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Original article

Evaluation of anthropometric measurements at birth in predicting birthweight less than 2000 g in African and Asian newborns: A meta-analysis

Évaluation des mesures anthropométriques à la naissance comme indicateurs d'un poids inférieur à 2000 g parmi les nouveau-nés africains et asiatiques : méta-analyse

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Abstract

Background. – Particularly in developing countries, lower birthweight may be associated with higher neonatal mortality, and deliveries frequently take place at home where scales are not always available. Therefore, surrogate measurements for birthweight are necessary as a primary screening measure. The aim of this study was to determine whether newborn chest and arm circumferences can predict birthweight less than 2000 g.

Methods. – The selection criteria were studies published in English that could provide all the true- and false-positive and true- and false-negative results with regard to the prediction of birthweight less than 2000 g by other anthropometric measurements among apparently healthy neonates. Ten bibliographic databases (e.g., PubMed) were searched and a bivariate meta-analysis was conducted with hierarchical summary receiver operating characteristic (ROC) curves. A total of 36,987 participants in 24 studies for chest circumference and 16,164 participants in 15 studies for arm circumference were included. The study regions were limited to Africa and Asia.

Results. – For chest and arm circumferences (24 and 15 studies, respectively), pooled sensitivity (0.94 and 0.89, respectively) and specificity (0.94 and 0.96, respectively), and diagnostic odds ratios (263 and 174, respectively) were sufficiently high to allow good predictions. The diagnostic odds ratio for chest circumference was significantly higher than for arm circumference ($P < 0.001$). The generalizability of the findings is to some extent guaranteed.

Conclusion. – Newborn chest and arm circumferences may be useful predictors of birthweight less than 2000 g, with chest circumference possibly better.

Keywords: Anthropometry; Birth weight; Meta-analysis; Newborn; Sensitivity and specificity

Résumé

Position du problème. – Un faible poids à la naissance peut être associé à une mortalité néonatale plus élevée, notamment dans les pays en développement, où un instrument permettant de peser le nouveau-né n'est pas toujours disponible lors des accouchements à domicile. Aussi, des mesures de substitution sont nécessaires pour permettre un premier dépistage d'un poids de naissance trop faible. L'objectif de la présente étude était de déterminer si la mesure des tours de poitrine et de bras des nouveau-nés permettait de prédire un poids de naissance inférieur à 2000 g.

Méthodes. – Dix bases de données bibliographiques (dont PubMed) ont été interrogées afin de sélectionner les études publiées en anglais présentant des résultats sur la prédiction des poids de naissance inférieurs à 2000 g au moyen d'autres mesures anthropométriques en termes de vrais et faux positifs, et de vrais et faux négatifs, chez les nouveau-nés en apparente bonne santé. Une méta-analyse bivariée a été conduite avec l'utilisation des courbes ROC. Au total, 36 987 participants dans 24 études sur les tours de poitrine et 16 164 participants dans 15 études sur les tours de bras ont été retenus. Les régions concernées par les études couvraient seulement l'Afrique et l'Asie.

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Résultats. – Concernant les tours de poitrine et de bras (respectivement, 24 et 15 études), les sensibilités (respectivement, 0,94 et 0,89), les spécificités (respectivement, 0,94 et 0,96) et les odds ratios diagnostiques (respectivement, 263 et 174) se sont révélés suffisamment élevés pour assurer de bonnes prédictions. L'odds ratio diagnostique du tour de poitrine était significativement supérieur à celui du tour de bras ($p < 0{,}001$). La généralisation des résultats est dans une certaine mesure garantie.

Conclusion. – Le tour de bras des nouveau-nés, et davantage encore le tour de poitrine, peuvent se révéler des indicateurs utiles d'un poids de naissance inférieur à 2000 g.

Mots clés : Anthropométrie ; Poids de naissance ; Méta-analyse ; Nouveau-né ; Sensibilité et spécificité

1. Introduction

Particularly in developing countries, newborns with birthweight <2000 g rather than <2500 g (i.e., low birthweight) may be at dramatically increased risk of neonatal death [1,2], and deliveries frequently take place at home where scales are not always available [3]. Therefore, surrogate measurements for birthweight, especially the identification of newborns with birthweight <2000 g, are necessary as a primary screening measure. When predicting low birthweight (i.e., birthweight <2500 g), chest and arm circumferences may have high and strong accuracy, though not confirmative, but chest circumference may be more precise [4]. A birthweight <2000 g indicates the need for more immediate and appropriate care [5]. Fewer studies have evaluated the prediction of birthweight <2000 g by other anthropometric measurements, in part because of lower prevalence of birthweight <2000 g than <2500 g. Summarized findings based on large sample sizes would be difficult not only to plan but also to implement in the field. Following this rationale, a meta-analysis of the literature was conducted aiming to determine whether newborn chest or arm circumference is useful in predicting birthweight <2000 g.

2. Methods

2.1. Primary outcomes

The primary outcomes were sensitivity and specificity, positive and negative likelihood ratios, and the diagnostic odds ratio, and area under the curve (AUC) on a hierarchical summary receiver operating characteristic (ROC) curve with regard to the prediction of birthweight <2000 g for chest and arm circumferences manually measured at birth.

2.2. Selection criteria

The selection criteria were studies, published in English, that could provide all the true- and false-positive and true- and false-negative results with regard to the prediction of birthweight <2000 g by other anthropometric methods among apparently healthy neonates. The studies missing some of these results were included when the missing results could be calculated from other known results, the number of participants, the prevalence of low birthweight, the diagnostic indices, etc., as long as there were consistencies among all the data.

More than one study was frequently extracted from one article, given that some of the articles provided more than one set of true- and false-positive and true- and false-negative results by assessing more than one anthropometric measurement, using more than one cut-off point of the same anthropometric measure, and/or involving more than one population. The same studies reported in more than one article were integrated into one study to prevent duplication.

PubMed (MEDLINE) was first searched to identify articles reporting eligible studies (February 2014). The search terms were: (''birthweight'' or ''birth weight'' or ''birth-weight'') and (''2000 g'' or ''2,000 g'' or ''2 kg'' or ''2.0 kg'') and (''height'' or ''heights'' or ''length'' or ''lengths'' or ''circumference'' or ''circumferences'' or ''thickness'' or ''thicknesses''). After excluding clearly unrelated articles by scanning titles and abstracts, the articles were collected for full-text retrieval. After excluding articles judged to be unrelated according to the full text, the remaining articles were considered potentially eligible articles, and their studies potentially eligible studies. Titles and abstracts of (a) articles displayed by clicking ''Related'' at the right of the screens of these potentially eligible articles and (b) articles retrieved in the reference sections of these potentially eligible articles were scanned to identify additional potentially eligible articles. Other databases searched included CINAHL, PsycINFO, Wiley Online Library (which offers integrated access to Cochrane Clinical Answers, Cochrane Library, EBM Guidelines: Evidence-Based Medicine, and Essential Evidence Plus), ProQuest (which includes ProQuest Health and Medical Complete and ProQuest Dissertations & Theses Database), Web of Knowledge, Google Scholar, and SciVerse Scopus.

2.3. Quality assessment

Quality Assessment of Diagnostic Accuracy Studies (QUADAS), a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews, consisting of 14 items [6], was used to assess study quality. The total number of ''yes'' responses to each of the QUADAS items was defined as the QUADAS score.

2.4. Statistical analysis

Stata/MP 13.0 (StataCorp, College Station, TX, USA) was used to statistically analyze the data. Each study's spike plots of Cook's distance and scatter plots of standardized residuals of sensitivity and specificity were displayed graphically to identify the candidate outliers [7,8]. Candidate outliers were excluded as true outliers if there were any flaws in study design when compared to the other studies included.

A bivariate random-effects meta-analysis of diagnostic studies was conducted with the inputs of the true- and false-positive and true- and false-negative results [8]. The outputs of this meta-analysis included pooled sensitivity and specificity, positive and negative likelihood ratios, and the diagnostic odds ratio. In addition, hierarchical summary ROC curves and the 95% confidence intervals and prediction regions around summary points were generated to calculate the AUC. The informational value was categorized as (a) small (and rarely important): positive and negative likelihood ratios = 1–2 and 0.5–1, respectively; (b) small (but sometimes important): positive and negative likelihood ratios = 2–5 and 0.2–0.5, respectively; (c) moderate: positive and negative likelihood ratios = 5–10 and 0.1–0.2, respectively; and (d) conclusive: positive and negative likelihood ratios >10 or <0.1, respectively [9]. Diagnostic accuracy was categorized as (a) low ($0.5 < AUC \leq 0.7$), (b) moderate ($0.7 < AUC \leq 0.9$), and (c) high ($0.9 < AUC \leq 1$) [10]. Welch's *t*-test was used to compare the logarithm of the diagnostic odds ratio between one measurement and another.

Homogeneity was assessed according to I^2 (<50%). Any attempt was made to reach homogeneity if the data were heterogeneous ($I^2 \geq 50\%$) by changing study regions (Africa, Asia, Europe, the Middle East, Latin and North America, and Oceania vs. others), QUADAS scores (≥8 vs. <8 and ≥10 vs. <10), two-by-two tables (presence vs. absence), responses to QUADAS items (yes vs. others), and control of the three major sources of bias (yes vs. others). It has been suggested that the three major sources of bias were attributed to poor control of (a) the same reference test irrespective of the results of the index test (yes vs. others), (b) the cohort vs. case-control study, and (c) the prospective vs. retrospective collection of the data [11,12]. Subgroup analysis was conducted to pool the data separately wherever possible, depending on study regions (Africa, Asia, Europe, the Middle East, Latin and North America, and Oceania vs. others), QUADAS scores (≥8 vs. < 8 and ≥10 vs. < 10), two-by-two tables (presence vs. absence), and control of the three major sources of bias in meta-analysis of diagnostic studies (yes vs. others). Meta-regression analysis was also conducted to calculate *P*-values for comparing pooled sensitivity and specificity between two counterparts with respect to the same categories as subgroup analysis. The Deeks funnel plot asymmetry test was used to assess for publication bias [13]. The cut-off points were proposed using the Youden indices (the points on the hierarchical summary ROC curves with the longest distance to straight lines drawn at a 45° angle from the origins [14]).

3. Results

A total of 12 articles were subjected to final analysis (Fig. 1), which included a total of 54 studies (Table 1) [15–26]. Two studies used birth height to predict birthweight <2000 g, one study used head circumference, 24 studies used chest circumference, 15 studies used arm circumference, two studies used thigh circumference, nine studies used foot length, and one study used calf circumference (Tables 1 and 2). All of the studies were limited to developing countries in Asia or Africa, i.e., India (*n* = 17), Bangladesh (*n* = 1), Nigeria (*n* = 5), Nepal (*n* = 25), and Tanzania (*n* = 6). The QUADAS items were relatively well controlled, as shown by low proportions of "No" in their responses (Fig. 2); the QUADAS scores in 79.5% of studies were 8/14 or more.

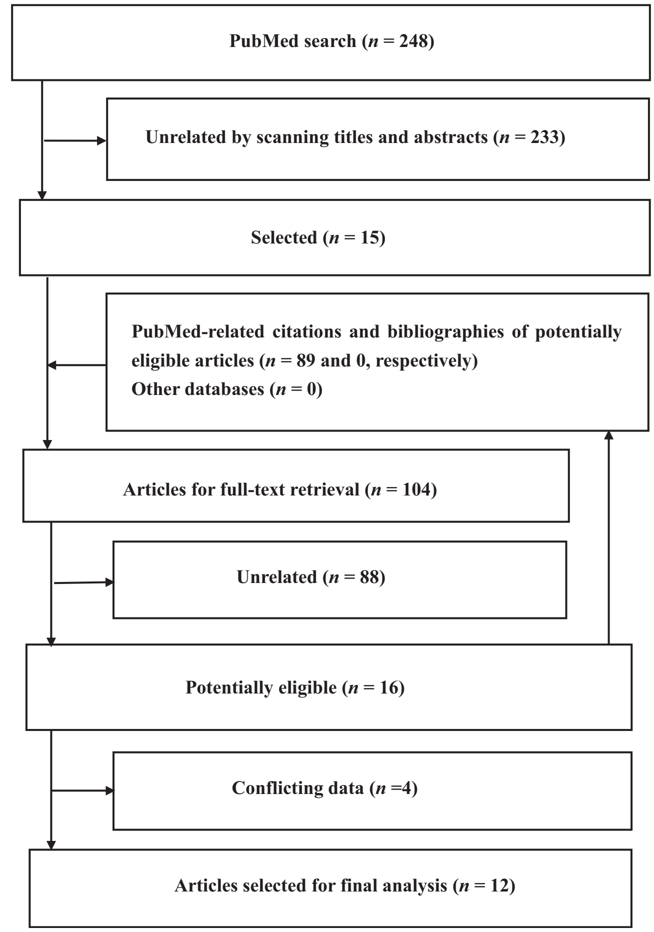

Fig. 1. Meta-analysis flow diagram. The PubMed search terms were: ("birth-weight" or "birth weight" or "birth-weight") and ("2000 g" or "2,000 g" or "2 kg" or "2.0 kg") and ("height" or "heights" or "length" or "lengths" or "circumference" or "circumferences" or "thickness" or "thicknesses").

Data for only chest and arm circumferences were pooled (Table 2) because the studies evaluating head, thigh, and calf circumferences were too few (four studies) to use for diagnostic bivariate meta-analysis, and studies evaluating foot length were all extracted from a single article. Cook's distance plots and standardized residuals showed a candidate outlier study in each of the chest and arm measurements (Singh et al. [24] and Barman et al. [15], respectively). However, each study was not regarded as a true outlier to omit, because it was one of a series of studies that had the same study design or quality but only used different cut-off points; all other studies in the same series had to be included.

Table 1
Characteristics of the studies included.

	Year	Region	Measurement	Cut-off point (cm)	Number of participants	Prevalence of birthweight <2000 g (%)	Prevalence of test-positive (%)	2 × 2 Table	QUADAS
Barman et al.	1994	Asia	MUAC	7.5, 8.5	197	16.24	2.03, 16.75	No	11/14
Das et al.	2005	Asia	MUAC	8	233	32.61	36.91	Yes	10/14
Ezeaka et al.	2003	Africa	BH	<45.5, 45.5[a]	756	7.54, 7.01	9.92, 10.58	No	9/14
			HC	32.3[a]	711	6.89	15.89	No	9/14
			MUAC	9.1[a]	723	6.92	14.52	No	9/14
			TC	14.9[a]	741	9.58	14.44	No	9/14
Kumar et al.	1987	Asia	MUAC	7.5	504	9.92	8.93	No	6/14
Mohan et al.	1990, 1991	Asia	MUAC	<7.4	2925	6.19	6.94	No	8/14
Mullany et al.	2007	Asia	CHC	27.8–29.3	1640	4.89	6.10–19.5	No	8/14
			FL	6.5–7.3	1640	4.89	4.15–56.52	No	8/14
Ngowi et al.	1993	Africa	CHC	<26.7	833	9.60	8.40	No	8/14
			MUAC	<8.4	833	9.60	7.56	No	8/14
Ramji et al.	1986	Asia	MUAC	8.0	216	18.98	23.15	Yes	10/14
			TC	13.9	216	18.98	24.07	Yes	10/14
Singh et al.	1988	Asia	CHC	27.0–30.0	446	11.88	11.66–40.13	No	8/14
			MUAC	≤8.0 to ≤9.0	446	11.88	12.78–46.86	No	8/14
Taksanda et al.[b]	2007	Asia	MUAC	9.25	868	12.56	22.47	No	6/14
			CC	8.75	868	12.56	24.08	No	6/14
Walraven et al.	1994	Africa	CHC	28–30	2710	2.51	4.02–12.14	No	7/14
			MUAC	8.0–9.0	2710	2.51	3.69–17.01	No	7/14

MUAC: mid-upper arm circumference; BH: birth height; HC: head circumference; TC: thigh circumference; CHC: chest circumference; FL: foot length; CC: calf circumference.

[a] The studies using the cut-off points of BH >45.5 cm, HC> and <32.3 cm, MUAC> and <9.1 cm, and TC> and <14.9 cm were excluded because of the disparity between the value of one diagnostic index in the study vs. the value of this index calculated from the remaining diagnostic indices.

[b] The studies evaluating HC and TC are excluded because of the disparity between the value of one diagnostic index in the study vs. the value of this index calculated from the remaining diagnostic indices.

For both chest and arm circumferences, all attempts failed to reach homogeneity by changing study regions or study design or quality. However, large proportions of heterogeneity, likely due to the threshold effect (1.00 and 0.91, respectively), were critically remarkable. Pooled sensitivity and specificity, and diagnostic odds ratios for chest and arm circumferences were both sufficiently high (Table 2 and Fig. 3). Accordingly, the AUC showed that the diagnostic accuracy of chest and arm circumferences was high. Based on the likelihood ratios, the informational value for chest and arm circumferences combined was also judged to be conclusive.

The data for chest and arm circumferences was pooled separately for Africa vs. Asia and QUADAS ≥8 vs. <8, respectively (Table 2). The other type of subgroup analysis with respect to at least one of two counterparts was impossible, probably because of the insufficient number of studies included (Table 2). In a meta-regression analysis, all the calculable *P*-values showed that study region, QUADAS score (≥8 vs. <8 and ≥10 vs. <10), two-by-two tables (presence vs. absence), and responses to QUADAS items did not make a statistically significant difference in pooled sensitivity and specificity for chest circumference (P = 0.07–0.08 and 0.10, respectively) and

Table 2
Results of meta-analysis and subgroup analysis.

	Number of studies	AUC	Sensitivity		Specificity		PLR	NLR	DOR	I^2
			Estimate (95%CI)	*P*-value	Estimate (95%CI)	*P*-value			Estimate (95%CI)	
CHC										
Total	24	0.98	0.94 (0.91–0.96)	–	0.94 (0.92–0.96)	–	16.0	0.06	263 (205–338)	99
Africa	4	0.98	0.89 (0.78–0.95)	0.07	0.97 (0.93–0.99)	0.10	28.0	0.11	244 (154–388)	96
Asia	20	0.98	0.95 (0.92–0.97)	–	0.93 (0.91–0.95)	–	14.4	0.05	276 (203–376)	99
MUAC										
Total	15	0.98	0.89 (0.71–0.96)	–	0.96 (0.89–0.98)	–	20.4	0.12	174 (102–296)	99
Africa	5	0.97	0.86 (0.72–0.94)	0.62	0.95 (0.90–0.98)	0.32	18.9	0.14	131 (89–193)	98
Asia	10	0.97	0.87 (0.70–0.95)	–	0.95 (0.88–0.98)	–	18.1	0.13	136 (76–241)	99
QUADAS ≥ 8	10	0.98	0.89 (0.71–0.96)	0.81	0.96 (0.89–0.98)	0.70	20.4	0.12	174 (102–296)	99
QUADAS< 8	5	0.95	0.84 (0.73-0.91)	–	0.95 (0.89–0.98)	–	15.7	0.17	92 (61–138)	98

CHC: chest circumference; MUAC: mid-upper arm circumference; AUC: area under the curve; CI: confidence interval; PLR: positive likelihood ratio; NLR: negative likelihood ratio; DOR: diagnostic odds ratio.

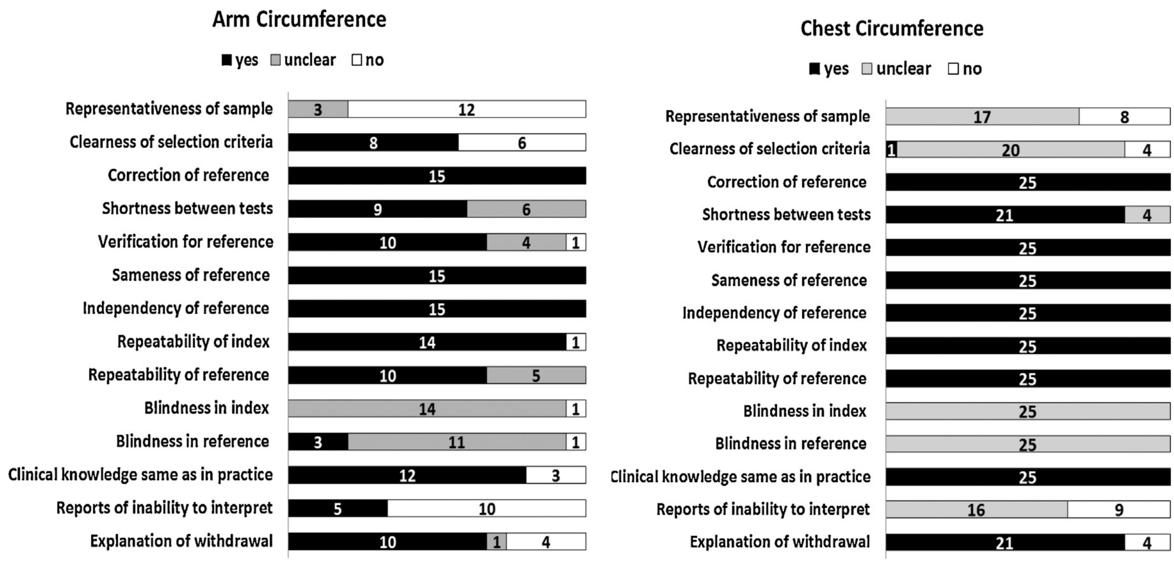

Fig. 2. Summary of quality assessment of studies included by Quality Assessment of Diagnostic Accuracy Studies (QUADAS).

arm circumference ($P = 0.15$–0.89 and $P = 0.21$–1.00, respectively). The results of the Deeks funnel plot asymmetry test in assessing publication bias for chest circumference ($P = 0.01$) and arm circumference ($P = 0.46$) are graphically displayed in Fig. 4. The Youden indices showed that the proposed cut-off points for chest and arm circumference were 28–29 cm, and nearly 8 cm, respectively.

4. Discussion

This study may be the first meta-analysis to evaluate the prediction of birthweight <2000 g by anthropometric measurements at birth. Chest and arm circumferences can be subjected to diagnostic bivariate meta-analysis (Tables 1 and 2). The heterogeneity among the data for chest and arm circumferences (Table 2) supports the rationale for using bivariate random-effects meta-analysis of diagnostic studies, which is workable on the premise of heterogeneity [8]. Based on the diagnostic odds ratio, chest circumference may be a better predictor than arm circumference (263 vs. 174; $P < 0.001$), which is the same as predicting low birthweight (birthweight <2500 g) [4]. The higher pooled sensitivity for chest circumference (0.94) than arm circumference (0.89) also suggests that chest circumference is more appropriate for primary screening because it can ideally detect almost all diseased populations. This was also shown in predicting low birthweight [4]. The reliability (internal validity) of pooled sensitivity and specificity, diagnostic odds ratios, and the AUC for chest and arm circumferences may be revealed by the remaining I^2 values (0.00% and 8.91%, respectively) after eliminating the portions of I^2 likely

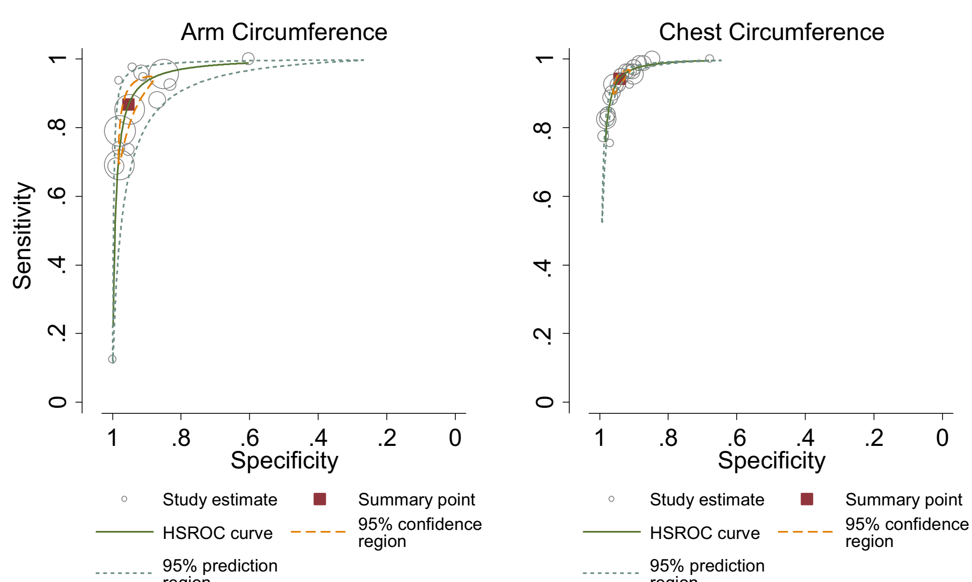

Fig. 3. Hierarchical summary receiver operating characteristic (ROC) curves.

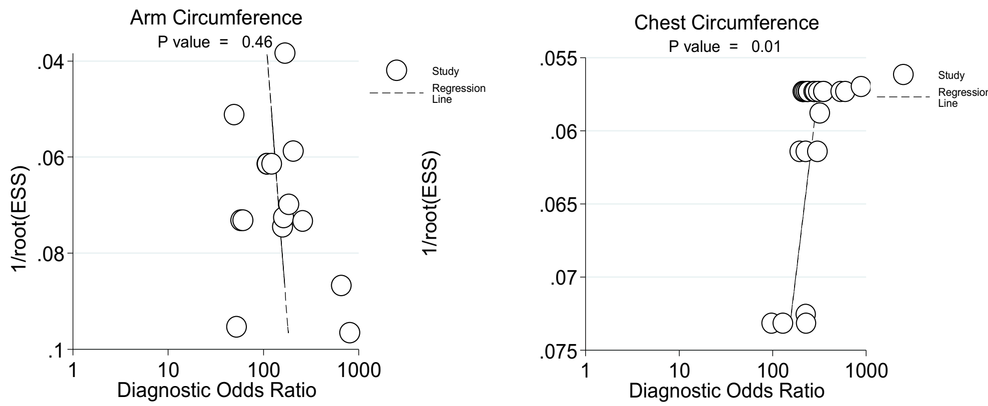

Fig. 4. Publication bias assessment (Deeks funnel plot asymmetry test).

caused by the threshold effect (i.e., the trade-off relation between sensitivity and specificity, which changes by varying the cut-off points), suggesting homogeneity. The generalizability (external validity) of the findings is also to some extent guaranteed; 36,987 participants in 24 studies from four articles for chest circumference and 16,164 participants in 15 studies from ten articles for arm circumference were included, whereas the study regions were limited to Africa and Asia.

Subgroup as well as meta-regression analysis identified no confounders (Table 2). For both chest and arm circumferences, every study included controlled all three major sources of bias, i.e., the same reference test used regardless of the results of the index test, cohort vs. case-control study and prospective vs. retrospective collection of data [11,12]. Therefore, there was no apprehension of the overestimated outcome due to poor control of these three major sources of bias. The Deeks funnel plot asymmetry test might have found publication bias in the results for chest circumference (Fig. 4). However, the unlikeliness that the outcome was overestimated due to publication bias was also shown by increasing the diagnostic odds ratio with the increasing effective sample size in the funnel plot. There was no publication bias in the results for arm circumference.

The proposed cut-off points corresponded to the values frequently used in the studies included as cut-off points. The diagnostic performance of chest and arm circumferences may be better to predict birthweight <2000 g than <2500 g, (i.e., low birthweight), in terms of greater informational values (i.e., conclusive vs. moderate), larger diagnostic odds ratios (263 vs. 67, and 174 vs. 55, respectively; $P < 0.001$), and narrower 95% confidence intervals and prediction regions (Table 2 and Fig. 3) [4].

The primary strength of this study is the appropriate study design to conduct this meta-analysis. The process of the study question formulation, study selection, search strategy, data collection, statistical analysis, and results interpretation was consistent with the guidance regarding the conduct of systematic reviews and meta-analyses [27,28]. An exception was that the authors of the articles were not contacted and the articles were reviewed by a single observer.

The second strength is the sophisticated statistical methods used. Plots of Cook's distance and standardized residuals were displayed to identify candidate outliers [8]. Bivariate meta-analysis was used with the consideration of heterogeneity and the correlation between sensitivity and specificity [7]. The hierarchical summary ROC curve was generated to provide the AUC and the 95% confidence intervals and prediction regions [8]. The Deeks funnel plot asymmetry test was performed to prevent misleading Egger and Begg test results [13].

The third strength of this study is that there were no optimistic effects of the three major sources of bias and publication bias on outcome. The three major sources of bias [11,12] were controlled in all the studies included to evaluate the prediction of birthweight <2000 g by both chest and arm circumferences. The graphical plot of publication bias assessment showed that smaller sample sizes did not lead to overestimation of the results of chest circumference (Fig. 4), despite the presence of publication bias. The plot did not indicate any publication bias in the data for arm circumference.

The first limitation of this study involves the applicability of the conclusions. The studies included were mostly conducted at hospitals, and the findings cannot be easily extrapolated to the healthcare practices conducted by lay workers in communities. However, intra- and interobserver variation was not considered to be a serious concern, because sensitivity and specificity were not found to vary substantially (P = 0.19–0.74 and 0.70–0.95, respectively) depending on the repeatability of the index test and reference test within the available P-values.

The applicability of the findings to groups not subjected to subgroup analysis is also limited. It cannot be guaranteed that the results are applicable to the subgroups of male vs. female, preterm vs. full term, singleton vs. non-singleton, and appropriate- vs. small-for-gestational-age infants.

The second limitation of this study is the inability to analyze confounders. This study did not identify any confounders, but study region and quality have been shown to affect pooled sensitivity and/or specificity to predict birthweight <2500 g (i.e., low birthweight) [4]. Including more studies would have shown similar confounders even on the prediction of birthweight <2000 g.

The third limitation of this study is the possibility of missing studies. The articles' authors were not contacted to obtain raw data in cases of missing data or disparities in the data. However, this does not seriously affect the conclusions, because the hierarchical summary ROC curves indicated sufficiently narrow 95% confidence intervals and prediction regions. Additionally, studies for which slight disparities existed in the data were still included, while the border between trivial and significant disparities was unclear.

In summary, for newborn chest and arm circumferences, pooled sensitivity and specificity, and diagnostic odds ratios were all sufficiently high. Diagnostic odds ratios showed that chest circumference exceeded arm circumference. The study regions were limited to Africa and Asia. Thus, chest and arm circumferences may be a very helpful predictor for screening birthweight <2000 g.

Disclosure of interest

The author declares that he/she has no conflicts of interest concerning this article.

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