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Original Research Article

Accuracy of foot length, head, chest, mid-arm and calf circumference for the diagnosis of low birth weight in Ile-Ife

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ABSTRACT

Background: Statistics from the Nigeria demographic and health survey (NDHS) 2018 revealed that about 59% of women delivered at home and only 24% of babies were weighed at birth. Subsequently, many small babies may have been missed. It is therefore necessary to identify alternative and effective surrogates to birth weight especially in places where weighing scales are not available through the use of simple and familiar tools.
Methods: It was a descriptive cross-sectional study involving the measurement of birth weight, occipitofrontal circumference (OFC), mid-upper arm circumference (MUAC), chest circumference (ChC), calf circumference (CC) and foot length (FL). Binary logistic regression analysis was used to determine degree of relationship between the anthropometric parameters and low birth weight. Cut-off values (with the highest sensitivity and specificity) were determined and diagnostic accuracy was performed using the area under the receiver's operating characteristics (ROC) curve.
Results: All anthropometric measurements correlated positively with birth weight. With each unit increase in the MUAC, the odds for low-birth weight outcome decreased with an odds ratio (OR) of 0.099 (95% CI 0.045-0.213; $p<0.001$). Cut-offs and area under the curve (AUC) values for OFC, MUAC, chest circumference, calf circumference and foot length were 32.9 cm, 9.8 cm, 30.2 cm, 9.8 cm and 7.4 cm; and 0.93, 0.97, 0.96, 0.96 and 0.92 respectively.
Conclusions: MUAC had the best predictive performance in detecting low birth weight. The findings of this study provide an opportunity for early identification of low birth weight especially among out-of-facility births so that life-saving interventions can be instituted early.

Keywords: Anthropometry, Surrogate marker, ROC curve, Low-birth weight, Cut-off

INTRODUCTION

Birth weight is an important indicator of growth, development and survival of babies.[1] Globally, about 20 million low birth weight infants are born annually.[2] Low birth weight is a risk factor for increased morbidity and mortality as about 40-80% of neonatal deaths occur among low birthweight infants globally.[2] In Nigeria, with majority of deliveries occurring outside the hospital and unsupervised, most of the babies are not being weighed at birth and the risk of morbidity and mortality is high due to the non-detection of small babies.[3]

Birth weight should ideally be measured as accurately as possible to identify high risk babies.[4,5] However, in Nigeria and other low-income countries where out-of-facility deliveries are still quite high, early identification of low-birth weight babies through simple alternative means in places where weighing scales not available will enable early referral to facilities where these high risk babies can be managed.

Head size (OFC), length at birth and mid-upper-arm circumference are important anthropometric measurements that depict how well a baby had thrived in-utero.[2,4,6] They are also surrogate markers of birth weight and can serve as screening tools for detecting low birth weight babies in a low resource setting like Nigeria.[2,4] These measurements can be made with simple tools like non-elastic measuring tapes which are readily available in our environment. Its use for clinical studies is also easily learned. The prompt identification of low-birth weight babies will impact positively on new born care, especially the reduction of morbidity and mortality.

Studies on the use of different anthropometric measurements as surrogates for birth weight have revealed different results. Anthropometric parameters measured include length at birth, chest circumference, mid-upper-arm circumference and foot-length.[4,7-9] The measurements were mostly taken using flexible non-elastic tape. In some studies, hard-plastic ruler was used to measure foot-length.[10] While Ndu et al and Otupiri et al found chest circumference to be the best surrogate for birth weight, Achebe et al reported that MUAC was a more accurate predictor of low birth weight.[7,11,12] Adejuyigbe et al found chest circumference to be the best surrogate for birth weight in Ile- Ife, Nigeria with all measurements made using a flexible non-elastic tape, including foot-length.[4] With the use of a hard-plastic ruler to measure foot length and the nipple line as a land mark for chest circumference measurement, another study is justified because a different surrogate marker that is more predictive of low birth weight may be found. This is a knowledge gap that would be filled by this study. In addition, changes in genetic and socio-economic factors in the society over the two decades may have impacted on new born anthropometry. Therefore, this study may show changes in cut-off values or differences in predictive performance of surrogate anthropometric measures when compared to previous studies. New inferences may be drawn from this research.

The aim of the study was to determine which of the selected anthropometric measurements (chest circumference, OFC, mid-upper-arm circumference, calf circumference and foot length) correlated best with birth weight and to determine cut-off values below which low birth weight is predicted. The specific objectives were to: determine the mean weight, chest circumference, OFC, mid-upper-arm circumference, calf circumference and foot-length of babies born in Ile-Ife; determine the degree of correlation between the above parameters and birth weight and to determine and compare the cut-off values of the parameters, below which low birth weight is predicted.

METHODS

This study was carried out at the Obafemi Awolowo University Teaching Hospitals complex (OAUTHC), Ile-Ife. The study population consisted of consecutive apparently well neonates delivered at the Ife hospital unit irrespective of gestational age, weight and sex.

The study design was a descriptive cross-sectional type carried out between April 20th 2019 to July 20th 2019 and 420 consecutively delivered babies were recruited until the sample size was attained. Inclusion criteria was all healthy new born irrespective of gestational age and sex seen within 12 hours of birth. Babies with congenital anomalies were excluded because malformations such as limb defects or hydrocephalus may affect measurements such as mid-upper arm chest and calf circumference.[13] Also, twins and other multiple births were excluded as in other studies on new born anthropometry.[14] Ethical approval was obtained from the OAUTHC research and ethics committee. Informed consent was obtained from mothers or care givers after providing a detailed explanation of the study procedure.

Study procedure

A research proforma was used to record data of subjects. The data included age, gender, date and place of delivery. Gestational age at delivery was determined using the last normal menstrual period of the mother or an ultrasound scan done in the first or early second trimester. Modified Ballard scoring was done for babies whose mothers did not remember their LMP and did not have ultrasound scan reports available.[15] Babies were weighed within the first 12 hours of life because changes in water composition after the first day of life have been found to cause a reduction in weight.[16]

For each recruited study subject, the procedure was explained to the mother. Hand washing was done before and after taking the measurements of each baby. The following measurements were taken within the first 12 hours of birth:

Weight[17]

Babies were weighed naked using the Seca baby weighing scale with the serial number 354. The weight was then approximated to the nearest 10 gm for this study.

OFC[17]

Measurement of the head was taken with the glabella anteriorly and occipital prominence posteriorly as landmarks. The tape was anchored on the skull to avoid slippage and pulled tight to compress the subcutaneous tissue slightly. Measurement was taken to the nearest 0.1 cm.

Mid-arm circumference (MAC)[18]

The acromion of the left arm was palpated; with the baby's arm flexed at about 90 degrees, the olecranon was also palpated. The mid-point between the tip of the acromion and olecranon processes of the left arm was identified and the arm circumference was taken. Care was taken not to compress the skin with the tape. The measurement was approximated to the nearest 0.1 cm.

Chest circumference (ChC)[18]

Using the two nipples as reference points anteriorly, the tape was passed around the chest and just below the inferior angle of the scapulae posteriorly. The measurement was then taken at expiration. Care was taken not to pull the tape too tight to the skin.

Foot-length (FL)[10]

This was measured from the heel medially to the tip of the big toe using a hard-transparent plastic ruler. The plastic ruler was pressed vertically against sole of the foot with the zero end at the heel and the measurement taken at the top border of the big toe.

Calf circumference (CC)[9]

With the knee held in a semi-flexed position, the tape was held perpendicular to an imaginary line joining the medial condyle of the left tibia to the medial malleolus. The measurement was taken by passing a flexible non elastic tape around the bulk of the calf muscle.

All measurements were taken twice by the researcher and two assistants and the average reading was recorded. This was done to ensure accuracy as much as possible. The flexible tapes were replaced when the graded marks faded to ensure validity of the measurement. Subjects were naked and supine while measurements were taken.

The weighing scale was calibrated after every 20 subjects using a set of standard 500 g, 1.0 kg, 2.0 kg, 3.0 kg and 4.0 kg weights.[19]

Data analysis

Chi square was used to test for association between weight categories (<2500 g, 2,500 g to 3,999 g and >4,000 g) and gender of the neonates. Likelihood ratio Chi square was also used to subclassify term and preterm LBW babies into SGA, AGA and LGA groups.[20] Continuous variables (ChC, CC, OFC, FL and MAC) were reported as mean and standard deviation while t-test statistics was used to compare the mean anthropometric parameters of term and preterm babies.

Correlation of continuous variables with birth weight was determined using Pearson correlation coefficient.[21] A correlation matrix was run on the independent variables (anthropometric parameters) to determine co-linearity. Logistic regression analysis was then used to determine the extent of relationship between the anthropometric parameters and low birth weight (dependent variable). ROC curve-analysis was conducted for each anthropometric measure and the sensitivity and specificity were calculated for a range of measures.[22] In each curve, the sensitivity is plotted on the y-axis and (1-specificity) is plotted on the x-axis at different cut-off points. The Youden's index (sensitivity + specificity-1) was determined to estimate the optimal cut-off that predicted low birth weight.[23] One cut-off point each, higher and lower than the optimal cut-off were selected and diagnostic tests were run to determine the respective sensitivity, specificity and predictive values.

The AUC at 95% confidence interval was also calculated as a measure of diagnostic accuracy to show which variable best predicted low birth weight at the selected cut-off point. The anthropometric parameters with curves closest to the top-left corner of the graph indicated a better performance at predicting low birth weight. Stata Roccomp analysis (a form of Chi square test) was then used to compare the AUCs of the five ROC curves at 95% confidence interval to determine a possible statistically significant difference.[24] Furthermore, Stata Rocgold analysis[24] was employed to compare other ROC curves against a single gold standard; which is the curve with the highest AUC. This was performed to determine how other curves differ statistically from the gold standard. Bonferroni adjusted p values were estimated to limit chances of a type 1 error. P values less than 0.05 were chosen as statistically significant.

RESULTS

Characteristics of study participants

Among the 420 neonates recruited for the study, 213 (50.7%) were males and 207 (49.3%) were females. Also, 121 (28.8%) babies were preterm while 299 (71.2%) babies were born at term. Using a cut-off value of <2.5 kg for low birth weight, a total of 131 (31.2%) babies were low birth weight, 266 (63.3%) babies were between 2.5 kg to 3.9 kg while 23 (5.5%) babies weighed 4.0 kg and above (χ^2=2.5559, p=0.278). Of the 131 low birth weight babies, 59 (45.0%) were males and 72 (55.0%) were females. Furthermore, from the low birth-weight population, 95 (72.5%) were preterm subclassified as: 16 (16.8%) preterm small for gestational age (SGA), 73 (76.9%) preterm Appropriate for gestational age (AGA), and 6 (6.3%) preterm Large for gestational age (LGA). Of the 36 (27.5%) term low birth weight babies, 19 (52.8%) were term SGA while 17 (47.2%) were term AGA with no baby belonging to the term LGA group (Likelihood ratio Chi-square LR=16.289; p<0.001).

Anthropometric data of the study participants

Table 1 shows the mean and standard deviation of anthropometric parameters as a whole as well as for both preterm and term study subjects. The mean anthropometric parameters of term and preterm babies are compared using t test statistics. The weight of the babies recruited ranged from 0.81 kg to 4.62 kg with an overall mean (SD) of 2.73±0.795 kg. The mean (SD) weight of preterm babies was 1.79±0.627 while that of term babies was 3.03±0.577 kg. (t=-19.34; p<0.001). Also, the mean MUAC for preterm and term babies were 8.43±1.622 cm and 10.88±1.241 cm respectively (p<0.001).

Correlation between birth weight and anthropometric parameters of neonates

All the anthropometric parameters had a positive correlation to birth weight with calf circumference attaining the highest correlation with birth weight (r=0.838) closely followed by chest circumference with a coefficient of 0.837. Mid-arm circumference, foot length and OFC had coefficients of 0.834, 0.755 and 0.746 respectively. All p values were statistically significant (<0.001).

Logistic regression analysis

The coefficient of determination (R^2) for the regression model was 0.785 and OFC, mid upper arm circumference and foot length were found to have a significant association with low birth weight with p<0.001 (Table 2). The regression model shows that with a unit increase in the anthropometric parameters, the odds of low birth weight generally decreased. For each unit increase in mid-upper-arm circumference, the odds of a low-birth weight outcome decreased by a factor of 0.099 (95% CI 0.045-0.213; p<0.001). Similarly, for each unit increase in foot length, the odds of low-birth weight outcome decreased by a factor of 0.120 (95% CI 0.036-0.398; p=0.001). The model shows that Odds ratio of chest circumference and calf circumference were 0.983 (95% CI 0.947-1.021) and 1.054 (95%CI 0.968-1.148) respectively and did not show a statistical relationship with a low-birth weight outcome (p=0.393 and 0.222 respectively) (Table 2).

The diagnostic performance of optimal cut-off points for the different parameters are shown (Table 3). Selected optimal cut off points had the highest combination of sensitivity and specificity. With a cut-off value of 9.8 cm, MUAC had a sensitivity of 91.9%, specificity of 91.6%, positive and negative predictive values of 96.0% and 83.9% respectively with an AUC of 0.97 (95% CI 0.95-0.98). At a cut-off value of 7.4 cm, foot-length had sensitivity and specificity values of 92.3% and 75.6% with an AUC of 0.92 (0.89-0.95 95% CI) which was the lowest of all the anthropometric parameters.

ROC curves for cut-off point determination

The ROC curves for the individual anthropometric measurements are shown in Figure 1 to 5 while Figure 6 depicts a combination of all the ROC curves. The respective AUC values of the anthropometrics are also highlighted. Figure 6 shows that MUAC out-performs other parameters as the plotted points are closest to the y-axis and it has the largest AUC of 0.97.

After Stata Roccomp analysis comparing the respective ROC areas of the anthropometric variables at 95% CI, there was significant statistical difference between the ROC areas of the anthropometric parameters (χ^2=12.23; p=0.0157). MUAC with the highest area was chosen as gold standard and compared with other ROC areas in Table 4. This table reveals that ROC of MUAC differed significantly with that of OFC (χ^2=4.355; p=0.036). Similarly, ROCs of MUAC and FL showed a statistically significant difference (χ^2=9.405; p=0.002). After Bonferroni adjustment, only FL ROC area showed a statistical difference to the gold standard (p=0.008) as shown in Table 4.

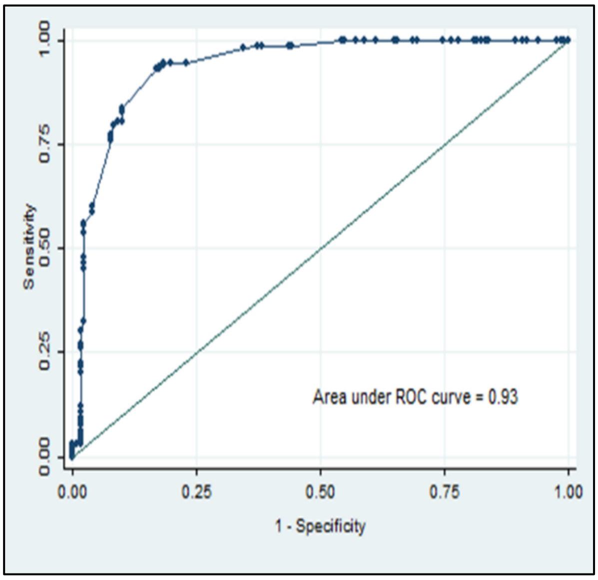

Figure 1: ROC of OFC for the diagnosis of low birth weight.

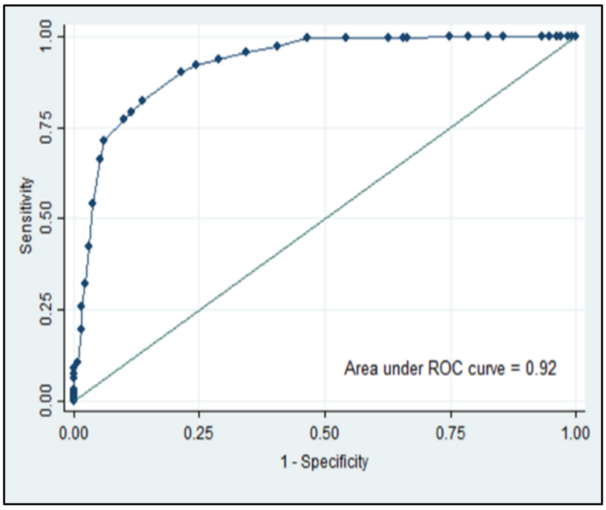

Figure 2: ROC of FL for the diagnosis of low birth weight.

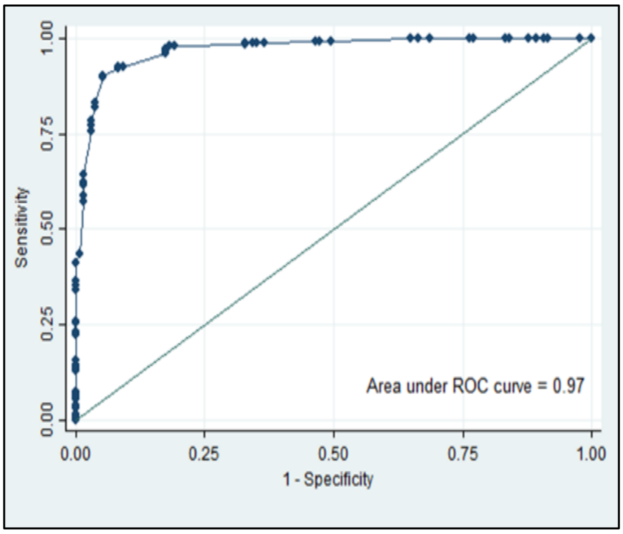

Figure 3: ROC of MUAC for the diagnosis of low birth weight.

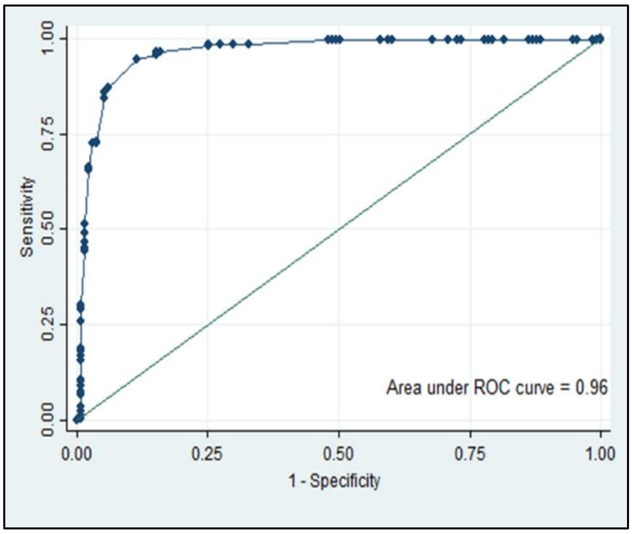

Figure 5: ROC of CC for diagnosis of low birth weight.

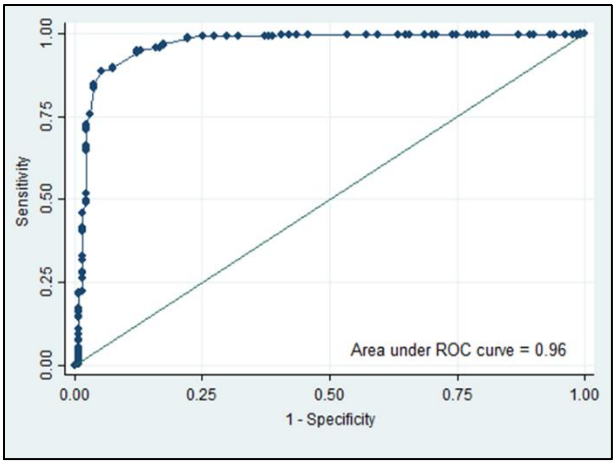

Figure 4: ROC of ChC for the diagnosis of low birth weight.

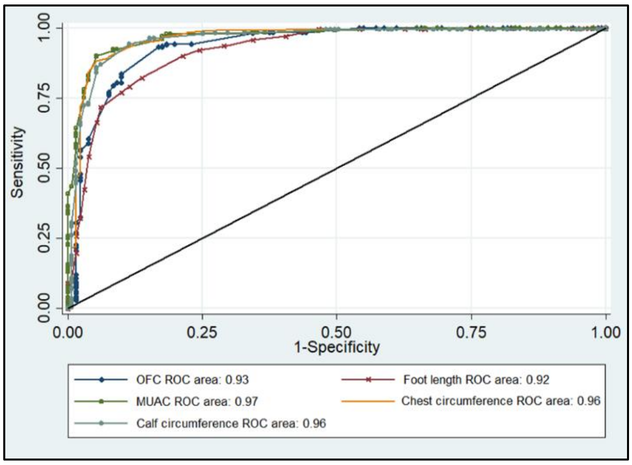

Figure 6: Combined ROC of all anthropometrics for the diagnosis of low birth weight.

Table 1: Mean anthropometric data of study participants with term and preterm subgroups.

Parameters	All babies	Preterm, mean±SD	Term, mean±SD	T test	P value
Weight (kg)	2.73±0.795	1.79±0.627	3.03±0.577	-19.34	<0.001
OFC (cm)	33.5±3.602	30.98±3.968	34.45±3.602	-11.20	<0.001
Foot length (cm)	7.7±0.869	6.97±0.796	8.01±0.600	-15.46	<0.001
MUAC (cm)	10.1±1.765	8.43±1.622	10.88±1.241	-16.37	<0.001
ChC (cm)	30.5±3.989	26.85±3.411	32.08±2.613	-16.92	<0.001
CC (cm)	10.5±2.162	8.68±1.693	11.08±1.300	-15.65	<0.001

OFC=Occipitofrontal circumference, MUAC=Mid-upper-arm circumference, ChC=Chest circumference, CC=Calf circumference.

Table 2: Binary logistic regression analysis for anthropometric parameters and low birth weight.

Low birth weight (kg)	Odds ratio	95% CI	P value
OFC (cm)	0.589	0.446-0.778	<0.001
FL (cm)	0.120	0.036-0.398	0.001
MUAC (cm)	0.099	0.045-0.213	<0.001
ChC (cm)	0.983	0.947-1.021	0.393
CC (cm)	1.054	0.968-1.148	0.222

OFC=Occipitofrontal circumference, MUAC=Mid-upper-arm circumference, ChC=Chest circumference, CC=Calf circumference.

Table 3: Predictive performance of anthropometric parameters at low, optimal and high cut-off values for the diagnosis of low birth weight.

Parameters	Youdens index (J)	Cut-off values (cm)	Sensitivity (%)	Specificity (%)	Predictive value (%)		AUC	95 CI
					Positive	Negative		
OFC (cm)	0.757	30.9	98.5	45.8	80.1	99.5	0.73	0.69-0.77
		32.9	93.3	82.4	92.0	85.0	0.93	0.91-0.96
		34.9	46.3	97.7	97.8	45.6	0.72	0.69-0.75
FL (cm)	0.0679	6.4	99.0	21.4	73.4	99.2	0.61	0.57-0.64
		7.4	92.3	75.6	89.1	81.8	0.92	0.89-0.95
		8.4	25.7	98.5	97.3	37.9	0.62	0.59-0.65
MUAC (cm)	0.835	8.8	98.6	65.6	86.2	95.6	0.82	0.78-0.86
		9.8	91.9	91.6	96.0	83.9	0.97	0.95-0.98
		10.8	61.4	98.5	98.9	54.0	0.80	0.77-0.83
ChC (cm)	0.819	28.2	99.3	70.2	87.9	90.3	0.85	0.81-0.89
		30.2	89.5	92.4	96.2	80.1	0.96	0.94-0.98
		32.2	49.8	97.7	97.9	47.2	0.74	0.71-0.77
CC (cm)	0.805	8.8	99.6	50.4	81.4	98.5	0.75	0.71-0.79
		9.8	95.8	84.7	93.2	90.2	0.96	0.93-0.98
		10.8	72.3	96.9	98.1	61.7	0.85	0.82-0.88

Table 4: Comparison of other ROC areas against the gold standard (MUAC).

Parameters	ROC area	Standard error	95% CI		Df	χ^2	P	Bonferroni adjusted p
			Lower	Upper				
MUAC (Std) (cm)	0.97	0.008	0.91	0.96	-	-	-	-
OFC (cm)	0.93	0.014	0.89	0.95	1	4.355	0.036	0.147
Foot length	0.92	0.015	0.95	0.98	1	9.405	0.002	0.008
ChC (cm)	0.96	0.011	0.94	0.98	1	0.312	0.576	1.000
CC (cm)	0.96	0.011	0.93	0.98	1	0.795	0.372	1.000

OFC=Occipitofrontal circumference, MUAC=Mid-upper-arm circumference, ChC=Chest circumference, CC=Calf circumference.

DISCUSSION

The findings from this study had similarities and differences from other studies on this subject. The mean anthropometric parameters from the present study were slightly lower than the mean from other local studies. The mean foot-length from the present study was 7.7 cm, lower than 8.12 cm found by the Modibbo et al in Kano, in the Northern region of Nigeria.[25] Also, the mean OFC and ChC values from the present study were 33.5cm and 30.5 cm respectively, lower than the mean values of 34.4 cm and 33.4 cm for OFC and ChC found by Ndu et al.[7] Similarly, the mean OFC, ChC and MUAC found in this study were lower than values by Achebe et al.[12] The higher prevalence of low birth weight from the present study could account for the lower mean MUAC, OFC and ChC as the prevalence of low birth weight from this study was higher than the prevalence figures of 14% and 15.2% reported by Ndu et al and Achebe et al respectively among babies in South-eastern Nigeria.[7,12] In the study by Hadush et al on Ethiopian babies, where the low-birth weight prevalence was 27% and comparable to the current study, the mean anthropometric parameters were similar to the present study.[26] For example, the mean OFC was 33.25 cm, comparable to a mean of 33.5 cm found in the present study. Similarly, the mean ChC and FL values from their study were 29.7 cm and 7.37 cm respectively, similar to a mean of 30.5 cm and 7.7 cm in the present study.[26]

All anthropometric parameters in this study correlated positively to birth weight as seen in other local studies.[4,7,8,11] There was a high positive correlation for all the anthropometric measurements as all correlation coefficients (r) were between 0.7-0.9.[27] Chest circumference, calf circumference and MUAC, however, jointly ranked higher than foot length and OFC using the Pearson correlation coefficient. Similarly, Adejuyigbe et al and Das et al reported that ChC and MUAC demonstrated the highest correlation to birth weight respectively.[4,28] The findings from the present study are also similar to the results of a meta-analysis by Gotto et al where ChC and MUAC had the highest pooled correlation coefficient compared to other anthropometric parameters.[29] Calf circumference, just as in the current study, was also found to have the strongest correlation to birth weight by Kaur et al where the prevalence of low birth weight was also high.[30] In the present study, ChC had a very strong correlation to birth weight probably because the use of the landmark for chest circumference (nipple line) has less chances of significant errors in measurement. MUAC and calf circumference demonstrated a high correlation to birth weight because both measures can assess foetal nutrition; a reduction in muscle mass or subcutaneous fat in these body regions would lead to corresponding changes in weight.[31] In spite of the use of a hard-plastic ruler in measuring foot-length in the present study, which was different from the non-elastic tape used by Adejuyigbe et al and Otupiri et al, foot-length still ranked low in the order of correlations as previously reported by these studies.[4,11] However, though foot-length ranked 4th in our study, it showed a higher correlation than in the Adejuyigbe et al study.[4] The use of a plastic ruler for measurement of foot-length may therefore be a more accurate method than the use of a tape.

Despite all anthropometrics showing an impressive correlation to birth weight, it was more informative to determine the relationship of these variables to low birth weight. Regression analysis revealed a significantly negative association between a unit increase in MUAC, OFC and FL to a low-birth weight outcome with odds ratio values less than 1.[32] This negative association was most observed with MUAC with the least recorded odds ratio. To put this observation in proper context, if the outcome variable were to be reversed from low birth weight to normal birth weight, the odds ratio would be an inverse of 0.099 which is 10.1.[32] This would mean that a unit increase in MUAC would yield a ten-times increase in the odds of normal birth weight. This interesting finding corroborates the fact that since MUAC reflects combined arm muscle and fat, it reasonably correlates with fat or muscle mass after birth and can be used in detecting changes in body composition or weight.[33] Though chest circumference also showed a negative-odds (less than 1), the model does not show a significant association with low birth weight because the 95% confidence interval includes a value of 1.[32]

In this series, the cut-off value for chest circumference was 30.2 cm which was similar to a cut-off range of 29.8 to 31 cm reported in other studies and identical to the findings of Srinivasa et al.[7,11,26,34] Also, this study confirms that chest circumference had both high sensitivity and specificity rates in detecting low birth weight. Furthermore, with an AUC of 0.96, chest circumference demonstrated high diagnostic accuracy in detecting low birth weight babies similar to AUC values of 0.91 and 0.93 reported by Otupiri et al, Hadush et al and Nabiwemba et al.[11,26,35] In all of these studies, chest circumference was measured using the nipple line as reference. Similarly, an OFC cut-off value of 32.9 cm was within the range of 30.9 cm to 34.15 cm reported by other studies.[12,35] However, the diagnostic performance of OFC was lower than other anthropometric measures in the present study. While OFC had a high sensitivity, it demonstrated a specificity that was lower than most of the other parameters. This implies that at the optimal cut-off value, OFC had a high false-positive rate, wrongly diagnosing babies as low birth weight. This may diminish its utility as a tool to screen for low birth weight. Calf circumference, however, had an impressive AUC value in the detection of low- birth weight babies. While the present study equally had high sensitivity and positive predictive values as reported by Otupiri et al and Sheikh et al it showed better specificity of 84.7% compared with a value of 42.8% by Sheikh et al and a negative predictive value of 90.2% in contrast to 52.9% reported by Sheikh et al.[11,36] The cut-off value of 9.8cm for calf circumference derived from the present study was similar to a value of 9.75 cm found by Sheikh et al.[36] Despite the high diagnostic ability of calf circumference in the present study, the validity of this anthropometric parameter as a surrogate to birth weight may be hampered by the subjective nature of its measurement. The prominence of the calf is not a definite landmark thereby making replication of measurements challenging on a large scale.

The use of a hard ruler for foot length measurement in this study yielded higher diagnostic accuracy compared to studies where flexible tapes were used to measure foot length.[10] Though a FL AUC of 0.92 was the lowest in the series, it was similar to AUC values of 0.97 found by Nabiwemba et al[35] where hard rulers were also used and higher than an AUC of 0.74 recorded by Otupiri et al[11] where flexible tapes were used. A cut-off value of 7.4 cm from our study also falls in the range of 7.3-7.85 cm reported in other studies where the same methodology was used.[26,34,35,37] However, from the findings of this study, FL had the lowest specificity which implies that it had higher false positive rates than other parameters. Overall, in addition to being relatively easy to carry out, foot length measurement does not require the kind of exposure needed to measure other parameters such as chest or head circumference.

MUAC was the most accurate measure in predicting low birth weight from the current study as it had the highest area under the curve. Similarly, Achebe et al and Thi et al reported high ROC areas of 0.89 and 0.98 for MUAC respectively.[12,37] Cut off for MUAC was 9.8 cm which was in the range of 9.4-10.5 cm observed by other studies.[4,8,11,12,26] In order to assess how the most accurate measure compares with others, the current study also compared area under the curves of MUAC alongside other parameters.[24] While the AUC of MUAC was not statistically different from that of ChC and CC, a statistically significant difference was observed when compared to OFC and FL initially, but only to FL after adjustment.[24] A logical inference that can be drawn is that mid-upper arm circumference, chest circumference and calf circumference are accurate surrogates for the identification of low birth weight babies. For chest circumference, errors in measurement are less likely because it has a wider circumference compared to other anthropometrics and the nipple line is an easily identifiable landmark, making measurements operationally feasible and replicable.[7] However, its measurement can increase the risk of hypothermia in smaller babies if not done rapidly enough. On the other hand, though the bulk of the calf muscle is visible and measurement of calf circumference is relatively easy to carry out, identifying this anatomic landmark is subjective and prone to errors which may reduce its validity under field conditions. MUAC measurements, however, are replicable with a reduction of intra and inter-observer variability. Furthermore, measuring MUAC requires less exposure of the baby compared to chest circumference and the process of its measurement is familiar to community health workers because it is employed in growth monitoring and assessment of nutritional status.

A major limitation was that validation of the flexible tape itself to confirm its measuring accuracy could not be performed. The tapes were therefore assumed to be accurate.

In conclusion, all anthropometric parameters studied were found to have positive correlation to birth weight. Mid-upper arm, chest and calf circumference had the highest coefficient of correlation (r) compared to OFC and foot length. MUAC demonstrated the highest diagnostic accuracy in predicting low birth weight with a cut off value of 9.8 cm and AUC of 0.97. It is also the best surrogate measure to birth weight because it showed a statistically significant difference in AUC when compared to other parameters. Though it is expected that all babies are weighed at birth, this is not the case in many delivery homes in Nigeria. Therefore, through this study, knowledge is advanced by the identification of a surrogate to birth weight that can be used to identify LBW babies that may need low-cost interventions such as Kangaroo mother care for temperature control and referral for further care.[38] Thus, knowledge on the burden of low birth weight in the community is enhanced and this is beneficial in attempts to reduce neonatal mortality.

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