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Clinical paper

Impact of electronic cardiac (ECG) monitoring on delivery room resuscitation and neonatal outcomes☆

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Abstract

Aim: In 2016, the neonatal resuscitation guidelines suggested electronic cardiac (ECG) monitoring to assess heart rate for an infant receiving positive pressure ventilation immediately after birth. Our aim was to study the impact of ECG monitoring on delivery room resuscitation interventions and neonatal outcomes.

Methods: Observational cohort study compared maternal, perinatal and infant characteristics, before (retrospective cohort, calendar year 2015) and after (prospective cohort, calendar year 2017) implementation of ECG monitoring in the delivery room. Association of ECG monitoring with delivery room resuscitation practice interventions and neonatal outcomes was assessed using unadjusted and adjusted multivariable regression analyses.

Results: Of 632 newly born infants who received positive pressure ventilation in the delivery room, ECG monitoring was performed in 369 (the prospective cohort) compared with no ECG monitoring in 263 (the retrospective cohort). Compared to neonates in the retrospective cohort, neonates with ECG monitoring had a significantly lower endotracheal intubation rate (36% vs 48%, $P < .005$) in the delivery room and higher 5-min Apgar scores (7 [5–8] vs 6 [5–8], $P < .05$). There was no difference in mortality (31 [8%] vs 23 [9%]), but infants who received ECG monitoring had increased odds of receiving chest compressions with an adjusted odds ratio of 3.6 (95% confidence interval: 1.4–9.5).

Conclusion: Introduction of ECG monitoring in the delivery room was associated with fewer endotracheal intubations, and an increase use of chest compressions with no difference in mortality.

Keywords: Newborn, Infants, Heart rate, Screening, Electrocardiography, Pulse oximetry, Auscultation, Ventilation, Airway, Chest compressions, ILCOR, NRP

Introduction

The transition from intrauterine to extrauterine life that occurs at the time of birth requires timely anatomic and physiologic adjustments to achieve the conversion from placental to pulmonary gas exchange.[1] After birth, 5–6% of newborns receive positive-pressure ventilation and about 1% require major resuscitative efforts such as intubation, chest compressions or emergency medications.[2]

In 1953 Virginia Apgar stated "heart rate was found to be the most important diagnostic and prognostic of the five signs" that now form the basis of the Apgar score.[3] Heart rate is the critical indicator for signaling the need for intervention in neonatal resuscitation and evaluating the patient's response to these interventions.[4] A rising heart rate remains the cardinal indicator of a successful intervention response. It is, therefore, critically important to utilize a rapid, reliable, and accurate method for measuring the newborn's heart rate.

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Traditionally, auscultation has been the preferred method of heart rate monitoring during neonatal resuscitation. In previous treatment guidelines, pulse oximetry was recommended as an adjunct to provide a noninvasive, rapid, and continuous heart rate assessment.[5] However, recent evidence demonstrates that palpation and auscultation significantly underestimated the true heart rate[6,7] and pulse oximetry is often inaccurate for heart rate assessment during the early minutes after birth.[8–12] Three-lead electrocardiography (ECG) identifies neonatal heart rate more rapidly and accurately.[6,8–10,12–14] Another example is that the ECG recorded a faint slow beat in a newborn who was thought to be in asystole by auscultation, this baby was resuscitated and happened to have a block in cardiac conduction.[7] In the revised International Liaison Committee on Resuscitation and American Heart Association guidelines, ECG is considered the preferred method for assessing heart rate accurately for newly born infants receiving positive pressure ventilation and recommended when chest compressions begin.[2,15]

In 2017, the Women's and Newborn Center at Oklahoma University (OU) Medicine implemented ECG monitoring as per seventh edition American Academy of Pediatrics' Neonatal Resuscitation Program guidelines. This study evaluated the impact of this practice change on delivery room interventions and patient health outcomes. We hypothesized that the introduction of ECG monitoring would be safe and associated with improved outcomes.

Methods

Management of newly born infants receiving positive pressure ventilation

Prior to January 1, 2017, our standard practice was auscultation of heart rate and pulse oximetry monitoring of all newly born infants receiving positive pressure ventilation. Starting January 1, 2017, this practice was changed to heart rate monitoring by 3-lead ECG, in addition to auscultation and pulse oximetry, for newly born infants receiving positive pressure ventilation (Fig. 1). No newborns were resuscitated with ECG monitoring prior to 2017 since ECG monitors were not available in the delivery room.

Implementation of ECG monitoring in the delivery room

The Women's and Newborn Center at the University of Oklahoma is a large tertiary center with up to 4000 deliveries a year and the state's only level IV neonatal intensive care unit (NICU). Being the referral center of the entire state, a significant proportion of deliveries are high-risk similar to other regional perinatal centers. A resuscitation team includes a neonatologist and a neonatal nurse practitioner among other neonatology providers. The discussions began with the team several months in advance on how to integrate ECG monitoring into neonatal resuscitation and what or which ECG monitor to purchase and utilize. The team reviewed the current literature on the practicality of implementing ECG monitoring in the delivery room.[16,17] Multidisciplinary training sessions were conducted. For term and late preterm infants, the ECG lead sites are wiped with normal saline and dried with gauze prior to applying the regular leads. For preterm infants less than 28 weeks who require the addition of a plastic wrap for thermoregulation, we discovered that using neonatal limbs leads have been optimal in maintaining integrity of the skin and providing a good signal. The task of applying ECG leads is assigned to the NICU delivery nurse while the respiratory therapist applies the pulse oximeter.

Data collection

With approval from our local institutional review board (IRB #16-7288), data were extracted from the medical records of mothers and infants receiving positive-pressure ventilation or higher support at the University of Oklahoma Health Sciences Center. The retrospective study period was 1 year, from January 1, 2015, to December 31, 2015 and the prospective study period, was from January 1, 2017, to December 31, 2017. Maternal demographics, obstetric and fetal complications, mode of delivery and type of anesthesia were recorded. The method of cord clamping was not recorded or analyzed for the subjects. Newborn data included gestational age, birth weight,

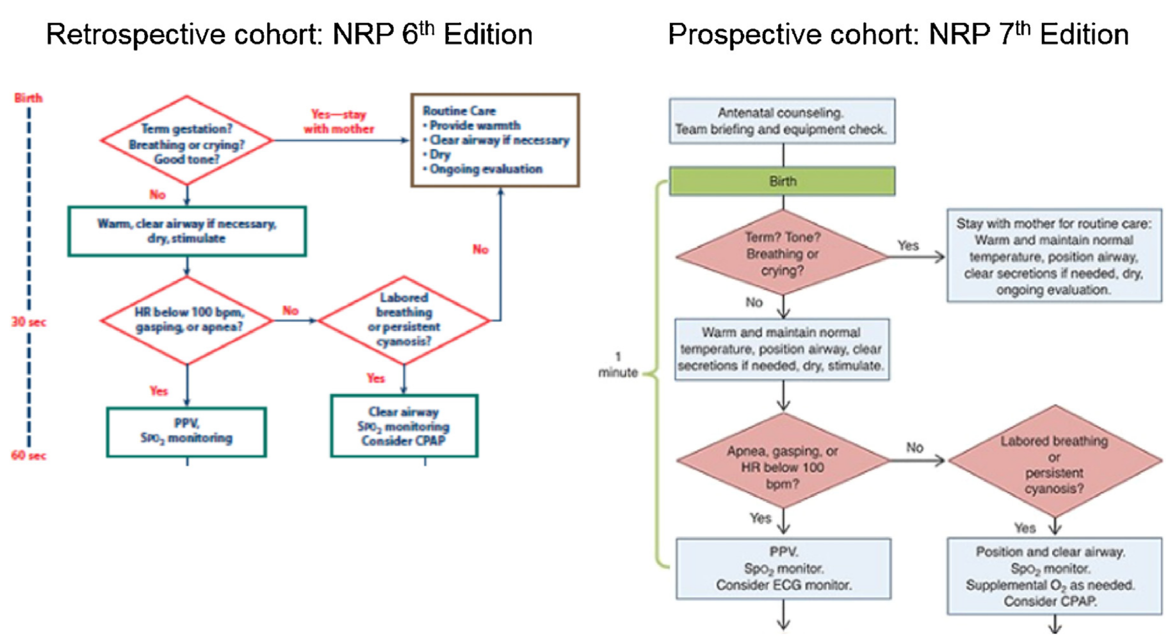

Fig. 1 – Study cohorts and Neonatal Resuscitation Program® (NRP) algorithms.

sex, Apgar scores, and other resuscitation variables. Neonatal outcome data included respiratory distress syndrome, pneumothorax, bronchopulmonary dysplasia, hemodynamically significant patent ductus arteriosus, sepsis, necrotizing enterocolitis, intraventricular hemorrhage (grade 3 or 4), and severe (threshold) retinopathy of prematurity. The need for mechanical ventilation (including high frequency), duration of mechanical ventilation, and length of hospital stay were collected. All collected data were entered into a password-protected, HIPAA compliant database. The staff who collected the data from electronic medical records underwent training for consistency in recording into this database.

Statistical analysis

For the purpose of this pre- and post-intervention cohort study in which we compared two different study periods, a sample size of total 598 subjects (249 pre-intervention and 349 post-intervention subjects) was deemed appropriate for detecting a 10% absolute difference in the rate of endotracheal intubations for respiratory support in the delivery room with a type I error rate of 5% and 80% power on the basis of previous study.[18] This sample size assumes an allocation rate of 1.4 (post-intervention/pre-intervention subjects) and was considered feasible with a 1-year study period for each arm. Descriptive statistics were computed for both arms separately. Continuous variables were assessed for normality and are presented as mean and SD or median and 25th to 75th interquartile range, as appropriate. Comparisons between retrospective and prospective cohorts were made using the Wilcoxon–Mann–Whitney *U* test. Categorical data are presented as frequency (percentage) and comparisons were made using Pearson's χ^2 test.

Multivariable logistic regression models were used to assess the associations between ECG monitoring and outcomes. The primary dependent variable was medical practice intervention or neonatal outcome. Variables significant at the .10 level or confounding covariates were entered into logistic regression analyses for adjustment using ECG monitoring as a categorical variable. These included race, maternal exposure to tobacco, alcohol or illicit drugs, pre-eclampsia, maternal diabetes, maternal antibiotics, fetal growth restriction, antenatal steroids, magnesium, meconium-stained amniotic fluid, cord accidents, forceps or vacuum delivery, abnormal fetal heart rate pattern, antepartum hemorrhage, general anesthesia, and emergency cesarean section. The results are presented as adjusted odds ratios (aORs) with 95% confidence intervals (CIs). Data are analyzed by using SAS V 9.4 (SAS Institute, Cary, NC, USA). Statistical significance is set at a probability value of $<.05$.

Results

During the retrospective period, 3681 mothers delivered and 263 (7.1%) newborns received positive pressure ventilation. During the prospective period, 3451 mothers delivered and 369 (10.7%) newborns received positive pressure ventilation. Table 1 shows maternal, perinatal and newborn characteristics. The groups were similar between retrospective and prospective cohorts except for more maternal gestational hypertension, pre-eclampsia, use of steroids and magnesium, cord accidents and white race in the prospective cohort compared with the retrospective cohort. Gestational age was evenly distributed between the retrospective and prospective cohorts (Fig. 2).

There was more usage of continuous positive airway pressure and face mask ventilation in the prospective cohort compared with the retrospective cohort (Table 2). There was no difference in the proportion of infants that received any supplemental oxygen between the two cohorts. A significantly smaller proportion of infants received endotracheal intubation with higher 5-min Apgar scores in the prospective cohort compared with the retrospective cohort. Of the nine infants ventilated with an endotracheal tube without receiving face mask ventilation in the prospective cohort, five had apnea in the setting of extreme prematurity and four had congenital diaphragmatic hernia. Of the twenty-three infants ventilated with an endotracheal tube without receiving face mask ventilation in the retrospective cohort, ten premature infants had apnea, six were non-vigorous with meconium-stained amniotic fluid, and seven had indications not to receive face mask ventilation (congenital diaphragmatic hernia and gastroschisis).

Eight infants received chest compressions without prior tracheal intubation in the prospective cohort compared with one infant in the retrospective cohort. One of these infants happened to have heart rate more than 60 beats per minute when ECG leads applied. While four infants were endotracheally intubated almost immediately after commencing chest compressions, the other four infants' heart rate improved to more than 100 beats per minute after about a minute of chest compressions without endotracheal intubation. No pulseless electrical activity was encountered.

Unadjusted in-hospital clinical outcomes are shown in Table 3. Admission temperature, use of mechanical ventilation, days on ventilator and severe retinopathy of prematurity were lower in the prospective cohort compared with the retrospective cohort. Adjusted odds ratios (aOR) and 95% confidence intervals (CI) using multivariable regression analyses for each included variable are shown in Table 4. ECG monitoring was associated with increased odds of chest compression in the delivery room.

Discussion

The principal finding of this study was that introduction of ECG monitoring in the delivery room was associated with a lower rate of endotracheal intubations, and an increase use of chest compressions without a difference in mortality. This change was also associated with higher 5-min Apgar score, fewer days on mechanical ventilation and a lower incidence of severe retinopathy of prematurity, after adjustment for confounding variables.

In our study, there were more high-risk deliveries (pre-eclampsia, cord accidents, white race) in the prospective cohort compared with the retrospective cohort. This could explain the difference in the proportion of infants that received positive pressure ventilation between two epochs. On the other hand, more mothers received antenatal steroids and magnesium sulfate in the prospective cohort compared with the retrospective cohort. The use of multivariable logistic regression analysis adjusted for all the confounding variables.

A combination of various factors may explain the positive association between ECG monitoring and non-invasive ventilation, and the inverse association between ECG monitoring and endotracheal intubation in this study. These include tracheal suctioning in setting of upper-airway obstruction or non-vigorous newly born infant with meconium-stained amniotic fluid as per previous neonatal resuscitation guidelines, apnea in extreme premature infants, and bradycardia in infants with congenital malformations such as diaphragmatic hernia or abdominal wall defects. Additionally, we

Table 1 – Demographic and descriptive characteristics of the study population.

Characteristics	Retrospective n = 263	Prospective n = 369	*P* value
Maternal[*]			
Age, years	27 (22–32)	27 (23–31)	.92
Primigravida	70 (26.7)	111 (30.1)	.36
No prenatal care	9 (3.4)	18 (4.9)	.38
Tobacco, alcohol, illicit drug use	42 (15.9)	82 (22.3)	.05
Diabetes mellitus	24 (9.1)	45 (12.2)	.22
Pre-eclampsia	79 (30)	140 (37.9)	.04
Steroids	128 (48.7)	236 (63.9)	<.01
Magnesium	82 (31.2)	177 (47.9)	<.01
Perinatal			
Multiple gestation	38 (14.5)	58 (15.7)	.66
Fetal growth restriction	22 (8.4)	22 (5.9)	.24
Fever	10 (3.8)	8 (2.2)	.22
Group-B *streptococcus*			
Positive	46 (27.1)	73 (32.2)	.27
Unknown	93 (35.4)	142 (38.5)	.40
Chorioamnionitis	26 (9.9)	28 (7.6)	.31
Rupture of membranes, >24 hrs	30 (11.4)	32 (8.7)	.25
Antibiotics	59 (22.4)	109 (29.5)	.05
Antepartum hemorrhage	13 (4.9)	9 (2.4)	.09
Abnormal fetal heart rate pattern	57 (21.7)	80 (21.7)	.99
Meconium-stained amniotic fluid	31 (11.8)	35 (9.5)	.36
Cord accidents	4 (1.5)	17 (4.6)	.03
Nuchal cord	25 (9.5)	25 (6.8)	.21
Shoulder dystocia	1 (.4)	6 (1.6)	.25
Forceps or vacuum delivery	6 (2.3)	13 (3.5)	.37
Cesarean delivery	193 (73.4)	270 (73.2)	.95
Emergency	138 (52.5)	202 (54.7)	.57
Anesthesia	221 (89.1)	295 (85.3)	.17
General	43 (17.3)	62 (17.9)	.85
Cord pH	7.22 (7.16–7.29)	7.24 (7.13–7.31)	.99
Cord pCO_2	56.5 (46.5–66.5)	55 (46–68)	.89
Cord base deficit	5.5 (2.9–7.5)	5.4 (3–8.5)	.72
Infant			
Gestation, weeks	33.6 (29–37.2)	33.4 (30.1–36.5)	.65
Birth weight, grams	2080 (1230–2940)	2100 (1320–2750)	.66
Male	135 (51.5)	191 (51.8)	.95
Race, white	147 (55.9)	226 (61.3)	<.01

[*] Categorical data are presented as n (%) where percentages are calculated based on non-missing data. Continuous data are presented as median and interquartile range. *P* values for categorical data were calculated using chi-square and continuous data using the Wilcoxon test.

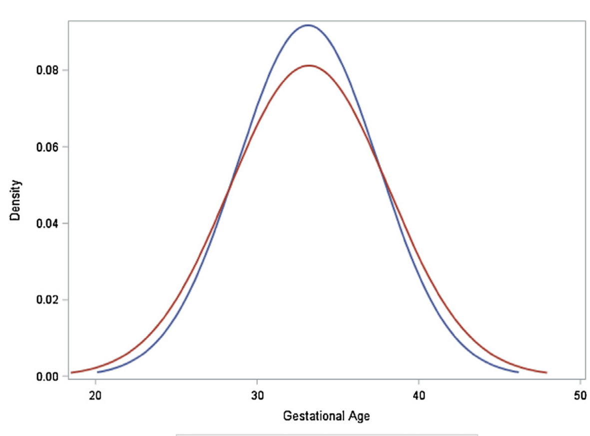

Fig. 2 – Normal distribution of gestational age in the prospective and retrospective cohorts.

Table 2 – Delivery room variables.

Variables	Retrospective n = 263	Prospective n = 369	*P* value
Face mask ventilation*	240 (91.3)	360 (97.6)	<.001
Endotracheal intubation	125 (47.5)	131 (35.5)	.002
Chest compressions	8 (3)	24 (6.5)	.050
Epinephrine use	1 (.4)	5 (1.4)	.409
Apgar scores			
1 min	3 (2–6)	4 (2–6)	.086
5 min	6 (5–8)	7 (5–8)	.016
10 min	7 (7–8)	7 (7–8)	.906
Supplemental oxygen	224 (85.2)	330 (89.4)	.109
Continuous positive airway pressure	186 (70.7)	324 (87.8)	<.001

* Categorical data are presented as n (%) where percentages are calculated based on non-missing data. Continuous data are presented as median and interquartile range. *P* values for categorical data were calculated using chi-square and continuous data using the Wilcoxon test.

Table 3 – In-hospital clinical outcomes (unadjusted).

Outcomes	Retrospective n = 263	Prospective n = 369	*P* value
Death*	23 (8.8)	31 (8.4)	.879
Admission temperature	36.7 (36.4–37.1)	36.6 (36.2–37)	.004
Surfactant	108 (41.1)	155 (42)	.813
Pneumothorax	21 (7.9)	17 (4.6)	.078
Bronchopulmonary dysplasia	23 (8.8)	27 (7.3)	.512
Mechanical ventilation	153 (58.2)	172 (46.6)	.004
Days on mechanical ventilation	1 (0–5)	0 (0–3)	.007
Days on supplemental oxygen	4 (1–34)	7 (1–20)	.309
Sepsis	38 (14.5)	43 (11.7)	.300
Necrotizing enterocolitis	2 (.8)	11 (2.9)	.053
Symptomatic patent ductus arteriosus	27 (10.3)	29 (7.9)	.294
Intraventricular hemorrhage (grade 3/4)	43 (16.4)	57 (15.5)	.759
Severe retinopathy of prematurity	33 (12.6)	21 (5.7)	.002
Length of hospitalization	22 (8–61)	23 (9–49)	.657

* Categorical data are presented as n (%) where percentages are calculated based on non-missing data. Continuous data are presented as median and interquartile range. *P* values for categorical data were calculated using chi-square and continuous data using the Wilcoxon test.

speculate that neonatal care has moved away from invasive support in delivery room towards non-invasive support (mask breaths followed by continuous airway positive pressure when breathing spontaneously). This culture change may have contributed to a lower rate of endotracheal intubation even though it might well be hard to quantify. This change in practice of greater willingness to mask ventilate until breathing along with early ECG screening of bradycardic infants could explain the increase use of chest compressions in combination with the lower rate of endotracheal intubation.

In a healthy newborn cohort of 468 infants who did not require interventions in the delivery room, Dawson et al. observed median heart rate to be less than 100 beats per minute at 1 min of life, and 21% of newborns had heart rate less than 100 beats per minute at 2 min after birth.[19] Hooper et al. also reported median (IQR) time of 126 s (96–160) from birth for heart rate to exceed 100 bpm in premature infants <32 weeks gestation.[20] In addition, infants who received delayed cord clamping had significantly lower initial heart rate compared with immediate cord clamping.[21,22] Hence, caution should be exercised with early ECG monitoring since bradycardia occurs normally after birth in some infants in the first two minutes of life[16]. A low heart rate alone does not always require intervention.[23]

Pulse oximetry provides continuous heart rate measurement for clinicians in the delivery room[24] that may be more helpful than intermittent measurements by auscultation or palpation. However, low perfusion states, common in the first minutes of life, limit its value for evaluating transition at birth.[25] Not all pulse waves, emanating from cardiac contractions as recorded by Doppler ultrasound, can be detected by pulse oximetry in the peripheral vessels, resulting in an underestimation of heart rate.[11,12] This is the result of large hemodynamic changes including left-to-right ductal shunt[26] associated with about 50% increase in pulmonary blood flow[27] and peripheral vasoconstriction caused by low venous return and left ventricular outflow associated with umbilical cord clamping.[28]

A potential result of ECG monitoring is that it may display heart rate when cardiac output is low (electromechanical dissociation). This cardiac electrical activity in the absence of pulse is called cardiac arrest with pulseless electrical activity, a preterminal rhythm which has been observed following severe asphyxiation.[29] In this study, bradycardia was confirmed with auscultation, and no pulseless electrical activity was encountered. Our data support that pulseless electrical activity is likely to be uncommon in neonates at delivery.

In the current study, ECG monitoring was associated with clinically insignificant lower temperature (.1 °C) upon NICU admission. There were no differences between the groups of the occurrence of admission

Table 4 – Adjusted associations of the ECG monitoring with medical practice outcomes.

Practice/outcomes	aOR* (95% CI)	*P* value
Delivery room practice interventions		
Supplemental oxygen	1.51 (.87–2.62)	.138
Continuous positive airway pressure	2.82 (1.77–4.51)	<.001
Face mask ventilation	3.85 (1.61–9.21)	.003
Endotracheal intubation	.65 (.45–.94)	.023
Chest compressions	3.59 (1.36–9.46)	.009
Epinephrine use	>99.99 (<.1–>99.99)	.934
Neonatal outcomes		
Death	1.58 (.83–3.03)	.167
Respiratory distress syndrome	.93 (.62–1.41)	.748
Pneumothorax	.70 (.34–1.46)	.343
Bronchopulmonary dysplasia	.94 (.44–1.99)	.867
Mechanical ventilation	.62 (.43–.89)	.011
Sepsis	.77 (.45-1.32)	.337
Necrotizing enterocolitis	5.85 (1.09–31.26)	.039
Symptomatic patent ductus arteriosus	.78 (.39–1.54)	.481
Intraventricular hemorrhage (grade 3/4)	1.27 (.75–2.17)	.375
Severe retinopathy of prematurity	.32 (.14–.71)	.005

aOR, adjusted odds ratio; *CI*, confidence interval.
* Adjusted association represents the odds of outcome for neonatal heart rate monitoring by ECG compared with auscultation/pulse oximetry in the delivery room. There were no significant interactions between ECG monitoring and covariates.

hypothermia or hyperthermia. Our temperature bundle including woolen hat, polyethylene bag, thermal mattress, and monitoring temperature in the delivery room is effective in decreasing hypothermia on NICU admission.[30] Although associations of introduction of ECG monitoring with mechanical ventilation, necrotizing enterocolitis and retinopathy of prematurity were found, our study was not powered to discern the differences in these outcomes, given the low frequency of such morbidities. Since respiratory function monitoring was not available in the delivery room, continuous measurement of pulmonary parameters and oxygen measures such as the maximum oxygen concentration or duration of oxygen supplementation, and their effects on neonatal outcomes were not evaluated.

The present study has several limitations. Since the seventh edition neonatal resuscitation guidelines suggested ECG monitoring to assess infant's heart rate immediately after birth, and our center had made the decision to implement ECG monitoring in all newly born infants receiving positive pressure ventilation, randomization was not feasible. Use of ECG monitoring was not confirmed for each subject in the prospective cohort since video recording was not universal at the time of this study and perinatal circulating nurses manually recorded changes in the heart rate and delivery room events during neonatal resuscitation. Although regression analysis was conducted to account for all known confounding variables, there may be other confounders of which we remain unaware. Changes in NICU practice during the course of study could have affected neonatal outcomes. However, to the best of our knowledge, no major practice changes occurred in the Children's NICU during the study period. The obstetrical practice of delayed cord clamping was variable during both study periods. Finally, this study cannot establish causality; caution must be taken when interpreting the results. Study strengths include predefined morbidities, inclusion of perinatal database, and population-based, unbiased collection of the data from all deliveries in a regional tertiary perinatal center during a defined period.

Conclusions

Implementation of electronic cardiac (ECG) monitoring in the delivery room is shown to be feasible at a tertiary care regional perinatal center. This change was associated with an increase in non-invasive respiratory support and fewer endotracheal intubations in the delivery room. The finding that chest compressions increased may be a sign that early ECG screening lead to more interventions for what may be physiologic bradycardia. The introduction of ECG monitoring in the delivery room may advance our understanding of physiologic heart rate changes after birth.

Conflicts of interest

None.

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