Who Should Be Screened for Postpartum Anemia? An Evaluation of Current Recommendations

Lisa M. Bodnar1,2, Anna Maria Siega-Riz1,2,3, William C. Miller4,5, Mary E. Cogswell6, and Thad McDonald7

1 Department of Nutrition, School of Public Health and School of Medicine, The University of North Carolina at Chapel Hill, Chapel Hill, NC.
2 Carolina Population Center, The University of North Carolina at Chapel Hill, Chapel Hill, NC.
3 Department of Maternal and Child Health, School of Public Health, The University of North Carolina at Chapel Hill, Chapel Hill, NC.
4 Department of Epidemiology, School of Public Health, The University of North Carolina at Chapel Hill, Chapel Hill, NC.
5 Department of Medicine, School of Medicine, The University of North Carolina at Chapel Hill, Chapel Hill, NC.
6 Division of Nutrition and Physical Activity, Centers for Disease Control and Prevention, Atlanta, GA.
7 Obstetrics and Gynecology Department, Wake Medical Center, Raleigh, NC.

Received for publication April 15, 2002; accepted for publication August 1, 2002.

The authors evaluated the utility of selective screening criteria for postpartum anemia developed by the Centers for Disease Control and Prevention (CDC) versus criteria developed among low-income women using prevalence-based screening principles. Pregnant women in Raleigh, North Carolina, were followed up to the postpartum visit in 1997–1999 (n = 345). Prevalence of postpartum anemia was 19.1%. Independent risk markers, arrived at through multivariate logistic regression, were multiparity (odds ratio (OR) = 1.5, 95% confidence interval (CI): 0.8, 2.9), obesity (OR = 3.0, 95% CI: 1.6, 5.5), anemia at 24–29 weeks' gestation (OR = 2.3, 95% CI: 1.2, 4.4), anemia before delivery (OR = 3.4, 95% CI: 1.8, 6.7), and not exclusively breastfeeding (OR = 2.8, 95% CI: 1.0, 7.7). Risk scores were calculated by counting risk markers present. Likelihood ratios were determined for all possible risk scores of our algorithm and CDC’s algorithm. Anemia screening decisions differed depending on clinic anemia prevalence. For example, if low test thresholds are assumed, when clinic prevalence is 10%, women with risk scores >3 on the authors’ algorithm and >0 on CDC’s algorithm should be screened. The authors’ algorithm, in combination with prevalence information, can save clinics more money than CDC’s current algorithm because a broader range of likelihood ratios was obtained, indicating a better ability to distinguish high- from low-risk women. However, if resources are available, universal screening should be considered in high-prevalence settings.

anemia; Bayes theorem; hemoglobins; iron; mass screening; puerperium; risk assessment; sensitivity and specificity

Abbreviations: CDC, Centers for Disease Control and Prevention; CI, confidence interval; LR, likelihood ratio; LR+, positive likelihood ratio; LR–, negative likelihood ratio.

Postpartum iron deficiency and anemia are major public health problems. In the United States, approximately 13 percent of women 0–6 months postpartum are iron deficient and 10 percent are anemic (1). Low-income postpartum women in the United States are disproportionately affected by these health outcomes: 22 percent are anemic, 30 percent are iron deficient, and 10 percent are iron deficient and anemic (1). In women, these conditions have been associated

This paper was awarded the Society for Epidemiologic Research (SER) Abraham Lilienfeld Student Prize for 2002.
Correspondence to Lisa M. Bodnar, Carolina Population Center, The University of North Carolina, Campus Box #8120, University Square, 123 West Franklin Street, Chapel Hill, NC 27516-2524 (e-mail: lisa_bodnar@unc.edu).
with reduced work performance (2–12) and impaired cognition (13–15). These functional outcomes have serious socioeconomic and behavioral consequences, but they also may be subtle, and rarely would they be a reason for women to seek medical attention. To reduce anemia-related morbidity in the postpartum period, therefore, screening is necessary to identify which women need treatment.

Currently, the Centers for Disease Control and Prevention (CDC; Atlanta, Georgia) recommends selective anemia screening at 4–6 weeks postpartum for women who have had “anemia continued through the third trimester, excessive blood loss during delivery, and multiple births” (16, p. 25). This selective screening algorithm was based on Institute of Medicine guidelines for the prevention, detection, and management of iron-deficiency anemia (17). To our knowledge, performance of the selective screening criteria for postpartum iron deficiency has yet to be evaluated, however. Thus, the current risk profile for postpartum anemia may not have the highest predictive accuracy compared with one developed on the basis of a thorough examination of additional potential predictors.

We sought to develop a simple and clearly defined selective screening (risk assessment) algorithm for women who have given birth to singletons that could guide clinical decision-making for postpartum anemia screening. We compared the performances of our algorithm and CDC’s algorithm for these women across a range of anemia prevalences to demonstrate the value of incorporating clinic prevalence information into selective screening recommendations.

MATERIALS AND METHODS

Study population and data collection

We used data from the Iron Supplementation Study, a randomized clinical trial during pregnancy. In 1997–1999, this study recruited women receiving care at a public prenatal clinic in Raleigh, North Carolina, serving women from mostly low socioeconomic backgrounds. Women who were English speaking and were carrying singletons were recruited at their first prenatal visit (<20 weeks’ gestation) after giving their informed, written consent.

Upon recruitment, blood was drawn and was analyzed for hemoglobin and serum ferritin concentrations. Women were randomized into one of four supplementation groups according to these iron status measures. Supplementation began immediately and continued until 24–29 weeks’ gestation, when blood was again drawn and analyzed for hemoglobin and serum ferritin concentrations. Subsequently, women received the prenatal supplement used by the clinic.

During the study period, data were collected on sociodemographic characteristics, health habits, medical history, and supplement use. Although active study participation ended at 24–29 weeks’ gestation, women were followed up into the postpartum period. Medical records were abstracted to obtain additional prenatal, delivery, and postpartum information, including hemoglobin concentration before delivery and at the postpartum visit. The study was approved by the Institutional Review Board of The University of North Carolina, School of Medicine; by the Institutional Review Committee of Wake Medical Center; and by the Human Subjects Committee at CDC.

A total of 867 women were randomized; 497 (57 percent) delivered a live infant, returned for a postpartum visit, and had blood drawn at that visit for determination of hemoglobin concentration. Of the 867 women, data on all variables in our final model were available for 345 (40 percent) of them. Compared with the excluded women, the 345 women included in the analysis were more likely to be primiparous (58 percent vs. 37 percent) and less than age 20 years (32 percent vs. 23 percent). There were no meaningful differences between the two groups regarding prevalence of anemia at the initial visit, ethnicity/race, body mass index (weight (kg)/height (m)²), or education (data not shown).

The three measures of prenatal anemia (at the first prenatal visit, at 24–29 weeks’ gestation, and before delivery) were defined by gestational age-specific hemoglobin concentration cutoffpoints (16). Predelivery hemoglobin concentration was abstracted if it was obtained no more than 7 days before delivery. We defined the postpartum period as 4–26 weeks after delivery, when maternal hemoglobin concentration is expected to return to first-trimester or prepregnancy levels (18). Postpartum anemia, defined as less than 118 g/liter for women aged 12–15 years and less than 120 g/liter for women at least age 15 years (16), was assessed by using hemoglobin concentration adjusted for smoking (16).

Prepregnancy body mass index was based on measured height and maternal report of prepregnancy weight. Prepregnancy obesity was defined as a body mass index of more than 29 (19). Hemorrhage at delivery was based on the physician’s subjective opinion documented in the medical record. Breastfeeding status was self-reported at the postpartum blood draw.

Statistical analysis

First, we identified demographic, reproductive history, prenatal, delivery, and early postpartum factors with potential clinical relevance to postpartum anemia. We examined relations between these factors and postpartum anemia by calculating odds ratios in bivariate analyses for all women who had blood drawn during the postpartum period (n = 497). To identify appropriate categorizations of continuous variables, we examined curves produced by using nonparametric regression smoothing with LOWESS (locally weighted regression) (20). Variables for which the unadjusted p value was ≤0.20 in logistic regression analysis were identified as potential risk markers and were included in the full model.

We conducted multivariate analyses by using logistic regression. Collinearity among potential risk markers was assessed. We reduced the model by using backward elimination (21), and we eliminated potential risk markers by using likelihood ratio tests. Next, we used a higher alpha value (p ≤ 0.10) to enhance the model’s predictive ability while reducing the chance of eliminating important variables. We assessed the performance of each risk marker alone in predicting postpartum anemia by calculating sensitivity, specificity, positive likelihood ratio (LR+; the true-positive rate divided by the false-positive rate), negative likelihood
ratio (LR–; the true-negative rate divided by the false-negative rate), and percentage of women tested.

To determine whether missing data biased our results, we compared our complete case modeling results \((n = 345)\) with those obtained by using a three-step multiple imputation process \((22–25)\) \((n = 867)\). We created 10 imputed data sets, since our fraction of missing data was large \((24)\). Multiple imputation assumes that the data are missing at random (i.e., the missingness depends on observed variables only), an assumption that we felt our data did not violate. Thus, we analyzed our full and final models by using the PROC MI and PROC MIANALYZE procedures in SAS software (SAS Institute, Inc., Cary, North Carolina) \((n = 867)\) with a Markov chain Monte Carlo approach, since we had complicated missing data \((26)\).

Risk assessment algorithm

To maintain the risk markers’ relative importance in the clinical prediction of postpartum anemia, we assigned each variable in the final model a weight based on the beta coefficient obtained from logistic regression. For this analysis, we weighted each risk marker by multiplying the beta coefficient by 10 and rounding to the nearest integer. Beta coefficients in logistic regression represent the log odds for a risk marker and are additive. Thus, a weighted risk score was obtained by summing the weights for each risk marker \((27)\).

To determine whether a simpler risk assessment algorithm could be implemented, we developed an unweighted risk score based on a count of the risk markers present.

To compare the accuracy of the weighted and unweighted risk assessment algorithms, we plotted receiver operating characteristic curves for all possible cutpoints and calculated the area under each curve. For all possible unweighted algorithm risk scores, we determined the stratum-specific likelihood ratios (LRs; the probability of the risk score given disease divided by the probability of the risk score given no disease) \((28)\). Adjacent risk scores were grouped if the LRs were similar. Only 2.6 percent of the women had five risk markers, leading to very imprecise LR confidence intervals. Thus, we collapsed the upper two risk score categories \((29)\). We used bootstrap techniques to validate model performance \((30)\).

The original data set was sampled with replacement to derive 1,000 data sets. The LRs were recalculated for each data set. The estimate’s standard error was then compared with the estimated bias of the original LR \((20)\).

Our study excluded women who had had multiple gestations so we could assess the performance of the CDC risk assessment criteria among only those women delivering singletons. In assessing the CDC criterion of excessive delivery blood loss, we used the medical record documentation of hemorrhage because neither expert group otherwise quantified the term “excessive.” The final criterion, “anemia continued through the third trimester” \((16, p. 25)\), may be interpreted in two ways: 1) anemic before delivery or 2) anemic at the start of the third trimester and before delivery. Therefore, we created two CDC algorithms (CDC1 and CDC2) based on these definitions of this risk marker.

Both CDC1 and CDC2 were based on two dichotomous factors, so we assigned women unweighted risk scores derived from a count of the risk markers present. The cutoff point for screening determined by the recommendations is a risk score of 1 or more. To test the performance of the CDC recommendations in our population of women delivering singletons, we calculated sensitivity, specificity, LR+, and LR– at the recommended cutpoint for both algorithms. For all possible risk scores on both algorithms, we also calculated the LR. Because 2.9 percent and 1.2 percent of women had two risk markers on CDC1 and CDC2, respectively, we collapsed the upper two risk score categories for both algorithms \((29)\). As described above, we used bootstrapping to estimate the bias of the LRs for both CDC algorithms.

Finally, we assessed the utility of the risk assessment criteria across a range of anemia prevalences by applying Bayes’ theorem \((28)\). We combined information about the pretest probability of anemia (clinic prevalence) with the LR for the risk scores of the unweighted algorithm, CDC1, and CDC2 to estimate the posttest probability of anemia (refer to the Appendix) \((28)\). Posttest probability was compared with the test threshold probability (the probability above which screening should be offered) \((28)\). For example, a test threshold probability of 0.2 indicates that, when the probability of anemia is 0.20 or more, the test should be performed. Test thresholds are calculated by weighing the net costs \((C)\) and net benefits \((B)\) of screening \((C/(C + B))\) \((31)\). Although, to our knowledge, a cost-benefit ratio for anemia screening has not been published, we estimated a low test threshold \((0.10–0.15)\) because anemia screening and iron treatment are inexpensive \((16)\), associated with few risks for women, and likely to have substantial benefits \((32)\).

We used SAS version 8.1 \((26)\) and Stata version 7.0 \((20)\) software for data analysis.

RESULTS

The sample of 497 women consisted of 28.2 percent non-Hispanic Whites, 64.0 percent non-Hispanic Blacks, and 7.8 percent women of other ethnicities/races. Most women were aged 20–29 years \((58.4\,\text{percent})\). Mean postpartum hemoglobin concentration was 129 \((\text{standard deviation,} \, 13)\, \text{g/liter,} \, \text{and mean number of weeks postpartum was 6.8} \,(\text{standard deviation,} \, 2.3)\). Prevalence of postpartum anemia was 19.1 percent. These characteristics were not different for the 345 women analyzed in the models.

Women with postpartum anemia were more likely to have anemia at each time point during pregnancy compared with women who did not have postpartum anemia \((\text{table 1})\). Twelve years of education or less, prepregnancy obesity, hemorrhage at delivery, and not exclusively breastfeeding, as reported at the postpartum visit, were more common among women with postpartum anemia.

After reducing a logistic regression model using all potential risk markers shown in \text{table 1}, we identified five factors as independent risk markers of postpartum anemia \((\text{table 2})\): multiparity, prepregnancy obesity, not exclusively breastfeeding, anemia at 24–29 weeks’ gestation, and anemia before delivery. In general, multiple imputation analyses \((n = 867)\) showed results similar to those for the complete case analysis in \text{table 2} for both the full model \((\text{data not shown})\) and final model. Adjusted odds ratios for the final model, after
multiple imputation, were as follows: multiparity, 1.1 (95 percent confidence interval (CI): 0.7, 1.7); prepregnancy obesity, 2.8 (95 percent CI: 1.6, 4.9); not exclusively breastfeeding, 1.6 (95 percent CI: 0.7, 3.6); anemia at 24–29 weeks’ gestation, 2.8 (95 percent CI: 1.7, 4.3); and anemia before delivery, 2.1 (95 percent CI: 1.3, 3.5).

When we examined the performance of each risk marker alone in predicting postpartum anemia (table 3), multiparity, prepregnancy obesity, and anemia at 24–29 weeks’ gestation each detected a moderate proportion of postpartum anemia cases while screening less than 43 percent of the women. Screening of all women not exclusively breastfeeding...
detected a high proportion of anemia cases but screened more than 83 percent of the women. When just over half of the women were tested, the risk marker anemia before delivery detected 76 percent of anemia cases.

Risk scores

The receiver operating characteristic curves and associated areas were similar for the weighted and unweighted algorithms (0.754 (standard error, 0.033) vs. 0.740 (standard error, 0.032); $p = 0.16$), indicating a comparable overall performance (figure 1). Because the unweighted algorithm would be simpler to implement, we chose to examine it in the remaining analysis. At the cutoff determined by CDC’s recommendations (a risk score of ≥1), CDC1 detected more anemia cases than CDC2 (78.8 percent (95 percent CI: 67.0, 87.9) vs. 42.4 percent (95 percent CI: 30.3, 55.2)) but had a lower specificity (53.2

### Table 2. Adjusted odds ratios and risk scores for the association of independent risk markers with postpartum anemia, Iron Supplementation Study, Raleigh, North Carolina, 1997–1999 ($n = 345$)

<table>
<thead>
<tr>
<th>Risk marker</th>
<th>Adjusted OR†</th>
<th>95% CI†</th>
<th>Weighted score‡</th>
<th>Unweighted score§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>Primiparous</td>
<td>1.0¶</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Multiparous</td>
<td>1.5</td>
<td>0.8, 2.9</td>
<td>4</td>
</tr>
<tr>
<td>Prepregnancy body mass index (kg/m²)</td>
<td>≤29 (nonobese)</td>
<td>1.0¶</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>&gt;29 (obese)</td>
<td>3.0</td>
<td>1.6, 5.5</td>
<td>11</td>
</tr>
<tr>
<td>Exclusive breastfeeding reported at postpartum hemoglobin measurement</td>
<td>Yes</td>
<td>1.0¶</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2.8</td>
<td>1.0, 7.7</td>
<td>10</td>
</tr>
<tr>
<td>Anemia at 24–29 weeks’ gestation</td>
<td>No</td>
<td>1.0¶</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2.3</td>
<td>1.2, 4.4</td>
<td>8</td>
</tr>
<tr>
<td>Anemia before delivery</td>
<td>No</td>
<td>1.0¶</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>3.4</td>
<td>1.8, 6.7</td>
<td>12</td>
</tr>
</tbody>
</table>

* Adjusted for parity, prepregnancy body mass index, breastfeeding status, anemia at 24–29 weeks’ gestation, and anemia before delivery.
† OR, odds ratio; CI, confidence interval.
‡ Weighted by multiplying the risk marker’s adjusted beta coefficient by 10 and rounding to the nearest integer. The weighted risk score is obtained by summing the weights for each risk marker.
§ The unweighted risk score is based on a count of the risk markers present.
¶ Reference group.

### Table 3. Sensitivities, specificities, positive and negative likelihood ratios, and percentage of women tested for risk markers for postpartum anemia, Iron Supplementation Study, Raleigh, North Carolina, 1997–1999 ($n = 345$)

<table>
<thead>
<tr>
<th>Risk marker</th>
<th>Sensitivity (%)</th>
<th>95% CI†</th>
<th>Specificity (%)</th>
<th>95% CI</th>
<th>Positive likelihood ratio†</th>
<th>95% CI</th>
<th>Negative likelihood ratio‡</th>
<th>95% CI</th>
<th>% of women tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiparity</td>
<td>54.5</td>
<td>41.8, 66.9</td>
<td>60.6</td>
<td>54.6, 66.3</td>
<td>1.4</td>
<td>1.1, 1.8</td>
<td>0.8</td>
<td>0.6, 1.0</td>
<td>42.3</td>
</tr>
<tr>
<td>Prepregnancy body mass index &gt;29 kg/m²</td>
<td>47.0</td>
<td>34.6, 60.0</td>
<td>74.9</td>
<td>69.4, 80.0</td>
<td>1.9</td>
<td>1.4, 2.6</td>
<td>0.7</td>
<td>0.6, 0.9</td>
<td>29.3</td>
</tr>
<tr>
<td>Not exclusively breastfeeding reported at postpartum hemoglobin measurement</td>
<td>92.4</td>
<td>83.1, 97.5</td>
<td>19.0</td>
<td>14.6, 24.1</td>
<td>1.1</td>
<td>1.0, 1.2</td>
<td>0.4</td>
<td>0.2, 1.0</td>
<td>83.2</td>
</tr>
<tr>
<td>Anemia at 24–29 weeks’ gestation</td>
<td>40.9</td>
<td>29.0, 53.7</td>
<td>80.3</td>
<td>75.1, 84.8</td>
<td>2.1</td>
<td>1.4, 3.0</td>
<td>0.7</td>
<td>0.6, 0.9</td>
<td>23.8</td>
</tr>
<tr>
<td>Anemia before delivery</td>
<td>75.8</td>
<td>63.6, 85.5</td>
<td>55.2</td>
<td>49.2, 61.1</td>
<td>1.7</td>
<td>1.4, 2.0</td>
<td>0.4</td>
<td>0.3, 0.7</td>
<td>50.7</td>
</tr>
</tbody>
</table>

* CI, confidence interval.
† Defined as the true-positive rate divided by the false-positive rate.
‡ Defined as the true-negative rate divided by the false-negative rate.
percent (95 percent CI: 47.2, 59.2) vs. 82.4 percent (95 percent CI: 77.4, 86.7)). The LR+ (1.7 (95 percent CI: 1.4, 2.0) vs. 2.4 (95 percent CI: 1.6, 3.5)) and LR– (0.4 (95 percent CI: 0.2, 0.6) vs. 0.7 (95 percent CI: 0.6, 0.9)) were also lower for CDC1. Stratum-specific LRs are shown in table 4 for the unweighted algorithm as well as for CDC1.

### TABLE 4. Performance of selective screening criteria for postpartum anemia from three algorithms: unweighted, CDC*1, and CDC2, Iron Supplementation Study, Raleigh, North Carolina, 1997–1999

<table>
<thead>
<tr>
<th>No. of risk markers</th>
<th>Anemic</th>
<th>Nonanemic</th>
<th>Likelihood ratio†</th>
<th>95% CI*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. %</td>
<td>No. %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unweighted algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 or 1‡</td>
<td>3</td>
<td>4.6</td>
<td>82 29.4</td>
<td>0.2</td>
</tr>
<tr>
<td>2 or 3‡</td>
<td>39</td>
<td>59.1</td>
<td>174 62.4</td>
<td>1.0</td>
</tr>
<tr>
<td>4 or 5§</td>
<td>24</td>
<td>36.4</td>
<td>23 8.2</td>
<td>4.4</td>
</tr>
<tr>
<td>CDC1 algorithm¶</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>14</td>
<td>21.2</td>
<td>148 53.2</td>
<td>0.4</td>
</tr>
<tr>
<td>1 or 2§</td>
<td>52</td>
<td>78.8</td>
<td>130 46.8</td>
<td>1.7</td>
</tr>
<tr>
<td>CDC2 algorithm#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>38</td>
<td>57.6</td>
<td>229 82.4</td>
<td>0.7</td>
</tr>
<tr>
<td>1 or 2§</td>
<td>28</td>
<td>42.4</td>
<td>49 17.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

* CDC, Centers for Disease Control and Prevention; CI, confidence interval.
† The probability of the risk score given postpartum anemia divided by the probability of the risk score given no postpartum anemia.
‡ Grouped together because of similar likelihood ratios.
§ Grouped together because <3% of the sample had risk scores in the highest category, leading to very imprecise confidence intervals for the likelihood ratio.
¶ Selective screening criteria defined as hemorrhage at delivery and anemia before delivery (16).
# Selective screening criteria defined as hemorrhage at delivery and anemia at the start of the third trimester and at the end of the third trimester (16).
and CDC2. With bootstrap validation, the LRs from all algorithms were stable, suggesting minimal bias.

The importance of the relation between pretest probability (prevalence) of anemia, risk score LR, and posttest probability of anemia for the unweighted algorithm, CDC1, and CDC2 is illustrated in figures 2, 3, and 4, respectively. If we assume low test thresholds, clinical decision making for postpartum anemia screening differs considerably depending on the clinic preva-
lence of postpartum anemia. For example, when we used the unweighted algorithm, we observed that, in clinics in which the prevalence of anemia is 5 percent and the test threshold is assumed to be 10 percent, women with risk scores of less than 4 should not be screened (figure 2). Such risk scores result in posttest probabilities of anemia that are lower than the test threshold. Women with risk scores of 4 and 5 would be screened because their probability of anemia is greater than the test threshold. In contrast, given a 10 percent test threshold, in clinics with a 15 percent prevalence of anemia, women with risk scores of 0 or 1 should not be tested, but all others should.

If we assume a 10 percent test threshold, the present CDC recommendations (screening women who have one or two risk markers) are appropriate in clinics in which the prevalence of anemia is 7–24 percent if the CDC1 algorithm is used (figure 3) and 5–14 percent if the CDC2 algorithm is used (figure 4). If the same test threshold is assumed, screening should not be performed in clinics with a prevalence of less than 7 percent if CDC1 is used or less than 5 percent if CDC2 is used; using the algorithm does not increase the posttest probability of anemia above the test threshold. In contrast, all women should be screened in clinics with a prevalence of 24 percent or higher if CDC1 is used, 14 percent or higher if CDC2 is used, and 41 percent or higher if the unweighted algorithm is used.

**DISCUSSION**

The goal of any selective screening program is to identify and treat nearly all diseased persons while carrying out a minimal number of tests (33). An algorithm or selective screening criteria are used to identify those persons at high or low risk of the outcome and refer high-risk persons for screening. The postpartum anemia risk assessment algorithm supported by CDC involves three equally weighted risk markers: third-trimester anemia, excessive blood loss during delivery, and multiple births (16). To our knowledge, our analysis is the first to evaluate the performance of the current algorithm and to compare its performance with an algorithm based on a wide selection of clinically relevant predictors of postpartum anemia.

We identified three risk markers of postpartum anemia not included in the CDC criteria: multiparity, prepregnancy obesity, and not exclusively breastfeeding. In the only known previous study of postpartum anemia predictors, these three factors were associated with increased odds of anemia (34). Multiparous women may have a higher anemia risk because of the high iron demand of pregnancy coupled with insufficient recovery of iron status between pregnancies (19). The association between obesity and anemia may be related to factors common to obese women: greater blood loss during delivery (35), less frequent use of vitamin and mineral supplements (36), and/or a poorer quality diet (37, 38). Exclusive breastfeeding may protect against postpartum anemia by lengthening amenorrhea (39, 40), thereby reducing iron loss. Alternatively, exclusive breastfeeding may be a marker of high socioeconomic status (41), better diet quality, or compliance with vitamin/mineral supplement use.

We confirmed that prenatal anemia was an important risk marker, but CDC’s other selective screening criterion, excessive blood loss during delivery, was not confirmed in our analysis. Because of the relatively low prevalence of
hemorrhage in this population (5 percent) and nationally (4–6 percent) (35), this factor is unlikely to facilitate anemia prediction in most populations. The same can be said for the final risk marker in CDC’s selective screening criteria: multiple births. Although we were not able to evaluate multiple births as a risk marker, the low incidence of multiple births nationally (<3 percent) (42) suggests that this risk marker also would likely have little influence on risk assessment of postpartum anemia.

We illustrated the substantial impact that the definition of “anemia continued through the third trimester” (16, p. 25) made on the performance of the CDC algorithm. When we defined this risk marker as anemia at the end of the third trimester (CDC1) rather than anemia at both the start and end of the third trimester (CDC2), sensitivity was higher and specificity, LR–, and LR+ were lower. In our algorithm, the presence of anemia at either time point performed well. These results highlight the importance of clearly defined risk markers to guarantee a standardized application of screening criteria.

Some might see one set of risk assessment criteria with a single cutpoint, such as CDC’s current guidelines, as desirable to create uniform public policy recommendations, but such an algorithm is unlikely to be applicable in all settings (33). Performance of selective screening criteria depends largely on the criteria’s positive predictive value. However, because this value depends on prevalence, criteria with a single cutoff will perform variably in populations with different prevalences. Furthermore, the strength of the association between risk markers and anemia fluctuates across populations, resulting in inconsistent performance of dichotomous selective screening criteria.

Thus, for wider and potentially more appropriate implementation of a single set of risk assessment criteria, incorporation of prevalence information may be beneficial (33). Prevalence-based screening has the advantage of providing each woman with a comparable opportunity for detection of the outcome, depending on her probability of the outcome. By using these principles, we demonstrated that use of one set of selective screening criteria in combination with prevalence information can guide clinical decision making for postpartum anemia screening. Our results showed that use of either the unweighted algorithm, CDC1, or CDC2 could benefit clinics by enabling them to screen only those women whose probability of anemia is greater than the test threshold—saving needed resources. Use of these algorithms in low-prevalence settings has the advantage of screening only those women with high-risk profiles (such as those with four risk markers on the unweighted algorithm) and detecting and treating cases of anemia that may have otherwise gone unnoticed. Alternatively, prevalence-based screening benefits high-prevalence settings by not using resources to screen women with low-risk profiles (such as those with zero risk markers on the unweighted algorithm).

In this sense, clinics may realize more cost savings with the unweighted algorithm over either CDC algorithm because its range of LRs is wider, giving the algorithm a better ability to distinguish low- from high-risk women.

Anemia screening is inexpensive (16), however, so clinics may choose universal screening over selective screening. This option seems particularly suitable in high-prevalence settings, such as public health clinics serving low-income women. Nevertheless, adequate resources for preventive programs such as screening may not be available in public clinics. Our analysis provides options for clinics without sufficient resources to screen all women.

Since we know of no published cost-benefit analysis for anemia screening, these results must be interpreted cautiously. Determination of the test threshold should rely on a formal cost-effectiveness analysis. We assumed a low test threshold because anemia screening and accompanying iron supplementation for women who test positive are expensive and are associated with few risks, and improving hemoglobin concentration is presumed to have substantial benefits (32). For universal screening to be warranted, the test threshold must be set at zero. Screening decisions can be made with confidence only after economists undertake this challenging, but essential investigation.

An important limitation of this analysis is the loss to follow-up we experienced. In this transient population, following women throughout pregnancy and the postpartum period was difficult because many women moved to another clinic before delivery, delivered at another hospital, or did not return for a postpartum visit. We cannot rule out the possibility that this selectivity biased our results. However, when comparing results from the full and final models, we were able to demonstrate similarities between the complete case analysis and the multiple imputation analysis, suggesting minimal bias due to missing data. Another limitation is the development and assessment of the unweighted algorithm in the same population without validation in an external population. While the bootstrap validation produced results similar to those from the original analysis, this algorithm should be applied to another population to confirm or refute our results.

In the current environment, budgetary constraints often limit available resources for screening programs, especially in public health care settings. We have provided empirical evidence that prevalence-based screening can help clinics use resources most wisely by testing only those women whose anemia probability is greater than the test threshold. To assess postpartum anemia prevention efforts in the future, we recommend collecting data to assess how screening recommendations are implemented in public and private settings and evaluating whether screening is effective in reducing the functional consequences of postpartum anemia.

ACKNOWLEDGMENTS

This research was funded by cooperative agreements from the Association of Schools of Public Health/Centers for Disease Control and Prevention (#S1326, #S0454) and a predoctoral traineeship from the National Institutes of Health.

The authors acknowledge the prenatal clinic staff of Wake County Human Services. They also thank Dr. Amy Herring for statistical expertise and Dan Blanchette for programming support.

REFERENCES


APPENDIX

To assess the utility of risk assessment criteria across a range of prevalences, we used the following three steps to estimate the posttest probability of anemia:

2. Estimate the posttest odds of anemia: Posttest odds of anemia = (pretest odds of anemia) × (LR for the algorithm risk score).
3. Estimate the posttest probability of anemia: Posttest probability = (posttest odds of anemia) ÷ (1 + posttest odds of anemia).