Association and prediction of neonatal acidemia

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OBJECTIVE: The objective of this study was to estimate the predictive ability of electronic fetal monitoring (EFM) patterns immediately prior to delivery for acidemia at term birth.

STUDY DESIGN: This was a 4-year retrospective cohort study of 5388 consecutive singleton, nonanomalous gestations of 37 weeks or longer. The primary exposure was the EFM pattern in the 30 minutes preceding delivery. EFM patterns were prospectively interpreted using *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) nomenclature as well as non-NICHD measurements of decelerations. The primary outcome was umbilical cord arterial pH of 7.10 or less.

RESULTS: Four NICHD-defined EFM features within the 30 minutes prior to birth demonstrated the greatest association with acidemia: repetitive prolonged decelerations (area under the curve [AUC] 0.81), baseline tachycardia (AUC 0.80), repetitive variable decelerations (AUC 0.79), and repetitive late decelerations (0.78) after adjusting for nulliparity, fever, prolonged first stage, and obesity. A non-NICHD measure, total deceleration area, demonstrated superior predictive ability for acidemia (AUC 0.83, $P = .04$).

CONCLUSION: A non-NICHD measure of deceleration frequency and severity in the second stage performed superior to 4 NICHD EFM features for predicting fetal acidemia.

Key words: acidemia, electronic fetal monitoring

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Intrapartum electronic fetal monitoring (EFM) is ubiquitous in obstetrics, despite the lack of evidence for improvement in birth outcomes and its substantial contribution to the rise in the national cesarean delivery rate. In a 2008 consensus conference, sponsored by the American College of Obstetricians and Gynecologists, the Society of Maternal Fetal Medicine, and the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD), the leading experts in obstetrics and fetal monitoring reconvened to prioritize areas for research and to reevaluate the definitions that were set forth by a similar group 11 years before.[1] The group acknowledged that virtually no evidence had emerged on EFM since the 1997[2] consensus conference, that the use of common nomenclature was paramount and specified a 3-category system. They again called for well-designed studies to fill the significant knowledge gaps that continue to exist. One of the areas of highest importance cited was observational studies focused on indeterminate EFM patterns.

★ EDITORS' CHOICE ★

Indeterminate fetal heart rate patterns, specified as category II tracings, are characterized most often by the presence of decelerations.[3] The NICHD system describes 4 deceleration definitions. However, visual inspection reveals that several decelerations may meet a single NICHD definition but have different characteristics such as length, depth, and shape. These additional features, if they have meaning, are lost in the currently broad system. Furthermore, none of the 4 deceleration types (variable, early, late, prolonged) has been consistently associated with acidemia or birth outcomes. Although this may be due to the paucity of study, it more likely is due to the summary nature of the current NICHD nomenclature that specifies assignment into 1 of 4 deceleration types and may result in loss of information.

We hypothesized that non-NICHD measures of fetal heart rate decelerations, which account for properties such as depth, deceleration duration, and number immediately prior to delivery, would have a greater predictive ability for acidemia compared with the NICHD category system or nomenclature for decelerations. To test this hypothesis, we studied the 30 minutes of EFM patterns prior to delivery because it is the most proximal to the measurement of acidemia.

Materials and Methods

We conducted a 4-year, retrospective cohort study of all consecutive term births from the second stage of labor at a large tertiary care medical center. Women were identified for possible inclusion in the study by diagnosis and procedure codes for the delivery of a live-born infant during the study period and then confirmed for complete ascertainment by the labor and delivery log.

Women were included in the study if they delivered at or beyond 37 0/7 weeks' gestation. Gestational age was determined by the last menstrual period (LMP) if known and concordant with ultrasound (within 7 days of first-trimester ultrasound or 14 days of second-trimester ultrasound) or by the earliest ultra-

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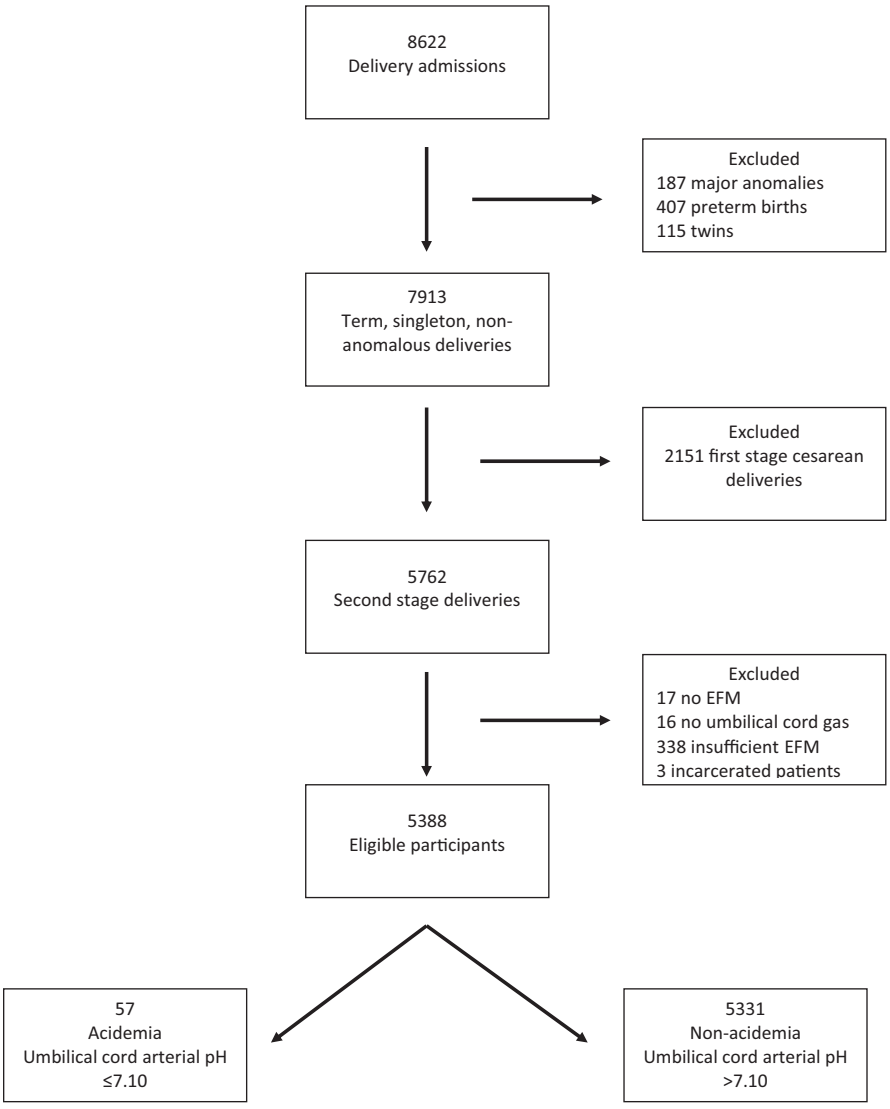
For Editors' Commentary, see Contents

FIGURE 1
Study population



EFM, electronic fetal monitoring.

Cahill. Electronic fetal monitoring to predict acidemia. Am J Obstet Gynecol 2012.

sound when the LMP was unknown or discordant. Additional inclusion criteria included cephalic presentation, reaching the second stage, and no known fetal anomalies.

Women who underwent cesarean prior to labor or cesarean in the first stage of labor prior to complete dilation were excluded because infants delivered from the first stage of labor tend to have higher umbilical cord pH than those delivered from the second stage.[4] Women were also excluded if they did not have at least 10 minutes of EFM tracing in the 30 minutes prior to delivery (insufficient EFM) and were excluded if an arterial umbilical cord gas (UCG) was not obtained. Finally, women carrying twins or higher-order multiple gestations were excluded.

The study was conducted with the approval of the institutional review board. Our institution utilizes a universal arterial umbilical cord gas acquisition policy and similarly uses universal continuous EFM during labor.

The primary outcome of the study was fetal acidemia, defined as an umbilical arterial cord gas of 7.10 or less. The primary exposure of the study was the EFM characteristics in the 30 minutes immediately prior to delivery, given the temporal proximity to the primary outcome measure. Each EFM tracing was prospectively extracted by 2 dedicated obstetric research nurses, formally trained and credentialed in the interpretation of EFM, blind to all clinical and outcome data. EFM tracings were extracted in 10 minute epochs as well as over the entire 30-minute period. Extraction was performed using the strict NICHD criteria for contractions and EFM patterns[3] as well as extraction of deceleration-specific elements such as duration, depth, and number of decelerations, which allowed additional calculations to be made.

When considering the overall category assignment for the 30 minutes prior to delivery, category I and III were specified when they were the category throughout, and category II throughout or category II in combination with epochs of other categories yielded a category II assignment (to mimic what is done in practice). The depth and duration allowed the area within each deceleration to be calculated, which was approximated as half (width × depth) of the deceleration. A feature called total deceleration area was also calculated as the sum of the area within all decelerations in the final 30 minutes of EFM as a measure of both quantity and severity. All extraction was completed using a closed-ended tool. Blind reextraction by the second reader was performed at 500 patient intervals to allow assessment of interobserver reliability. A total of 270 (5.0% of tracings) were reabstracted.

Detailed maternal sociodemographics information, obstetric and medical history, antepartum course, and complications data were extracted from the electronic medical record. Additional data extracted included admission diagnoses and physical examination; tobacco, alcohol, and drug exposures; labor and delivery course including all cervical examinations; labor type; and mode of delivery; and medication exposures with doses and timing. Time from incision to delivery was extracted for women who delivered by cesarean. Fetal umbilical cord gas analysis was also extracted. Birth outcomes included maternal postpartum complications, neo-

natal Apgar scores, weight, and nursery disposition.

Women who delivered an infant with a pH of 7.10 or less (acidemia) were compared with those without acidemia (pH >7.10). Baseline characteristics were compared between groups using a Student *t* test or Mann-Whitney *U* for continuous variables as appropriate and a χ^2 test for categorical variables. Continuous variables were tested for normality visually and with the Kolmogorov-Smirnov test. Relative risks and 95% confidence intervals were calculated to estimate the association of individual EFM features with acidemia.

Individual features included categories and NICHD-defined baseline, variability, and deceleration characteristics as well as measures such as deceleration severity using the system described by Kubli et al,[5] total number of decelerations overall, and total deceleration area. These non-NICHD features and calculations were compared between groups as continuous measures as well as dichotomously using the 95th percentile from the entire cohort to define abnormal. Deceleration types were considered dichotomously, both if they ever occurred and if they occurred repetitively (with ≥50% of contractions), as specified by the NICHD classification system. Stratified analyses were used to identify potentially confounding variables in the EFM feature–acidemia association.

Multivariable logistic regression was used to refine the estimate of risk for acidemia in the presence of each feature in the 30 minutes prior to delivery. Biologically plausible and historically known factors associated with acidemia were included in the initial models along with factors identified in the stratified analyses. Additionally, 6 a priori specified interaction terms of EFM characteristics were considered in the models. Backward, step-wise logistic regression was used to develop the final models. Covariates were retained in the model if they changed the effect size around the primary covariate by more than 10%. Labor type (induced vs augmented vs spontaneous), maternal race, and length of the second stage did not remain significant and thus were not included in the final models.

TABLE 1
Baseline demographic, labor, and delivery characteristics of the cohort by acidemia

Characteristic	Acidemia (n = 57)	No acidemia (n = 5331)	*P* value
Maternal age, y[a]	23 (20–28)	23 (20–28)	.55
Advanced maternal age	15.5%	7.0%	.30
Gestational age at delivery, wks[a]	39.0 (38.0–40.0)	39.0 (38.0–40.0)	.77
Maternal black race	70.2%	72.8%	.65
Body mass index[a]	32.1 (26.8–37.1)	30.5 (26.9–35.0)	.30
Preeclampsia	5.3%	6.5%	.70
Gestational diabetes	4.1%	2.8%	.76
Pregestational diabetes	3.5%	1.2%	.11
Nulliparous	57.9%	36.8%	< .01
Prior low transverse cesarean	12.3%	6.4%	.07
Labor type			.42
Spontaneous	31.5%	37.6%	
Augmented	35.1%	31.9%	
Induction	33.3%	30.5%	
Regional anesthesia	94.7%	83.7%	.02
Prostaglandin	15.8%	12.9%	.52
Foley bulb	5.3%	4.5%	.78
Oxytocin	64.9%	58.8%	.35
Birthweight, g[a]	3210 (2995–3515)	3250 (2960–3555)	.96
Birthweight >4000 g	5.3%	5.4%	.94
Birthweight <1800 g	1.8%	0.8%	.41
Vaginal delivery	47.4%	86.1%	< .01
Operative vaginal delivery	36.8%	12.4%	< .01
Cesarean	15.8%	1.5%	< .01
Maternal fever	15.8%	8.6%	.06

[a] Medians (interquartile ranges).

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To estimate and compare the predictive ability for individual categories or factors for acidemia in the 30 minutes prior to delivery, sensitivity, specificity, positive predictive value (PPV), and negative predictive values were calculated. Receiver-operator curves were constructed from the final logistic regression models for the 5 EFM features with the highest magnitude of association with acidemia and were compared by area under the curve (AUC). The analyses were repeated for the association and predictive ability of categories and features in the 10 minutes prior to delivery. In addition, a planned subgroup analysis of women with infants with metabolic acidemia, which we defined as an arterial UCG of 7.10 or less and base excess less than −8.0, was performed.

Based on pilot data, we estimated the incidence of acidemia in the cohort to be 1.0% and the incidence of late decelerations in the nonacidemic group to be 10%. With an alpha error of 0.05, we estimated we needed 56 cases of acidemia to have 80% power to detect a 2-fold or greater association with any EFM feature

TABLE 2
Association of NICHD categories and defined features 30 minutes before delivery

Variable	pH ≤7.10 (n = 57)	pH >7.10 (n = 5331)	Unadjusted relative risk (95% CI)	Adjusted OR (95% CI)[a]	*P* value
Category I	0.0%	2.3%	Referent	—	—
Category II	100.0%	97.6%	—	—	—
Category III	0.00%	0.09%	—	—	—
Moderate variability	91.2%	87.2%	Referent	Referent	—
Minimal variability	8.8%	12.5%	0.68 (0.27–1.69)	0.68 (0.27–1.71)	.41
Marked variability	0.0%	0.3%	—	—	—
Absent variability	0.00%	0.02%	—	—	—
Repetitive late decelerations[b]	15.8%	7.3%	2.35 (1.16–4.76)	2.06 (0.99–4.27)	.05
Repetitive prolonged decelerations[b]	14.0%	5.2%	2.90 (1.39–6.07)	2.56 (1.19–5.52)	.02
Repetitive variable decelerations[b]	49.1%	32.5%	1.99 (1.19–3.33)	1.91 (1.07–3.08)	.03
Baseline tachycardia	12.3%	4.5%	2.95 (1.35–6.44)	2.15 (1.21–3.82)	< .01
Baseline bradycardia	0.0%	0.2%	—	—	—

CI, confidence interval; *NICHD,* National Institute of Child Health and Human Development; *OR,* odds ratio.

[a] Adjusted for nulliparity, fever, prolonged first stage, and obesity; [b] Repetitive: occurring with 50% or greater of contractions.

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and acidemia. The statistical analyses were performed using STATA, version 10, Special Edition (College Station, TX).

Results

Of 8622 consecutive delivery admissions, 5762 women with nonanomalous, term, vertex pregnancies delivered in the second stage. From these, 17 were excluded for no recorded EFM, 16 were excluded for lack of UCG, 338 were excluded for insufficient EFM, and 3 patients were excluded for concurrent incarceration, leaving 5388 patients included in the study. Arterial acidemia (pH of ≤7.10) occurred in 57 infants (1.1%) and 5331 (98.9%) had a pH greater than 7.10 (Figure 1). Women who delivered infants with acidemia were more likely to be nulliparous and have regional anesthesia. They were also more likely to deliver by operative vaginal delivery or cesarean compared with women delivering nonacidemic infants. Women delivering acidemic infants tended to have higher rates of maternal fever and a history of a prior low-transverse cesarean, although these did not reach statistical significance (Table 1).

Of the 3 categories, none demonstrated statistically significant association with acidemia when considered in the last 10 minutes or in the last 30 minutes prior to delivery (Table 2). Baseline, variability, and decelerations were individually considered. Compared with moderate variability, minimal variability was not associated with acidemia (adjusted odds ratio [aOR], 0.68; 95% confidence interval [CI], 0.27–1.70). Absent and marked variability occurred too infrequently to estimate association. Repetitive late decelerations (aOR, 2.07; 95% CI, 1.00–4.29), repetitive prolonged decelerations (aOR, 2.57; 95% CI, 1.19–5.53), and repetitive variable decelerations (aOR, 1.83; 95% CI, 1.09–3.10) were all significantly associated with acidemia after adjusting for fever, obesity, prolonged first stage, and nulliparity. Compared with a normal baseline, tachycardia was significantly associated with acidemia (aOR, 2.16; 95% CI, 1.22–3.83), but bradycardia occurred rarely in the nonacidemic group and not at all in those with acidemia, precluding risk estimation.

Infants with acidemia at birth had a greater number of decelerations in the final 30 minutes compared with those without acidemia (9 vs 6, $P < .01$) as well as a greater number of severe decelerations (nadir of ≤60 beats/min), and a greater total deceleration area (Table 3). After adjusting for fever, obesity, prolonged first stage, and nulliparity, only abnormal total deceleration area (greater than the 95th percentile) was significantly associated with an increased risk for acidemia (aOR, 3.79; 95% CI, 2.04–7.04). When the association of NICHD and non-NICHD characteristics with metabolic acidemia was tested, a similar pattern was seen (Table 4).

In the 10 minutes preceding delivery, no category or type of variability was significantly associated with acidemia (Table 5). Similar to the findings over the final 30 minutes of labor, repetitive late (aOR, 3.12; 95% CI, 1.84–5.31) and repetitive variable (aOR, 2.24; 95% CI, 1.27–3.94) decelerations, repetitive prolonged decelerations (aOR, 3.82; 95% CI, 2.25–6.50), and tachycardia (aOR, 2.50; 95% CI, 1.24–5.02) were significantly associated with acidemia at birth.

The NICHD-defined categories and features demonstrated poor discriminatory ability for cases of acidosis, reflected by their test characteristics (Table 6). The best single NICHD feature was tachycardia, with 14.0% sensitivity and 95.7% specificity for acidemia, although the low incidence was reflected by the poor PPV of 3.4%.

Prediction models for NICHD features and non-NICHD measures with significant association were built and

TABLE 3
Incidence and association of non-NICHD deceleration measures in final 30 minutes with acidemia

Variable	pH ≤7.10 (n = 57) (1.1%)	pH >7.10 (n = 5331) (98.9%)	Unadjusted relative risk (95% CI)	Adjusted OR (95% CI)[a]	*P* value
Number of decelerations, median (range) [IQR]	9 (1–17) [6–12]	6 (0–22) [3–9]	—	—	< .01
Greater than 95th percentile[b]	9 (15.8)	427 (8.0)	2.12 (1.05–4.31)	1.74 (0.84–3.61)	.13
Number of severe decelerations, median (range) [IQR]	1 (0–8) [0–2]	0 (0–12) [0–1]	—	—	< .01
Greater than 95th percentile[b]	5 (8.8)	308 (5.8)	1.56 (0.63–3.88)	1.61 (0.64–4.06)	.32
Total deceleration area, median (range) [IQR]	21116.0 (650.0–54502.0) [6780.5–36972.5]	8940.0 (147.0–71881.5) [3855.0–16709.5]	—	—	< .01
Greater than 95th percentile[b]	18 (41.9)	558 (13.4)	4.52 (2.48–8.24)	3.79 (2.04–7.04)	< .01

IQR, interquartile range; *NICHD,* National Institute of Child Health and Human Development.

[a] Adjusted for nulliparity, fever, prolonged first stage, and obesity; [b] Greater than 95th percentile of number of decelerations, number of severe decelerations, or total deceleration area in cohort.

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compared by area under the receiver-operator curve. Total deceleration area was the best discriminator between cases and noncases with an AUC of 0.83, compared with repetitive prolonged decelerations (AUC 0.81), baseline tachycardia (AUC 0.80), repetitive variable decelerations (AUC 0.79), and repetitive late decelerations (0.78) after adjusting for fever, nulliparity, prolonged first stage (less than the fifth percentile), and obesity (Figure 2). Combining all of the significant features (repetitive late and variable decelerations, prolonged decelerations, tachycardia) did not improve the predictive ability of the NICHD model for acidemia, with an AUC of 0.71. None of the interaction terms demonstrated a significant predictive ability for acidemia (Table 7).

Comment

We found that of the 3 categories and characteristics defined by the NICHD, only repetitive late and repetitive variable decelerations, one or more prolonged decelerations, and baseline tachycardia in the last 30 minutes of labor were associated with acidemia at birth in women delivering from the second stage at term. None of the NICHD-defined features demonstrated clinically useful predictive ability for acidemia, either alone or in combination. A non-NICHD feature, total deceleration area, calculated as the sum of the estimates of area within of all the decelerations, showed the greatest association and best predictive ability for acidemia when combined with other significant clinical factors. Total deceleration area, which captures both temporal and dose effect of periodic features, demonstrates the need for new measures to improve on our ability to use EFM.

At the 2008 NICHD consensus conference,[1] experts readily acknowledged that despite the ubiquitous use of EFM, virtually no work had been done to examine EFM patterns and estimate their association and predictive ability for acidemia and birth outcomes in large unselected cohorts. Chen et al,[6] utilizing the United States–linked birth and infant death data, performed a retrospective cohort study to estimate the association between EFM and term neonatal morbidity and mortality. The authors concluded that the use of intrapartum EFM was associated with a significant reduction in short-term neonatal morbidity and neonatal mortality in the United States. However, the comparison group of women unexposed to EFM by definition likely represents an unreasonable control group for the accurate estimation of the association between EFM use and improved outcomes because that group included, among other things, home births, which can have an impact on outcomes but in instances in which EFM is not available. As important, to improve the clinical use of EFM, it is critically important to investigate the association between specific elements of EFM, such as

TABLE 4
Association of EFM patterns during the 30 minutes before delivery and metabolic acidemia

Variable	Metabolic acidemia (n = 50)[a]	Adjusted OR (95% CI)
Moderate variability	21	0.72 (0.42–1.22)
Category III	0	—
Minimal variability	3	0.68 (0.27–1.71)
Prolonged decelerations	7	3.02 (1.64–5.55)
Tachycardia	10	2.99 (1.55–5.77)
Recurrent late decelerations	8	2.46 (1.10–4.29)
Total deceleration area greater than 95th percentile	15	3.79 (2.04–7.04)

CI, confidence interval; *EFM,* electronic fetal monitoring; *OR,* odds ratio.

[a] Metabolic acidemia is arterial UCG of 7.10 or less and base excess less than −8.

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TABLE 5
Association of NICHD categories and defined features 10 minutes before delivery

Variable	Acidemia (pH ≤7.10) (n = 57)	No acidemia (n = 5331)	Unadjusted relative risk (95% CI)	Adjusted OR (95% CI)[a]	*P* value
Category I	3.9%	5.4%	Referent	Referent	—
Category II	96.2%	94.3%	1.41 (0.35–5.78)	1.18 (0.29–4.90)	.82
Category III	0.0%	0.4%	—	—	—
Moderate variability	71.1%	73.5%	Referent	Referent	—
Minimal variability	20.0%	22.9%	0.90 (0.43–1.89)	0.93 (0.44–1.96)	.86
Marked variability	8.9%	3.4%	2.66 (0.95–7.44)	2.13 (0.74–6.13)	.16
Absent variability	0.0%	0.3%	—	—	—
Repetitive late decelerations[b]	50.9%	22.7%	3.47 (2.07–5.81)	3.12 (1.84–5.31)	< .01
Repetitive prolonged decelerations[b]	50.9%	19.3%	4.24 (2.53–7.09)	3.82 (2.25–6.50)	< .01
Repetitive variable decelerations[b]	68.4%	46.4%	2.48 (1.42–4.32)	2.24 (1.27–3.94)	< .01
Baseline tachycardia	17.5%	6.6%	2.98 (1.52–5.85)	2.50 (1.24–5.02)	.01
Baseline bradycardia	0.0%	1.1%	—	—	—

CI, confidence interval; *NICHD,* National Institute of Child Health and Human Development; *OR*, odds ratio.

[a] Adjusted for nulliparity, fever, prolonged first stage, and obesity; [b] Repetitive: occurring with 50% or greater of contractions.

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category II and its components, and outcomes.

In 2011, Jackson et al[7] described the association between EFM categories and neonatal outcomes at term including 1- and 5-minute Apgar scores and neonatal intensive care unit admission. The authors concluded that there was an association between category II in the last 2 hours of labor and short-term neonatal morbidity. However, they were neither able to describe the association of specific components of category II features and morbidity, nor were they able to adjust for confounding effects that are known to be associated with short-term morbidity. Importantly, this retrospective cohort study was performed using medical record extraction for EFM assessment.

Although this study provided important descriptive data that may be generalizable to similar systems, bedside interpretation and charting of EFM is itself confounded and not independent from individual clinical factors, making it difficult to draw conclusions of association between EFM patterns and outcomes. Our prospective, blinded extraction and interpretation allowed estimates of association, independent of these confounding factors.

Although the charge from the NICHD consensus to speak the same language when referring to EFM tracings is critical, some investigators have alluded to the fact that the current category system and definitions may not sufficiently summarize the data from EFM in a way that allows it to be clinically predictive.

Parer and Ikeda[8] have described a 5-tier system for the interpretation of EFM, but it has yet to be found superior to the 3-tier system for the prediction of acidemia. However, even a more complex category system with additional tiers will not capture the complex differences in recurring elements, such as decelerations and variability, nor will it capture the temporal impact on the meaning of EFM. Elliott et al[9] used computer analysis and the 5-tiered system to investigate the effect of frequency and

TABLE 6
Test characteristics of presence of each EFM feature in final 30 minutes of labor for acidemia

Characteristic	Sensitivity	Specificity	Positive predictive value	Negative predictive value
Category I	0.0%	97.7%	0.0%	98.9%
Category II	100.0%	2.4%	1.1%	100.0%
Category III	0.0%	99.9%	0.0%	98.9%
Minimal variability	8.8%	87.5%	0.7%	98.9%
Marked variability	0.0%	99.7%	0.0%	98.9%
Repetitive late decelerations[a]	7.0%	97.8%	3.2%	99.0%
Repetitive prolonged decelerations[a]	7.0%	94.7%	1.4%	99.0%
Baseline tachycardia	14.0%	95.7%	3.4%	98.9%

EFM, electronic fetal monitoring.

[a] Repetitive: occurring with 50% or greater of contractions.

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duration of the occurrence of each tier on the prediction of base deficit with, and without, neonatal encephalopathy. They found that both the frequency and the duration of particular tracing types were associated with outcome. Hamilton et al[10] hypothesized that the frequency of variable decelerations, as well as other characteristics of each deceleration such as depth, could discriminate between cases of metabolic acidosis and metabolically normal controls. They found that only prolonged decelerations in addition to the variability within the deceleration and a depth below 60 beats/min for more than 60 seconds were discriminatory for metabolic acidemia. However, none of their receiver-operator curve analyses demonstrated features with clinically useful efficiency (AUC 0.57-0.61).

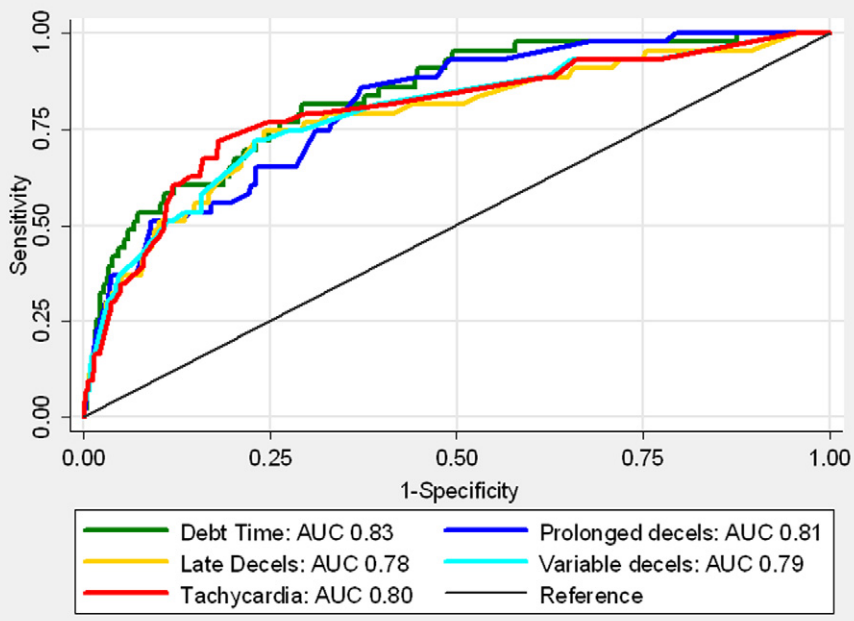
Our findings build on this early report that features of decelerations that are not acknowledged by the current nomenclature are of importance in the discrimination between acidemia and normal fetuses in a large, unselected term population. However, we found non-NICHD features that, when combined with clinical factors, demonstrate much improved ability to predict acidemia likely caused by their ability to capture the effect of dose over time of decorations on the consumption of the fetal buffer system.

In addition to the exploration of non-NICHD EFM features compared with those specified by the NICHD, our robust clinical data allowed us to adjust for known and identified confounding factors. Although some potential participants were excluded for lack of sufficient EFM and lack of UCG at birth, our universal EFM and UCG policies dramatically reduced the number of women excluded and thus limited the potential for selection bias.

An important strength of our study is the prospective, blind reading and interpretation of EFM patterns by dedicated and formally trained obstetric research nurses. Bedside interpretation and charting can introduce bias with unpredictable direction and limits retrospective analyses of EFM patterns charted for clinical use when attempting to estimate the true association between patterns and outcomes. It is true that a prospective approach, such as the one we used, may strike practitioners as one with reduced generalizability, but we would offer that the misuse of EFM over the past 4 decades obviates that we start at the beginning, simply associating the EFM patterns interpreted by humans with outcomes. A secondary question, beyond the scope of this study, is how best to improve the use of EFM clinically once the meaning of patterns is understood.

It is important to consider that the women included in this study reached

FIGURE 2
Comparative predictive ability of EFM features for acidemia



All models are adjusted for nulliparity, fever, prolonged first stage, and obesity.

AUC, area under the curve; *EFM,* electronic fetal monitoring.

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TABLE 7
Synergy of EFM features in the association and prediction of acidemia

Variable	Adjusted OR (95% CI)[a]	*P* value	AUC
Minimal variability × tachycardia	0.65 (0.07–6.39)	.71	.71
Minimal variability × bradycardia	Dropped for collinearity	—	—
Minimal variability × repetitive late decelerations[b]	2.78 (0.26–29.89)	.40	.71
Minimal variability × repetitive prolonged decelerations[b]	4.20 (0.38–46.89)	.24	.71
Tachycardia × repetitive late decelerations[b]	2.04 (0.46–9.03)	.35	.72
Tachycardia × repetitive prolonged decelerations[b]	1.25 (0.26–5.86)	.78	.71

AUC, area under the curve; *EFM,* electronic fetal monitoring; *OR,* odds ratio.

[a] Adjusted for nulliparity, fever, prolonged first stage, and obesity; [b] Denotes interaction term; [c] Repetitive: occurring with 50% or greater of the contractions.

Cahill. Electronic fetal monitoring to predict acidemia. Am J Obstet Gynecol 2012.

the second stage of labor. Although the exclusion of women delivered during the first stage prevented comparison of pH in infants born from the second stage with those born out of the first, which has been described to differ,[4] by definition the EFM tracings studied were from the second stage of labor, which may limit generalizability.

It is also important to remember that the EFM analyzed in this study was the 30 minutes prior to delivery. Although this was chosen based on the proximity to the measured outcome (acidemia) and the biological plausibility of effect on the fetal acid-base status, we cannot draw conclusions about the associations and predictive ability of features earlier in labor and acidemia at birth. Also, our total deceleration area calculation was done so using an estimate of area half (depth × duration) to allow reproducibility but would tend to underestimate the absolute value for each estimate. However, this nondifferential estimate is very unlikely to have had an impact on the relative results.

Lastly, arterial UCG acidemia is a surrogate endpoint, and most term infants with this finding will ultimately be clinically well. The ability to predict acidemia is only a first step toward improving upon the use of EFM; prediction of more meaningful birth outcomes will be critical.

We found that the NICHD category system did not demonstrate discriminatory ability for acidemia when examining the final 10 or 30 minutes of EFM in the second stage prior to delivery at term. Although prolonged decelerations, repetitive variables and late decelerations, and baseline tachycardia were associated with acidemia, none were as predictive, alone or in combination, of acidemia as a calculation called the total deceleration area, which captured deceleration frequency and depth. The improved predictive ability of novel measures of decelerations for acidemia over the existing taxonomy highlights the importance of discovery of new ways to quantify and interpret the complex and time-dependent patterns created by EFM at the bedside.

Although the 2008 consensus document carries the important message that obstetric providers use the same nomenclature when reading and interpreting EFM, the 3-tiered system seems insufficient to summarize the complex patterns captured by EFM and use them to predict acidemia. Although continuing to speak the same EFM language, progress toward a more descriptive system seems necessary. ■

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