for detection of LBW (BW <2500 gm) [18-23].

[Table/Fig-19] shows a comparison of cut-off values of MUAC for detection of VLBW (BW<1500 gm) from previous studies [13,19].

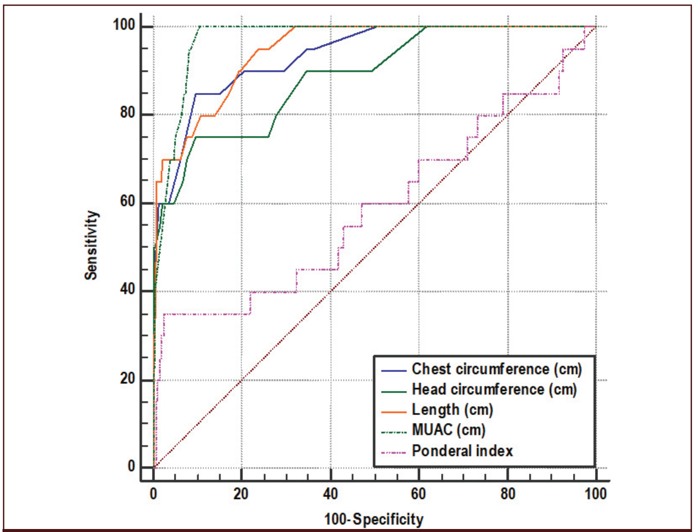
Very few studies [13,23] have been carried out to predict the birth weight <1000 gm using this simple anthropometric parameter such as MUAC as shown in [Table/Fig-19].

Birth weight (grams) (<1500)	Length (cm)	MUAC (cm)	Head Circumference (HC) (cm)	Chest Circumference (CC) (cm)	Ponderal index (gm/cm^3)
Area under curve (AUC)	0.909	0.962	0.845	0.868	0.656
Standard error	0.0147	0.00679	0.0185	0.017	0.0272
95% Confidence interval	0.884 to 0.930	0.945 to 0.976	0.815 to 0.873	0.839 to 0.893	0.618 to 0.693
p-value	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Cut-off	≤40	≤7.5	≤28.3	≤28	≤2.3324
Sensitivity (95% CI)	88.89% (82.8-93.4%)	92.81% (87.5-96.4%)	60.78% (52.6-68.6%)	73.86% (66.1-80.6%)	49.02% (40.9-57.2%)
Specificity (95% CI)	82.96% (79.3-86.2%)	89.12% (86.0-91.7%)	92.61% (89.9-94.8%)	83.98% (80.4-87.1%)	81.52% (77.8-84.9%)
PPV (95% CI)	62.1% (55.3-68.6%)	72.8% (66.0-78.9%)	72.1% (63.5-79.6%)	59.2% (51.8-66.2%)	45.5% (37.7-53.4%)
NPV (95% CI)	96% (93.6-97.6%)	97.5% (95.6-98.8%)	88.3% (85.1-90.9%)	91.1% (88.1-93.6%)	83.6% (79.9-86.8%)
Diagnostic accuracy	84.38%	90.00%	85.00%	81.56%	73.75%

[Table/Fig-10]: Receiver Operating Characteristics (ROC) to find out cut-off point of anthropometric parameters for predicting birth weight <1500 gm.



[Table/Fig-11]: ROC Curve showing comparison of area under curve between different anthropometric parameters for predicting birth weight <1500 grams.



[Table/Fig-14]: ROC curve showing comparison of area under curve between different anthropometric parameters for predicting birth weight <1000 grams.

Birth weight (grams) (<1500)	Difference between areas	Standard error	95% Confidence interval	p-value
Chest Circumference (CC) (cm) vs. Head Circumference (HC) (cm)	0.0222	0.0122	0.00159-0.0461	0.0674
Chest Circumference (CC) (cm) vs. Length (cm)	0.0411	0.0204	0.00110-0.0810	0.044
Chest Circumference (CC) (cm) vs. MUAC (cm)	0.0947	0.0157	0.0640-0.125	<0.001**
Chest Circumference (CC) (cm) vs. Ponderal index	0.211	0.0359	0.141-0.282	<0.001**
Head Circumference (HC) (cm) vs. Length (cm)	0.0633	0.019	0.0261-0.101	<0.001**
Head Circumference (HC) (cm) vs. MUAC (cm)	0.117	0.0174	0.0828-0.151	<0.001**
Head Circumference (HC) (cm) vs. Ponderal index	0.189	0.0386	0.114-0.265	<0.001**
Length (cm) vs. MUAC (cm)	0.0536	0.0148	0.0246-0.0827	<0.001**
Length (cm) vs. Ponderal index	0.252	0.0364	0.181-0.324	<0.001**
MUAC (cm) vs. Ponderal index	0.306	0.0285	0.250-0.362	<0.001**

[Table/Fig-12]: Comparison of area under curve between different anthropometric parameters for predicting birth weight <1500 grams.

Birth weight (grams) (<1000)	Length (cm)	MUAC (cm)	Head Circumference (HC) (cm)	Chest Circumference (CC) (cm)	Ponderal index (gm/cm^3)
Area under ROC curve (AUC)	0.946	0.972	0.887	0.935	0.59
Standard error	0.0201	0.00813	0.0416	0.0266	0.0799
95% Confidence interval	0.926-0.962	0.955-0.983	0.860-0.910	0.912-0.952	0.551-0.629
p-value	<0.001*	<0.001*	<0.001*	<0.001*	0.2593
Cut-off	≤39	≤6.8	≤27	≤25	≤1.8311
Sensitivity (95% CI)	95% (75.1-99.9%)	100% (83.2-100.0%)	75% (50.9-91.3%)	85% (62.1-96.8%)	35% (15.4-59.2%)
Specificity (95% CI)	76.29% (72.7-79.6%)	89.35% (86.7-91.7%)	90.32% (87.7-92.5%)	90.32% (87.7-92.5%)	97.42% (95.8-98.5%)
PPV (95% CI)	11.4% (7.0-17.3%)	23.3% (14.8-33.6%)	20% (11.6-30.8%)	22.1% (13.4-33.0%)	30.4% (13.2-52.9%)
NPV (95% CI)	99.8% (98.8-100%)	100% (99.3-100.0%)	99.1% (97.9-99.7%)	99.5% (98.5-99.9%)	97.9% (96.4-98.9%)
Diagnostic accuracy	76.88%	89.69%	89.84%	90.16%	95.47%

[Table/Fig-13]: Receiver Operating Characteristic (ROC) curve to find out cut-off point of anthropometric parameters for predicting birth weight <1000 gm.

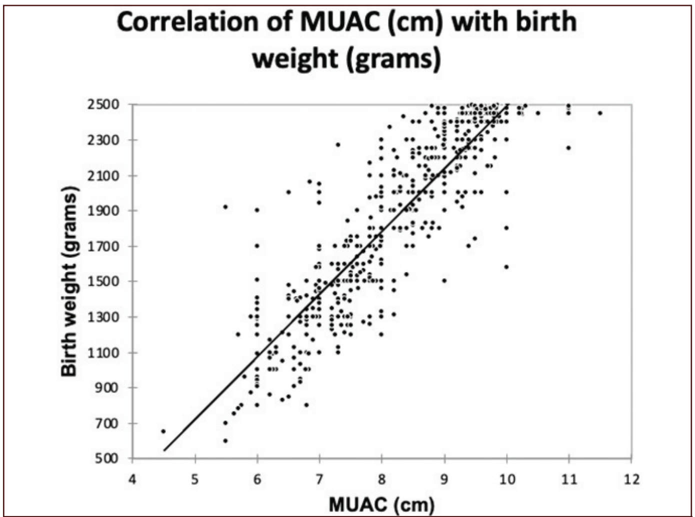
Birth weight (grams) (<1000)	Difference between areas	Standard error	95% Confidence interval (CI)	p-value
Chest Circumference (CC) (cm) vs. Head Circumference (HC) (cm)	0.0477	0.033	-0.0171-0.112	0.149
Chest Circumference (CC) (cm) vs. Length (cm)	0.0115	0.0239	-0.0354 -0.0584	0.6308
Chest Circumference (CC) (cm) vs. MUAC (cm)	0.037	0.0245	-0.0110-0.0851	0.1311
Chest Circumference (CC) (cm) vs. Ponderal index	0.344	0.0966	0.155-0.534	0.0004
Head Circumference (HC) (cm) vs. Length (cm)	0.0592	0.0317	-0.00290-0.121	0.0617
Head Circumference (HC) (cm) vs. MUAC (cm)	0.0847	0.042	0.00237 -0.167	0.0438

Head Circumference (HC) (cm) vs. Ponderal index	0.297	0.111	0.0792-0.514	0.0075
Length (cm) vs. MUAC (cm)	0.0255	0.0204	-0.0145-0.0656	0.2118
Length (cm) vs. Ponderal index	0.356	0.0946	0.170 -0.541	0.001**
MUAC (cm) vs. Ponderal index	0.381	0.0815	0.222-0.541	<0.001**

[Table/Fig-15]: Comparison of area under curve between different anthropometric parameters for predicting birth weight <1000 grams.

Variable	Beta coefficient	Standard error	p-value	Lower bound (95%)	Upper bound (95%)	Equation
Length (cm)	100.521	2.869	<0.001**	94.888	106.155	-2285.383+100.521*Length (cm)
MUAC (cm)	354.100	7.167	<0.001**	340.026	368.173	-1046.921+354.1*MUAC (cm)
Head Circumference (HC) (cm)	118.786	3.677	<0.001**	111.564	126.007	-1770.862+118.786* Head Circumference (HC) (cm)
Chest Circumference (CC) (cm)	115.075	3.387	<0.001**	108.423	121.726	-1526.847+115.075*Chest Circumference (CC) (cm)
Ponderal index (gm/cm^3)	292.738	44.176	<0.001**	205.990	379.485	1142.06+292.738*Ponderal index

[Table/Fig-16]: Univariate linear regression to assess effect of anthropometric parameters on birth weight.
Linear regression equation derived from present study is -1046.921+354.1×MUAC



[Table/Fig-17]: Scatter diagram of MUAC (cm) with birth weight (grams).

Sr. no	Anthropometric measurement	<2 kg	<1.5 kg	<1 kg
1.	Length (cm)	≤41.8	≤40	≤39
2.	MUAC (cm)	≤8.45	≤7.5	≤6.8
3.	HC (cm)	≤30	≤28.3	≤27
4.	CC (cm)	≤29.5	≤28	≤25
5.	Ponderal index (gm/cm^3)	≤2.68	≤2.33	≤1.83

[Table/Fig-18]: Cut-off values of different anthropometric measurements corresponding to birth weight of <2 kg and <1.5 kg <1 kg.

Sr. no.	Author	Year	Place	Cut-off values (cm)
LBW (BW <2500 gm)				
1.	Ezeaka VC et al., [18]	2003	Nigeria	9.6
2.	Das JC et al., [19]	2005	Bangladesh	9.0
3.	Taufiq M et al., [20]	2009	Indonesia	10.5
4.	Otupiri E et al., [21]	2014	Ghana	9.4
5.	Jyothi SD and Gopal K [22]	2016	Mysore, Karnataka, India	9.9
6.	Rajesh N and Kiran P [23]	2018	Kammam, Telangana India	10.5
7.	Agrawal A et al., [24]	2020	Gwalior, Madhya Pradesh, India	8.1-9.0
VLBW (BW <1500 gm)				
1.	Sood SL et al., [13]	2002	Pune, Maharashtra, India.	6.1-7
2.	Das JC et al., [19]	2005	Bangladesh	6.8
3.	Present study	2022	Nagpur, Maharashtra, India	7.5
ELBW (BW<1000 gm)				
1	Sood SL et al., [13]	2002	Pune, Maharashtra, India.	5.5-6
2	Agrawal A et al., [24]	2020	Gwalior, Madhya Pradesh, India.	5.5-6
3	Present study	2022	Nagpur, Maharashtra, India	6.8

[Table/Fig-19]: Literature review of cut-off values of Mid Upper Arm Circumference (MUAC) for detection of LBW, VLBW, ELBW [13,18-24].

Linear regression equation derived from present study was-1046.921+354.1× MUAC. MUAC value of 8.3 cm was seen to predict a birth weight of 1893 grams (95% PI 1775 gm, 2008 gm). MUAC of 8.7 cm was seen to predict birth weight as 2033gm (95% PI 1911 gm, 2156 gm).

It means that just by sampling variation a value of birth weight could more than 2000 gm. Hence, MUAC value of 8.7 cm definitely excludes newborns with birth weight <2000 gm which may lead to miss many LBW newborns.

In present study, MUAC was found to be the best surrogate to predict LBW newborns in rural settings of a developing country like India. The mean cut-off point of MUAC can be 8.3cm which showed highest sensitivity and specificity.

Limitation(s)

In present study, all LBW newborns were included because of which cut-off of any of the various anthropometric measurements that correlated with birth weight of <2.5 kg could not be calculated hence, < 2 kg cut-offs were calculated. For the same reason prevalence of LBW for this study in Nagpur could not be calculated. Cut-offs of normal BW could not be calculated and compared with LBW cut-offs. This study was done in Nagpur, India and whether these cut-offs can be applied to babies from other countries this question remains unanswerable.

CONCLUSION(S)

The results of the study clearly establish the usefulness of MUAC as an indicator of LBW. This surrogate anthropometric parameter could be of great help for health personnel in rural setting to detect high risk neonates. Present study has given cut-offs for different categories of LBW. This is for the urgent referral of very LBW and extremely LBW babies to prevent morbidity and mortality. This will be available as an example of cost effective health care strategy.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Jun 29, 2022
- Manual Googling: Nov 10, 2022
- iThenticate Software: Nov 17, 2022 (9%)

ETYMOLOGY: Author Origin

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? Yes
- For any images presented appropriate consent has been obtained from the subjects. Yes

Date of Submission: **Jun 22, 2022**
Date of Peer Review: **Oct 12, 2022**
Date of Acceptance: **Nov 19, 2022**
Date of Publishing: **Jun 30, 2023**