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CLINICAL ARTICLE

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# The utility of fetal heart rate deceleration's descending slope in searching for a non-National Institute of Child Health and Human Development parameter for the detection of fetal acidosis

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## Abstract

**Objective:** To identify new parameters predicting fetal acidemia.

**Methods:** A retrospective case–control study in a cohort of deliveries from a tertiary referral hospital-based cohort deliveries in Zaragoza, Spain between 2018 and 2021 was performed. To predict fetal acidemia, the NICHD categorizations and non-NICHD parameters were analyzed in the electronic fetal monitoring (EFM). Those included total reperfusion time, total deceleration area and the slope of the descending limb of the fetal heart rate of the last deceleration curve. The accuracy of the parameters was evaluated using the specificity for (80%, 85%, 90%, 95%) sensitivity and the area under the receiver operating characteristic curve (AUC).

**Results:** A total of 10362 deliveries were reviewed, with 224 cases and 278 controls included in the study. The NICHD categorizations showed reasonable discriminatory ability (AUC=0.727). The non-NICHD parameters measured during the 30-min fetal monitoring, total deceleration area (AUC=0.807, 95% CI: 0.770, 0.845) and total reperfusion time (AUC=0.750, 95% CI: 0.707, 0.792), exhibited higher discriminatory ability. The slope of the descending limb of the fetal heart rate of the last deceleration curve had the best AUC value (0.853, 95% CI: 0.816, 0.889). The combination of total deceleration area or total reperfusion time with the slope demonstrated high discriminatory ability (AUC=0.908, 95% CI: 0.882, 0.933; specificities of 71.6% and 72.7% for a sensitivity of 90%).

**Conclusions:** The slope of the descending limb of the fetal heart rate of the last deceleration curve is the strongest predictor of fetal acidosis, but its combination with the total reperfusion time shows better clinical utility.

KEYWORDS
acidemia, cardiotocography, deceleration, fetal heart rate, reperfusion, slope

## 1 | INTRODUCTION

The National Institute of Child Health and Human Development (NICHD) established a categorization system for electronic fetal monitoring (EFM) in 2008 to detect fetal acidosis.[1] Among the parameters used in this system, fetal heart rate (FHR) variability has shown the highest predictive capacity, although it has limited sensitivity when used as a single parameter.[2,3]

Categorization systems based on FHR parameters by the NICHD,[4] National Institute for Health and Care Excellence (NICE),[1] or International Federation of Gynecology and Obstetrics (FIGO) have shown limited sensitivity to detect acidosis.[5–8] According to Santo et al., the NICHD guidelines show low sensitivity (32%), and high specificity (95%) in predicting fetal acidemia.[6] On the other hand, the FIGO and NICE guidelines have higher sensitivity (89% and 97%), and lower specificity (63% and 66%) in predicting acidemia. In addition, a new categorization by fetal physiology had the highest discriminatory capacity for fetal acidosis, although this was only moderate.[7] It is crucial to identify novel single or straightforward combinations of FHR parameters and it is essential to show higher specificity in assessing the fetal response to acidosis with respect to previous classification systems.

Deceleration, which is the most common change observed in the cardiotocographic record during childbirth, indirectly reflects fetal tolerance to hypoxemia. It is influenced by the acute response of the parasympathetic nervous system, which becomes more active with the onset and progression of fetal acidosis.[9] The morphologic analysis of parameters related to deceleration during childbirth can serve as a complementary method to quantify fetal status by reflecting the level of parasympathetic activation. This approach shows promise and is supported by robust evidence from animal models.[10]

In recent years, there has been an increased search for additional non-NICHD parameters in the fetal monitoring signal to predict fetal acidosis. These parameters include: (i) the total area of deceleration, determined for each deceleration by calculating the product of its duration and depth and then dividing it by two. The sum of these calculated values is used to estimate the overall deceleration area;[11,12] (ii) the total reperfusion time,[13] which is defined as the cumulative duration, measured in minutes, in which the fetus maintains a baseline FHR without any decelerations within a specified time frame window. Evidence supports that cerebral oxygenation is affected by short intervals between decelerations within this time frame, leading to progression towards acidosis and fetal hypotension;[14,15] and (iii) the slope, which refers to the slope of the descending limb of the FHR of the last deceleration curve.[16] Studies on term sheep fetuses have shown that the slope of decelerations is associated with the severity of acidosis, indicating its usefulness for grading the fetal adaptive response during childbirth.[14,16,17]

Our objective was to study FHR parameters and their evolution at two points in a 30-min frame window and compare them with other non-NICHD parameters that have already shown its usefulness in predicting acidosis, the total deceleration area, total reperfusion time, and the slope of the descending limb of the FHR of the last deceleration curve.

## 2 | MATERIALS AND METHODS

### 2.1 | Study design

This retrospective case–control study was carried out at Hospital Miguel Servet, a tertiary referral hospital in Zaragoza, Spain, from June 2018 to December 2021. The study enrolled singleton term pregnancies (37–42 weeks) with a cephalic presentation, no fetal anomalies, and a deceleration pattern in EFM consisting of two or more decelerations in the last 30 min of labor. Participants were excluded if they experienced a sentinel event (such as uterine rupture, cord prolapse, or shoulder dystocia), had less than 30 min of EFM data, had recurrent loss of focus that hindered EFM evaluation, cord arterial blood gas was not available or did not enter active labor. Out of the initial cohort of 10 362 women, 337 infants (3.3%) were identified as acidotic. The selection of the control group followed a non-randomized 1:1 consecutive method, where each selected control was chronologically consecutive to a case before applying exclusion criteria. Figure S1 illustrates a flow chart outlining the study, where 113 acidotic fetuses were excluded from the analysis due to not meeting the stipulated criteria. Subsequently, among the remaining participants, 224 infants displaying arterial acidemia were categorized as cases, while 278 infants were chosen as controls, meeting the inclusion criteria.

The primary variable of interest (cases) was fetal acidemia, defined as arterial cord blood pH less than 7.10 at birth.

Maternal and pregnancy data were recorded, including maternal characteristics (such as age, parity, maternal pathology, and maternal risk factors), labor course data (including the onset of labor, maternal fever, presence of meconium, and way of delivery), newborn characteristics (such as gestational age, birthweight, fetal gender and Apgar score at 5 min), and arterial blood gas cord-related characteristics.

### 2.2 | Fetal heart rate features

The analysis and interpretation of the EFM data in the last 30 min prior to delivery were performed by a single expert obstetrician for all cases and controls included in the final study population. The obstetrician was blinded to the neonatal outcomes to ensure unbiased evaluation. According to NICHD classification, individuals were classified as category I (normal), category II (suspicious) and category III (pathologic) (Table S1). The non-NICHD parameters studied were total deceleration area and total reperfusion time. Total deceleration area has been defined as the sum of the area within all decelerations in the last 30 min of labor.[11] Total reperfusion time is defined as the sum in minutes of the period that the fetus remains at baseline without deceleration during the last 30 min.[13]

Furthermore, parameters related to the initial and final decelerations during this 30-min time frame were also analyzed and compared between them. These parameters encompassed measures such as amplitude, duration, drop and area of the deceleration; the slope of the descending limb of the FHR of the deceleration curve; overshoot; baseline instability; and reduced variability. Additionally, we introduced the concept of parameter evolution by analyzing the differences between periods through the 30-min EFM frame.

Figure S2 provides an illustration of the non-NICHD parameters: reperfusion time, deceleration area, and the slope of the descending limb of the FHR of the deceleration curve.

### 2.3 | Statistical analysis

A descriptive analysis of the variables of the study was performed, comparing them by separating EFM in two groups regarding its acidotic status (yes vs no). The normality assumption was verified using the Shapiro–Wilk test. Non-normal continuous variables are described by median and interquartile range, and categorical variables are described by absolute and relative frequencies. Comparisons between groups were performed using non-parametric Mann Whitney or chi-squared tests for continuous or categorical variables, respectively, with a significance level of $P<0.05$.

Univariate logistic regression models were employed to determine the most effective predictors of acidosis, utilizing electrocardiographic fetal signal parameters related to the initial and final decelerations within a 30-min timeframe, as well as the disparity between them. The odds ratios (OR) and their corresponding 95% confidence intervals were calculated. Additionally, the NICHD classification, total deceleration area, and total reperfusion time throughout the entire 30-min interval were analyzed as potential factors. The study aimed to investigate the utilization of a combination of the most effective parameter derived from a single deceleration and the conventional FHR features, namely total deceleration area and reperfusion time, to establish a reliable predictive model for acidosis.

To assess the predictive efficacy of the variables employed, both individually and in combination, we conducted evaluations focusing on discrimination and clinical utility.

The discrimination performance was evaluated employing the receiver operating characteristic (ROC) curve methodology. Choosing a specific cutoff point for the parameter, individuals will be classified as acidotic or non-acidotic based on whether the probability assigned by the model is above or below the established threshold. Since our model is not perfect, we will correctly classify some fetuses as acidotic (true positives [TP]) or non-acidotic (true negatives, TN) at times, but there will also be misclassified cases, including both non-acidotic (false negatives, FN) and acidotic (false positives [FP]) instances. The ROC curve illustrates the relationship between sensitivity (true positive rate (TP/(TP+FN)), *y*-axis) and 1-specificity (false positive rate (FN/(TN+FP)), *x*-axis), computed across varying thresholds of acidemia probability. The area under the ROC curve (AUC) serves as a metric summarizing the discriminatory efficacy of a predictive model. It quantifies the likelihood of the model assigning a higher acidotic probability to a genuinely acidotic case compared to a non-acidotic case. AUC values range from 0 to 1, where 0.5 denotes a random classifier, 0.7 is deemed acceptable, 0.8 signifies good discriminatory performance, 0.9 indicates excellent discrimination, and 1 denotes perfect discrimination. Confidence intervals for the AUC were derived utilizing the DeLong estimation method. Specificity and cutoff points were estimated for sensitivities of 80%, 85%, 90%, and 95% to provide practical clinical guidance. Bootstrap and proportion tests were used to compare AUCs and sensitivities, respectively. Lastly, a comparative analysis of features associated with early and late decelerations observed in fetal heart rate traces over the analyzed 30-min period was conducted using the De Long test to compare the AUCs.

Furthermore, the practical utility of the developed models was assessed by examining their clinical applicability. This assessment involved treating the prediction models as binary classifiers, using a predetermined cutoff point of acidemia probability to distinguish between individuals classified as acidotic and non-acidotic. To evaluate clinical utility, the clinical utility curve was employed, plotting threshold acidemia probability on the *x*-axis against two distinct metrics on the *y*-axis. The first metric represented the percentage of acidotic infants incorrectly classified below the chosen cutoff point, while the second metric indicated the number of infants falling below this threshold. By analyzing this curve across various cutoff points, we could determine the percentage of misclassified acidotic fetuses and identify those with a low risk of acidemia who might be spared unnecessary cesarean sections, thus addressing concerns regarding fetal well-being.

All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM, statistical package for social sciences, San Francisco, US) and R programming language version 4.2.2 (The R Foundation for Statistical Computing, Vienna, Austria).

## 3 | RESULTS

### 3.1 | Comparison of neonates without acidemia

Table 1 provides an overview of the maternal and perinatal characteristics. Fetal growth abnormalities were more prevalent in the acidotic group (13.39%) compared to the non-acidotic group (7.79%), and this difference was statistically significant ($P=0.022$). The median values of arterial and venous pH were 7.06 and 7.15, respectively, for the acidotic and non-acidotic groups, showing a statistically significant difference ($P<0.001$). The $pCO_2$ level in the arterial blood cord gas exhibited a median of 78 mmHg in the cases group and 62 mmHg in the control group, being a statistically significant difference ($P<0.001$).

### 3.2 | Comparative analysis of NICHD system (categorizations and parameters) and non-NICHD parameters to detect fetal acidosis

Table 2 provides a comprehensive analysis of various factors related to fetal acidosis, including NICHD classification, deceleration area,

**TABLE 1** Maternal characteristics and perinatal results.

| | Total sample $n=502$ | No acidosis $n=278$ | Acidosis $n=224$ | $P$ value |
|---|---|---|---|---|
| Maternal age | 34 (30–37) | 34 (30–36) | 34 (30–37) | 0.440 |
| Parity zero | 302 (60.2%) | 148 (53.2%) | 149 (66.5%) | <0.001 |
| Gestational diabetes | 54 (10.8%) | 29 (10.4%) | 25 (11.2%) | 0.793 |
| Pregestational diabetes | 1 (0.2%) | 1 (0.4%) | 0 (0%) | |
| Hypertensive disease of pregnancy | 14 (2.8%) | 5 (1.8%) | 9 (4.1%) | 0.133 |
| Induction | 166 (33.1%) | 86 (30.9%) | 80 (35.7%) | 0.258 |
| Prostaglandins | 137 (27.3%) | 72 (25.9%) | 65 (29.1%) | 0.055 |
| Mechanics | 19 (3.8%) | 11 (3.9%) | 8 (3.5%) | |
| Prostaglandins and mechanics | 3 (0.6%) | 0 (0%) | 3 (1.3%) | |
| Oxytocin | 7 (1.4%) | 3 (3.5%) | 4 (5%) | |
| Gestational age (weeks) | 280.5 (274, 286) | 280 (273.75, 286) | 281 (274.25, 286) | 0.205 |
| Sex | | | | 0.870 |
| Male | 262 (52.2%) | 146 (52.5%) | 116 (51.8%) | |
| Female | 240 (47.8%) | 132 (47.5%) | 108 (48.2%) | |
| Newborn percentile weight | 3251.74 (471.07) | 3281.09 (454.45) | 3215.31 (489.3) | 0.123 |
| <10 | 73 (14.54) | 30 (10.8%) | 43 (15.5%) | 0.011 |
| >90 | 60 (11.95) | 33 (11.9%) | 27 (12.1%) | 0.999 |
| Eutocic birth | 303 (60.4%) | 193 (69.4%) | 110 (49.1%) | <0.001 |
| Instrumental delivery | 121 (24.1%) | 60 (21.6%) | 61 (27.2%) | 0.141 |
| Vacuum extraction | 115 (22.9%) | 58 (20.9%) | 57 (25.5%) | |
| Forceps | 6 (1.2%) | 2 (0.7%) | 4 (1.8%) | |
| Cesarean section | 78 (15.5%) | 25 (8.9%) | 53 (23.7%) | <0.001 |
| Gestation more than 41 + 3 weeks | 91 (18.1%) | 50 (17.9%) | 41 (18.3%) | 0.814 |
| Meconium | 63 (12.6%) | 26 (9.4%) | 37 (16.5%) | 0.016 |
| Fever | 111 (22.1%) | 57 (20.5%) | 54 (24.1%) | 0.333 |
| Alterations in amniotic fluid volume | 36 (7.2%) | 19 (6.8%) | 17 (7.6%) | 0.745 |
| Oligoamnios | 27 (5.4%) | 15 (5.4%) | 12 (5.4%) | |
| Polyhydramnios | 9 (1.8%) | 4 (1.4%) | 5 (2.2%) | |
| Apgar 5 min | 10 (9–0) | 10 (10–10) | 9 (8–10) | <0.001 |
| Apgar 5 min ≤7 | 36 (7.2%) | 4 (1.4%) | 32 (14.3) | <0.001 |
| Umbilical arterial pH | 7.12 (7.07, 7.20) | 7.18 (7.14, 7.27) | 7.06 (7.01, 7.09) | <0.001 |
| Umbilical venous pH | 7.18 (7.13–7.22) | 7.23 (7.18, 7.26) | 7.15 (7.09, 7.19) | <0.001 |
| Base deficit (BE) | −6.1 (−9.2, −2.3) | −3.1 (−5.9, 1.25) | −9.2 (−1.2, −6.8) | <0.001 |
| Lactic* | 6.63 (2.69) | 5.07 (2.08) | 8.59 (2.01) | <0.001 |

*Note*: All medians (percentage or standard deviation) except *Mean (standard deviation).
Abbreviation: BE, base excess.

and reperfusion time measurements during the last 30 min of fetal electrocardiogram. Additionally, the parameters measured during the initial and final deceleration of the fetal CTG, together with their odds ratios and AUC values from univariate logistic regression models, are included to predict acidosis.

The NICHD classification demonstrates reasonable discriminatory ability, with an AUC value of 0.727. The suspicious category carries a higher risk of acidosis OR = 9.87 (95% CI: 5.41, 18.00), while the pathological category presents an even greater risk OR = 22.49 (95% CI: 15.65, 32.32) compared to the normal category. However, better discriminatory ability is observed for variables measured during the 30-min fetal monitoring window. The deceleration area exhibits a good discriminatory AUC value of 0.807, while the reperfusion time shows a slightly lower value of 0.750.

Regarding parameters measured on a single deceleration (initial, final, or their difference), the analysis reveals that parameters associated with the final deceleration are more accurate in predicting acidemia compared to those from the initial period. Table 3 presents the $P$ values of the comparisons conducted. Across all variables, a

**TABLE 2** Categorization and parameters by NICHD and non-NICHD parameters.

| | Total $n = 502$ | No acidosis $n = 278$ | Acidosis $n = 224$ | *P* value | OR (95% CI) | AUC |
|---|---|---|---|---|---|---|
| NICHD categorization | | | | | | |
| Normal (I) | 137 (27.3%) | 123 | 14 | | | 0.727 |
| Suspect (II) | 294 (58.6%) | 130 | 164 | <0.001 | 9.87 (5.41, 18.00) | |
| Pathological (III) | 71 (14.1%) | 25 | 46 | <0.001 | 22.49 (15.65, 32.32) | |
| NICHD and non-NICHD parameters | | | | | | |
| Total time | | | | | | |
| Total deceleration area ($mm^2$) | 14.16 (7.71, 22.54) | 9.71 (5.37, 15.42) | 20.93 (13.75, 28.65) | <0.001 | 1.14 (1.11, 1.17) | 0.807 |
| Total reperfusion time (min) | 19.35 (15.37, 23.20) | 21.69 (18.10, 25.12) | 17.04 (13.86, 19.10) | <0.001 | 0.82 (0.79, 0.86) | 0.750 |
| Initial window | | | | | | |
| Deceleration amplitude (bpm) | 63.33 (49.96, 75.09) | 56.46 (44.96, 67.19) | 73.22 (59.14, 83.98) | <0.001 | 1.05 (1.03, 1.06) | 0.721 |
| Deceleration duration (bpm) | 65.22 (55.32, 90.22) | 61.35 (51.24, 89.94) | 76.23 (59.94, 91.64) | <0.001 | 1.01 (1.00, 1.02) | 0.617 |
| Deceleration drop (bpm) | 34.56 (23.34, 49.56) | 43.59 (31.08, 57.47) | 24.81 (19.20, 37.71) | <0.001 | 0.95 (0.94–0.96) | 0.767 |
| Slope (bpm/s) | 1.74 (1.05, 2.85) | 1.29 (0.92, 1.89) | 2.75 (1.76, 3.68) | <0.001 | 3.13 (2.51, 3.91) | 0.803 |
| Deceleration area ($mm^2$) | 216 (161, 302) | 189 (149, 264) | 270 (184, 361) | <0.001 | 1.01 (1.04, 1.09) | 0.674 |
| FHR (bpm) | 150 (140, 160) | 150 (140, 160) | 150 (145, 160) | <0.001 | 1.01 (1.00, 1.01) | 0.552 |
| Overshoot | 71 (14.1%) | 29 (10.4%) | 42 (18.8%) | 0.008 | 1.98 (1.19, 3.30) | 0.542 |
| Baseline instability | 148 (29.5%) | 42 (15.1%) | 106 (47.3%) | 0.013 | 1.02 (1.01, 1.03) | 0.662 |
| Reduced variability | 86 (17.1%) | 37 (13.3%) | 49 (21.9%) | <0.001 | 5.05 (3.32, 7.68) | 0.550 |
| Final window | | | | | | |
| Deceleration amplitude (bpm) | 72.99 (54.94, 87.04) | 60.06 (49.96, 74.92) | 84.87 (74.18, 95.11) | <0.001 | 1.06 (1.05, 1.08) | 0.796 |
| Deceleration duration (bpm) | 71.25 (59.88, 90.69) | 61.8 (55.68, 89.92) | 80.9 (64.32, 100.14) | <0.001 | 1.02 (1.02, 1.03) | 0.670 |
| Deceleration drop (bpm) | 32.63 (23.26, 46.51) | 40.90 (30.79, 53.47) | 23.96 (19.18, 32.32) | <0.001 | 0.93 (0.92, 0.95) | 0.792 |
| Slope (bpm/s) | 2.08 (1.31, 3.47) | 1.57 (1.01, 2.05) | 3.51 (2.49, 4.69) | <0.001 | 3.33 (2.68, 4.12) | 0.853 |
| Deceleration area ($mm^2$) | 251 (189, 371) | 215 (160, 272) | 355 (245–469) | <0.001 | 2.47 (2.05, 2.99) | 0.781 |
| FHR (bpm) | 155 (145, 165) | 150 (140, 160) | 160 (150, 170) | <0.001 | 1.04 (1.03, 1.06) | 0.664 |
| Overshoot | 67 (13.4%) | 24 (8.63%) | 43 (19.2%) | 0.001 | 2.51 (1.47, 4.29) | 0.552 |
| Baseline instability | 188 (37.5%) | 50 (17.98%) | 138 (61.61%) | <0.001 | 7.32 (4.87, 11.00) | 0.718 |
| Reduced variability | 110 (21.9%) | 38 (13.67%) | 72 (32.1%) | <0.001 | 2.99 (1.92, 4.66) | 0.592 |
| Variation between final and initial window | | | | | | |
| Deceleration amplitude (bpm) | 6.12 (−1.97, 19.63) | 4.16 (−4.11, 13.11) | 12.32 (1.32, 24.38) | <0.001 | 1.02 (1.01, 1.03) | 0.631 |
| Deceleration duration (s) | 2.15 (−7.31, 14.44) | 1.31 (−4.71, 13.45) | 3.90 (−8.76, 23.55) | 0.136 | 1.01 (1.00, 1.02) | 0.538 |

(Continues)

TABLE 2 (Continued)

| | Total $n = 502$ | No acidosis $n = 278$ | Acidosis $n = 224$ | *P* value | OR (95% CI) | AUC |
|---|---|---|---|---|---|---|
| Deceleration drop (s) | −1.41 (−10.84, 6.24) | −1.62 (−12.47, 8.11) | −0.78 (−8.72, 5.04) | 0.611 | 1.01 (0.99, 1.01) | 0.513 |
| Slope (bpm/s) | 0.29 (−0.24, 1.01) | 0.24 (−0.22, 0.59) | 0.64 (−0.29, 1.70) | <0.001 | 1.33 (1.15, 1.52) | 0.599 |
| Deceleration area ($mm^2$) | 32.41 (−19.11, 99.12) | 17.20 (−25.10, 54.57) | 70.28 (−1.05, 163.74) | <0.001 | 1.01 (1.00, 1.01) | 0.657 |
| FHR variability (bpm) | 0 (0, 10) | 0 (0, 5) | 5 (0, 15) | <0.001 | 1.00 (1.00, 1.01) | 0.651 |

Abbreviations: AUC, area under the curve; bpm, beats per minute; CI, confidence interval; FHR, fetal heart rate; mm, millimeters; NICHD, The National Institute of Child Health and Human Development; s, seconds.

TABLE 3 Comparison of deceleration parameters between early (initial) and late (final) fetal traces.

| | Initial AUC | Final AUC | *P* value |
|---|---|---|---|
| Deceleration amplitude (bpm) | 0.721 | 0.796 | 0.001 |
| Deceleration duration (bpm) | 0.617 | 0.670 | 0.019 |
| Deceleration drop (bpm) | 0.767 | 0.792 | 0.309 |
| Slope (bpm/s) | 0.803 | 0.853 | 0.021 |
| Deceleration area ($mm^2$) | 0.674 | 0.781 | <0.001 |
| FHR (bpm) | 0.552 | 0.664 | <0.001 |
| Overshoot | 0.542 | 0.552 | 0.429 |
| Baseline instability | 0.662 | 0.718 | <0.001 |
| Reduced variability | 0.550 | 0.592 | <0.001 |

Abbreviations: bpm, beats per minute; FHR, fetal heart rate; s, seconds.

higher area under the curve (AUC) is observed for the last deceleration, and this difference is statistically significant for all variables except deceleration drop and overshoot. These findings support the notion that information obtained closer to delivery provides more informative insights. Notably, the measure of the slope during the final deceleration demonstrates the highest AUC value of 0.853, surpassing those measured over the entire 30-min period.

Although the non-NICHD parameters demonstrated high discriminatory ability, we explored predictive models of acidosis using the combination of deceleration area, reperfusion time, and the slope of the last deceleration. This approach provides an easy tool that combines the information from the last 30 min of the CTG and the last deceleration measured during monitoring, which is closest to delivery. Table 4 shows the specificity and threshold value for sensitivity values of 80%, 85%, 90%, and 95%, as well as the AUC for all possible combinations of predictor variables.

Analyzing the specificity values corresponding to a sensitivity of 90% and their cutoff points for each of the parameters, we observe variations ranging from a minimum of 40% with a cutoff point of 22.9 min for the reperfusion time, to 46% with a cutoff point of 9.10 $mm^2$ for the deceleration area, and a maximum of 52% with a cutoff point of 1.590 bpm/s for the slope. Regarding the multivariate models, the optimal one corresponds to a logistic regression model that combines the three parameters (slope, deceleration area and reperfusion time), resulting in an AUC of 0.908 and a specificity of 73.7% at a sensitivity threshold of 90%. The combination of three parameters did not exhibit significant differences, neither in AUC or specificity for a sensitivity of 90%, compared to the combination of slope and reperfusion time (AUC = 0.902, $P = 0.196$; specificity = 72.7%, $P = 0.865$), or the combination of slope and deceleration area (AUC = 0.902, $P = 0.171$; specificity = 71.6%, $P = 0.645$). However, statistically significant differences were observed when comparing the combination of deceleration area and reperfusion time (AUC = 0.807, $P < 0.001$; specificity = 50.0%, $P < 0.001$), slope (AUC = 0.853, $P < 0.001$; specificity = 52.3%, $P < 0.001$), deceleration area (AUC = 0.807, $P < 0.001$; specificity = 46.0%, $P < 0.001$),

**TABLE 4** Combination of total deceleration area, total reperfusion time and slope of last deceleration.

| | Specificity for a sensitivity value of | | | | |
|---|---|---|---|---|---|
| | 80% (95% CI) | 85% (95% CI) | 90% (95% CI) | 95% (95% CI) | AUC (95% CI) |
| Deceleration area | 62.2 (52.2, 67.9) | 54.3 (48.3, 60.2) | 46.0 (40.1, 52.1) | 34.9 (29.4, 40.8) | 0.800 (0.770, 0.850) |
| Threshold | 12.40 | 10.91 | 9.10 | 6.86 | |
| Reperfusion time | 57.9 (51.6, 63.9) | 50.0 (44.0, 56.0) | 40.4 (34.5, 46.7) | 32.7 (27.1, 38.9) | 0.75 (0.707, 0.792) |
| Threshold | 20.6 | 21.7 | 22.9 | 24.2 | |
| Slope (bpm/s) | 78.7 (73.1, 83.4) | 71.6 (65.6, 76.9) | 52.3 (46.1, 58.5) | 12.7 (9.1, 17.5) | 0.853 (0.816, 0.889) |
| Threshold | 2.170 | 2.000 | 1.590 | 0.860 | |
| Slope + reperfusion time | 84.2 (79.0, 88.3) | 79.1 (73.6, 83.8) | 72.7 (66.7, 77.9) | 63.3 (57.1, 69.1) | 0.902 (0.876, 0.928) |
| Threshold | 42.6 | 36.1 | 27.5 | 21.5 | |
| Slope + deceleration area | 85.8 (81.0, 89.6) | 82.7 (77.6, 86.9) | 71.6 (65.8, 76.7) | 56.1 (50.0, 62.0) | 0.902 (0.875, 0.930) |
| Threshold | 45.9 | 38.1 | 26.4 | 16.8 | |
| Reperfusion time + deceleration area | 62.2 (56.2, 67.9) | 53.6 (47.5, 59.5) | 50.0 (44.2, 55.8) | 38.8 (33.1, 44.8) | 0.807 (0.769, 0.844) |
| Threshold | 32.8 | 28.9 | 26.5 | 20.3 | |
| Slope + reperfusion time + deceleration area | 84.9 (80.0, 88.8) | 80.2 (74.9, 84.6) | 73.7 (68.1, 78.7) | 57.6 (51.5, 63.4) | 0.908 (0.882, 0.933) |
| Threshold | 44.4 | 35.0 | 28.7 | 17.1 | |

Abbreviations: AUC, area under the curve; bpm, beats per minute; CI, confidence interval; s, seconds.

and reperfusion time (AUC = 0.750, $P < 0.001$; specificity = 40.4%, $P < 0.001$).

In terms of simplicity, the combination of slope and the deceleration area or reperfusion time constitutes the simplest model that achieves discriminatory ability comparable to the best model. Based on the principle of parsimony, these combinations are preferred. Figure 1 depicts the comparison of ROC curves for all analyzed models. Additionally, the combination of slope and reperfusion time show the best specificity (72.7%) for a high acidosis detection rate (90%).

To assess the clinical utility of the two models, namely reperfusion time + slope and deceleration area + slope, we examined the clinical utility curve. Figure 2 displays the number of missed acidotic cases and the count of fetuses at low risk of acidosis for which cesarean deliveries can be avoided, based on varying threshold probabilities of acidosis. Detailed values can be found in Table 5.

For the model incorporating the combination of reperfusion time and slope of the last deceleration, a cutoff point of 21% results in misclassification of less than 5% of acidosis cases while avoiding 36% of cesarean deliveries. On the other hand, when using deceleration area and slope, a cutoff point of 16% allows for the avoidance of 32% of cesarean deliveries with the loss of 5% acidotic cases. Consequently, the combination of reperfusion time and the slope of the last deceleration demonstrates the highest clinical utility, considering both the identification of acidosis cases and the reduction of unnecessary cesarean deliveries.

## 4 | DISCUSSION

### 4.1 | Main findings

In the present study, we show that the FHR final deceleration descending slope, in its final window, is the non-NICHD parameter with the highest predictive capacity for fetal acidosis, surpassing the deceleration area and the total reperfusion time, which were previously considered the parameters with the greatest ability to predict acidosis.[11–13] However, we found that the FHR deceleration descending slope (which studies a single window), along with a parameter that studies the total 30-min window, such as the total reperfusion time and the total deceleration area, show a greater capacity to predict fetal acidosis. Moreover, the combination of FHR deceleration slope and total reperfusion time has higher specificity for a sensitivity of 95%, as well as greater clinical applicability, than the total deceleration area. It was also notable that the information pertaining to deceleration was more predictive of acidosis in the later records of deceleration compared to the initial ones.

Therefore, the FHR final deceleration descending slope is the single parameter within the 30-min predelivery window that has the highest predictive capacity for fetal acidosis. Nevertheless, it requires other parameters that evaluate the last 30 min of EFM for a better discriminatory ability (AUC = 0.9) in predicting acidosis.

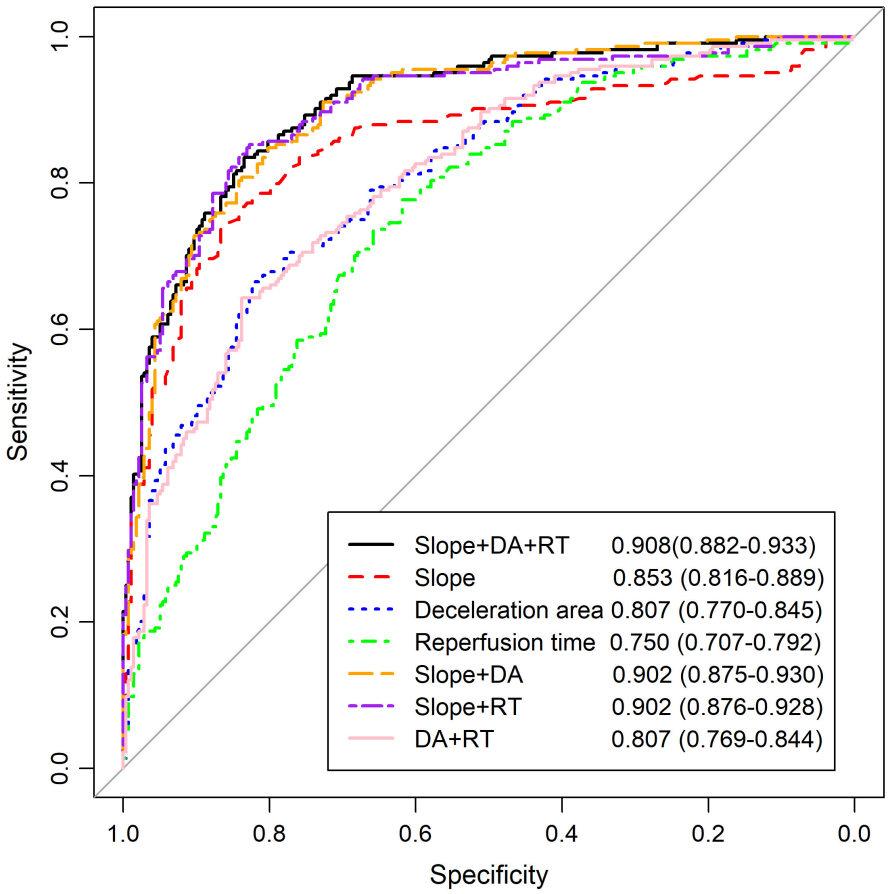


**FIGURE 1** Comparison of the receiver operating characteristic curves provided by all analyzed models for cutoff values corresponding to a sensitivity threshold of 90%. DA, deceleration area; RT, reperfusion time.

## 4.2 | Categorization and parameters by NICHD

The prediction of fetal acidemia is a critically important issue in obstetrics and neonatology. Several studies have evaluated the discriminative capacity of the NICHD categorizations for this purpose. Di Tommaso et al. evaluated the discriminative capacity of NICHD guidelines with a higher acidemia cutoff point of 7.15.[18] Their study showed a moderate discriminative capacity with an AUC of 0.60 (95% CI: 0.47, 0.74). Santo et al. evaluated NICHD guidelines with a lower acidemia cutoff point of 7.05 and only seven cases of acidemia were included among the 151 records studied.[6] Their study showed a limited sensitivity of 32% and specificity of 95% for type III categorization and prediction of fetal acidemia. Choliz et al. presented their study on the prediction of fetal acidosis with pH <7.10 for NICHD categorization, finding a total AUC of 0.750 (95% CI: 0.70, 0.798) and a sensitivity of 42% (specificity 90%) for the NICHD categorization system, and an AUC of 0.520 (95% CI: 0.470, 0.578) for the NICHD III categorization.[13] Zamora Del Pozo et al. evaluated the NICHD categorization for predicting fetal acidosis with an acidemia cutoff point of <7.10.[7] Their study showed an AUC of 0.60 (95% CI: 0.49, 0.71) and a sensitivity of 15.15% and specificity of 95.73%.

In our study, we evaluated the discriminative capacity of NICHD guidelines with an acidemia cutoff point of <7.10, and our results showed an AUC of 0.727. Despite methodological differences with other studies, our results showed similar predictive capacity to those studies that evaluated NICHD guidelines with a close acidemia cutoff point.

The NICHD parameter variability reduction showed a low ability to predict fetal acidosis in our study, with an AUC of 0.592. In contrast, undetectable or minimal FHR variability in the presence of late or variable decelerations has been reported the most consistent predictor of fetal acidemia, though the association was only 23%.[3] In 2017, Martí Gamboa et al. also reported a low sensitivity (28.4%) for acidosis prediction with minimal variability.[11]

## 4.3 | Non-NICHD parameters

Regarding the non-NICHD parameters, the total deceleration area has been shown to be the non-NICHD parameter with the greatest predictive capacity for acidosis to date. Martí et al. reported an AUC of 0.83,[11] while Cahill et al. reported an AUC of 0.76,[12] and Chóliz Ezquerro et al. reported an AUC of 0.717,[13] all for pH 7.10 as a cutoff.

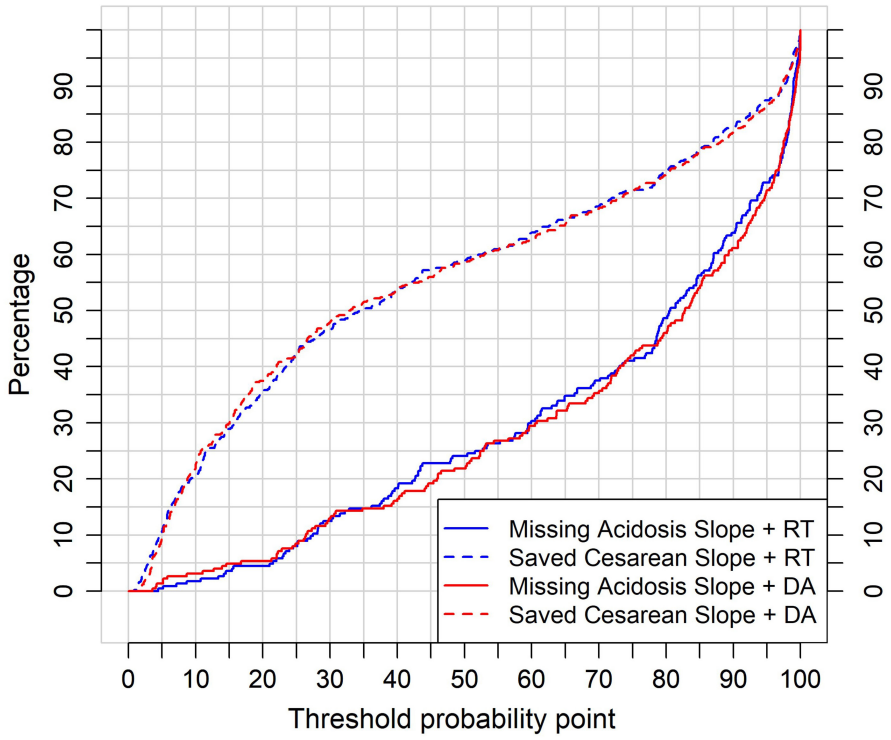


**FIGURE 2** Clinical utility curve of the combination of reperfusion time or deceleration area and slope of the last deceleration. DA, deceleration area; RT, reperfusion time. Missing acidosis, acidotic cases wrongly classified as non-acidotic below the threshold point. Saved cesarean, number of cases below the threshold point, representing the potentially avoided cesarean sections.

However, clinical application is not easy, unless computerized methods are used.

In recent studies, the total reperfusion time has shown a satisfactory predictive capacity with an AUC of 0.704 for pH 7.10, without significant differences from the total deceleration area.[13] In our study, the AUC for the total deceleration area and total reperfusion time were 0.807 and 0.750, respectively. In any case, these parameters require 30 min of monitoring and improve their predictive capacity if combined in multivariable models.

The final window FHR deceleration descending slope is a non-NICHD parameter that has only been studied in animal experimentation on sheep, using a different methodology from that currently applied in our study.[19] According to our study, it is the only non-NICHD parameter that achieved the highest AUC (0.853), and does not require a 30-min window. Nonetheless, the highest AUC is achieved by combining FHR deceleration slope with a non-NICHD parameter in the 30 min EFM final window, such as the total deceleration area and total reperfusion time, finding no differences regarding its combination with any of them. Additionally, the combination with the time of reperfusion has greater practical application.

In 1988 Akagi et al. conducted animal studies in sheep and found that a more pronounced and frequent deceleration in fetal heart rate is strongly associated with severe acidosis.[16] Therefore, they concluded that the fetal heart rate deceleration slope serves as a reliable indicator for assessing fetal acid–base status. In a recent study by Lear et al. in 2023 it was observed that in hypoxemic fetuses, in animal studies with near-term fetal sheep, decelerations showed faster falls in FHR over the first 40 s of 1 min complete umbilical cord occlusions than in normoxic fetuses.[20] Similar results have been found in humans with fetal acidosis compared with non-acidotic fetuses.

## 4.4 | Strengths and weaknesses

The present study has several important strengths that make it a valuable contribution to the field. First, we have explored the predictive capacity of the slope of the descending limb of the FHR in the final window, a non-NICHD parameter, in humans, which is an interesting tool for a better understanding of fetal monitoring. Additionally, we have compared our findings with the NICHD categorization and other NICHD and non-NICHD parameters, performing a comprehensive evaluation of the different approaches to EFM.

Furthermore, our study includes a large number of cases with acidosis, providing strong statistical power to draw meaningful conclusions. This is particularly important considering the relatively low incidence of acidosis, which can make it challenging to obtain reliable results. Despite these strengths, our study also had some limitations that should be considered. First, only one observer assessed the FHR tracings, although we emphasize that this observer is an expert in the field with extensive experience. However, there is always a possibility of intraobserver variability, which could potentially impact the reliability of our findings. Additionally, our study was conducted in a single center, which limits the generalizability of our results to other populations and settings.

**TABLE 5** Missing acidotic cases wrongly classified as non-acidotic, and cesarean sections than can be avoided due to the probability of being acidotic falls below the cutoff point for different thresholds values.

| | Missing acidosis | Avoided cesarean | Missing acidosis | Avoided cesarean |
|---|---|---|---|---|
| Threshold points | Slope + reperfusion time | | Slope + deceleration area | |
| 1 | 0 | 0.2 | 0 | 0 |
| 2 | 0 | 2.6 | 0 | 1 |
| 3 | 0 | 5.8 | 0 | 2.6 |
| 4 | 0 | 8 | 0.4 | 6.6 |
| 5 | 0.4 | 10.6 | 1.3 | 9.6 |
| 6 | 0.9 | 14.3 | 2.7 | 12.5 |
| 7 | 0.9 | 16.5 | 2.7 | 15.7 |
| 8 | 1.3 | 18.7 | 2.7 | 17.7 |
| 9 | 1.8 | 19.3 | 3.1 | 20.5 |
| 10 | 1.8 | 20.5 | 3.1 | 22.1 |
| 11 | 2.2 | 23.3 | 3.1 | 25.3 |
| 12 | 2.2 | 25.5 | 3.6 | 26.1 |
| 13 | 2.2 | 26.1 | 4 | 27.9 |
| 14 | 2.7 | 27.5 | 4.5 | 28.3 |
| 15 | 3.6 | 28.9 | 4.9 | 29.9 |
| 16 | 4.5 | 30.3 | 4.9 | 32.3 |
| 17 | 4.5 | 32.1 | 5.4 | 33.9 |
| 18 | 4.5 | 32.7 | 5.4 | 35.3 |
| 19 | 4.5 | 34.1 | 5.4 | 37.3 |
| 20 | 4.5 | 35.3 | 5.4 | 37.5 |
| 21 | 4.5 | 36.3 | 5.4 | 38.6 |
| 22 | 5.4 | 37.8 | 5.8 | 39.6 |
| 23 | 6.2 | 39.2 | 7.6 | 41 |
| 24 | 7.6 | 40.4 | 7.6 | 41.4 |
| 25 | 8 | 42 | 8.5 | 41.8 |
| 26 | 8.9 | 43.6 | 8.9 | 43.4 |
| 27 | 9.4 | 44.4 | 10.7 | 45.4 |
| 28 | 10.3 | 45 | 11.6 | 46.2 |
| 29 | 12.5 | 46.2 | 11.6 | 46.8 |
| 30 | 12.5 | 46.6 | 12.9 | 48 |

### 4.5 | Clinical and research implications of the slope of the descending limb of the fetal heart rate

Using a combination of parameters represents a significant advancement in the prediction of fetal acidosis, with the highest prediction accuracy achieved through at least two non-NICHD parameters. The best single parameter is the slope of the descending limb of the FHR in the final window, which can be combined with the total deceleration area or the total reperfusion time in 30-min EFM windows. The combination with the total reperfusion time has greater practical application. Further studies are necessary to confirm these findings, and it is worth considering moving away from classifications based on static morphologic appearances of FHR decelerations.[21]

The visual analysis of FHR signals, particularly when dealing with certain non-NICHD parameters such as deceleration area or slope, remains a subjective process. However, in the future, computer assistance, including systems based on artificial intelligence (AI) technology, will take the forefront in aiding obstetricians and midwives to make more objective decisions.[21] In this regard, our findings provide pertinent insights into the importance of continuous fetal monitoring. They suggest that implementing continuous analysis of the signal, incorporating variables derived from the entire recording such as reperfusion time and the slope of the most recent deceleration in the analysis, could establish a streamlined system for alerting to the risk of acidosis.

In the present study, we developed a prediction model of acidosis by integrating reperfusion time and the slope of the last

deceleration. By selecting a probability of acidemia of 26.4% as the cutoff point, we can establish a continuous alert system whereby predictions exceeding this acidemia probability trigger alerts.

## 5 | CONCLUSION

The most effective individual predictor of fetal acidosis is the slope of the descending limb of the fetal heart rate in the final window. However, the best predictive capacity for fetal acidosis can be attained by combining this parameter with other non-NICHD parameters in 30-min windows, such as the total deceleration area and total reperfusion time. The combination of these parameters has been shown to improve their predictive ability for fetal acidosis with no significant differences found between combinations.

### AUTHOR CONTRIBUTIONS

Berta Castán Larraz contributed with the conceptualization and writing-original draft preparation. Luis Mariano Esteban performed the data curation, methodology, writing-original draft preparation, writing-reviewing and editing. Sergio Castán Mateo drafted the conceptualization, visualization and investigation. Marta Chóliz Ezquerro provided the data curation. Javier Esteban Escaño built the methodology. Javier Calvo Torres, Belén Rodríguez Solanilla and Ana Cisneros Gimeno contributed to writing-reviewing. Ricardo Savirón-Cornudella arranged the conceptualization, writing-original draft preparation and writing-reviewing and editing.

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### CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interest.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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