Annals of Pediatric Research

Research Article
Published: 12 Nov, 2020

Heart Rate Determination Using Electrocardiogram in Comparison with Pulse Oximeter at Neonatal Resuscitation: The Singapore General Hospital Experience

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Abstract

Introduction: Heart rate (HR) determination is vital in a neonatal resuscitation. Evidence suggests that electrocardiogram (ECG) provides more rapid and accurate measurement of Heart Rate (HR). Recent neonatal resuscitation guidelines recommended the use of the ECG over conventional methods such as auscultation using a stethoscope, palpation of umbilical cord pulsations by placing the cord between the thumb and index finger or the brachial or femoral artery, and pulse rate (PR) measurement using the pulse oximeter (POX). However, concerns regarding clinical feasibility of applying ECG electrodes and the potential risk of damage to newborn's skin have been raised as barriers to its implementation.

Objectives: The study aims to assess the feasibility of using ECG to determine the HR as compared to PR measured using the POX by comparing (1) time taken to apply ECG leads *vs*. POX sensors (seconds), (2) time taken to display of first reliable HR/PR (seconds) and evaluating the agreement between HR measured on ECG versus PR measured using the POX.

Methods: Eligible deliveries managed in the Department of Obstetrics and Gynecology at Singapore General Hospital from October 2018 to May 2019 was enrolled. Newly born infants had both ECG/POX sensors applied from the time the neonate was placed under the resuscitaire with continuous HR and PR monitoring initiated simultaneously. Time to apply ECG electrodes and POX sensors and time to display of reliable HR and PR tracings were compiled and compared using the Wilcoxon signed rank test.

Results: Of the 104 infants enrolled and analyzed, the median (interquartile range, IQR) time to obtain a reliable HR on ECG was 10 (5.0 to 20.0) *vs*. 30.5 (22.8 to 53.0) seconds (sec) on the POX ($p<0.001$). The median 1st reliable HR reading on ECG is higher at 170 beats per minute (bpm) as compared to 167 bpm on POX ($p=0.002$).

In addition, the time taken to apply ECG leads is faster compared to the POX sensors. Looking at the median time, it takes 27 sec for the ECG leads to be applied as compared to the POX sensors that requires 33.5 sec with p-value <0.001.

Conclusion: The ECG provided a faster and more reliable display of HR reading during resuscitation than PR on POX.

Keywords: Electrocardiogram(ECG); Heart Rate(HR); Pulse Oximeter(POX); Pulse Rate(PR); Neonatal Resuscitation

Abbreviations

ECG: Electrocardiogram; HR: Heart Rate; POX: Pulse Oximeter; PR: Pulse Rate; PPV: Positive Pressure Ventilation; CPAP: Continuous Positive Airway Pressure; bpm: Beats per Minute; sec: Seconds

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Received Date: *05 Oct 2020*
Accepted Date: *05 Nov 2020*
Published Date: *12 Nov 2020*

Citation:
Tan MGS, Lee WL, Ereno I, Tagamolila V, Edison P, Ying H, et al. Heart Rate Determination Using Electrocardiogram in Comparison with Pulse Oximeter at Neonatal Resuscitation: The Singapore General Hospital Experience. Ann Pediatr Res. 2020; 4(4): 1047.

Introduction

Approximately 10% of newborn infants require assistance during transition from intra-uterine to extra-uterine life [1]. Heart rate (HR) is the most sensitive indicator in evaluating the hemodynamic status of a newly born infant and resuscitation protocols recommend intervening when there is evidence of neonatal bradycardia as defined by HR of less than 100 bpm [2]. An increase in HR signifies a good response to resuscitation [3]. It is therefore imperative that HR assessment is both fast and accurate, as it guides further resuscitative efforts.

Conventional methods for HR determination include clinical methods such as auscultation using a stethoscope, as well as palpation of umbilical cord pulsations by placing the cord between the thumb and index finger, or the brachial or femoral artery [1]. However, these clinical methods have been shown to be inaccurate as it is operator dependent and underestimates the HR [4,5]. Kamlin et al. [6] reported a mean difference of 22 bpm and 14 bpm in HR measured using electrocardiogram compared with clinical assessment using auscultation or palpation of cord pulsation respectively. Murphy et al. [5] compared HR measured using the stethoscope against that measured on ECG and POX. Authors found that auscultation underestimated HR measurements with mean difference of -9 bpm (95% CI of -15 to -2) as compared to that using ECG and mean difference of -5 bpm (95% CI; -12 to 2) compared with PR on pulse oximetry. The median (IQR) time to HR measurement by auscultation was 14 (10 to 18) sec.

Studies on the use of pulse oximetry to determine PR showed that the instrument takes more than 30 sec to give a reliable pulse reading [7,8]. Van Vonderen et al. [8] in their study on use of POX showed that PR measured is lower than HR readings measured using the ECG.

Recent evidence suggested benefit of using the ECG for a faster and more accurate measurement of HR [1,7,9]. In addition, the International Liaison Committee on Resuscitation (ILCOR) recommended that the ECG be used at resuscitation of newborns [2]. The Singapore Neonatal Resuscitation Guidelines (2016), proposed the use of the 3-lead ECG in advanced resuscitation to provide a continuous assessment of HR [10]. However, this recommendation is not consistently practiced in the local context. Barriers to clinical implementation include poor adherence of ECG leads onto the wet, vernix-covered skin of the newborn, delay in initiation of resuscitation as time is required to apply ECG leads, the risk of break in integrity of the skin in particular that of preterm newborns and increased cost of care with the implementation of ECG to determine HR at resuscitation. While studies on the use of ECG at delivery have not reported adverse concerns, study to evaluate the feasibility of ECG to determine HR and its correlation with PR measured on POX, with the secondary outcome of possible side effects (e.g. damage to skin) can aid in proving its applicability and in assuring practitioners of its safety.

This study aims to evaluate (1) rapidity and (2) reliability at which HR can be measured using the ECG compared with PR measured using the POX during resuscitation at delivery. We hypothesize that electrocardiography provides more rapid and reliable measurement of HR than PR measured using the POX, with no delay in the application of the electrographic leads and no adverse effects on the newborn's skin.

Materials and Methods

Study design, location and ethical considerations

This prospective cohort study conducted in the Department of Neonatal and Developmental Medicine, Singapore General Hospital was approved by the Centralized Institutional Review Board (CIRB 2018/2430).

Participant selection, intervention and data collection

Patient selection and sampling: Expectant women admitted during office hours (8 AM to 5 PM) from October 2018 to May 2019 for an impending delivery either by normal vaginal delivery or elective caesareans were identified. Participant information sheet detailing study aims, methodology and the rights to withdraw from participation was given to all eligible parents. A written consent of participation was obtained from women who consented to the study. The progress of labor was tracked closely up to the time of delivery by the investigators. Pregnancies with known congenital malformations that may potentially interfere with the placement of chest leads or pulse oximeter sensors were excluded.

Based on the preliminary study by Katheria et al. [12] which showed a median time of 26 (17 to 41) and 38 (33 to 44) seconds to apply the ECG leads and POX sensors respectively, the standard deviation of the change, S(Δ), was determined to be 5.06. Guided by the mean difference and standard deviation of the mean reported by Katheria et al. [12] the estimated effect size was 2.12. Using the two-sample t-test in comparing the time taken to apply the ECG leads versus the POX sensors on the same subject, a minimum sample size of 32 was estimated to detect a standardized effect size of 1.0 with power of 90% at α=0.05.

Intervention and Data collection

A dedicated team of doctors and nurses whose sole responsibility was to support and resuscitate the newborns performed the necessary interventions where indicated following local neonatal resuscitation algorithms. Appropriate steps were taken to ensure that the research procedure did not disrupt or interfere with the required resuscitative care or transitional support from intrauterine to extra-uterine life.

At birth, delayed cord clamping practices were performed as deemed beneficial by the attending obstetrician. Once the cord was clamped, infants were nursed under the open resuscitaire to maintain warmth. Two study investigators present at delivery prepare the skin over the infant's chest wall using alcohol swabs and dried it using clean tissue. Electrocardiographic leads (Philips 13953D Neonatal ECG Electrodes) and the Philips Reusable Neonatal Wrap (M1193A) POX sensors were applied simultaneously, followed by a skin temperature probe once the chest wall was cleaned of blood and vernix. The ECG electrodes were then connected to a Phillips Intelli Vue MX500 monitor. In applying the POX sensor, the sensor was applied to the baby's right hand or wrist before connecting to the monitor [11].

The Phillips IntelliVue MX500 monitors provided a graphic and digital display of the HR, PR and oxygen saturation (SpO_2) which were saved at timed intervals of 2 sec. Monitoring continued for a maximum of 10 min or until transfer was initiated. The stored parameters were then downloaded onto a Microsoft excel sheet programmed in a laptop linked to the monitor. The first HR reading after three consecutive QRS complexes was taken as the first reliable ECG reading. Similarly, the PR following three consistent plethysmograph waveforms defined a reliable POX reading [8]. The

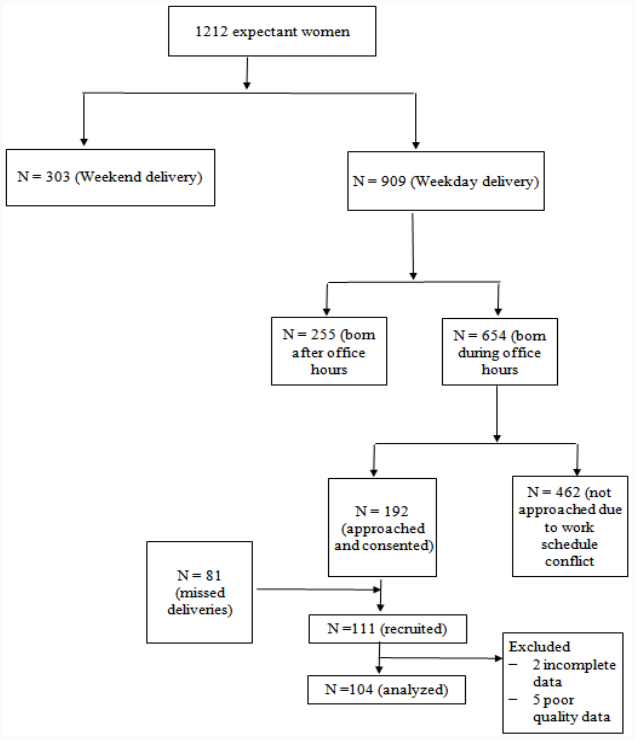

Figure 1: Participant Flowchart.

time of appearance of these signals were recorded as time of first reliable HR and PR.

Continuous, live video recording of the waveforms displayed on the Phillips IntelliVue MX500 monitor was stored for subsequent analysis. Time taken to apply the ECG leads and POX sensor electrodes were determined using audible voice indicators (i.e. 'ECG'/'POX') captured on video recordings. Start time was taken as the point the newborn was placed on the open resuscitaire (noted by audible "baby landed") and the end points taken upon hearing 'ECG' and 'POX' upon successful application of the ECG leads and POX sensor respectively. Video recordings of the waveforms were reviewed and analyzed separately by 2 investigators and the median time IQR taken to (1) apply ECG leads and the POX sensors and (2) display of 1st reliable HR and PR were determined, compiled and recorded. Analyses were done using R (R Core Team <2019>. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org). Only good quality data were included in the final analyses.

Maternal medical and obstetric conditions as well as demographics of the newborns were collated and compiled. Interclass correlation coefficient between two investigators was evaluated for 1st reliable HR. The infant's skin was monitored for at least 24 h for any skin integrity concerns related to the ECG lead or POX sensor placements.

Statistical analysis

Continuous variables were summarized as median and inter-quartile ranges and categorical variables as count and percentage in each group. Wilcoxon signed rank test was performed to compare time taken to apply ECG leads and POX sensor, time to display of first reliable HR and PR readings and difference in the measurements of the first reliable HR and PR readings. Time taken to apply the ECG leads and POX sensors, and the time taken to display of first reliable HR reading on electrocardiogram versus PR measurement on POX were compared using the linear mixed model with adjustment for gender, birth weight and mode of delivery. Statistical significance was set at $p<0.05$.

Table 1: Demographic and characteristics of study participants (N=104).

Gestational Age, median (weeks)	38 (Range 30-40)
Term, n (%)	90 (86.5)
GA 37 weeks	14 (13.4)
GA 38 weeks	32 (30.8)
GA 39 weeks	28 (26.9)
GA 40 weeks	16 (15.4)
Preterm, n (%)	14 (13.5)
GA 30 weeks	2 (1.9)
GA 31 weeks	1 (0.9)
GA 34 weeks	3 (2.9)
GA 36 weeks	8 (7.7)
Birthweight (g)	3027.5 (1345-3940)
Male, n (%)	54 (52)
Mode of delivery, n (%)	
Normal Vaginal Delivery	45 (43.2)
Lower segment Caesarean section	56 (54.0)
Assisted Delivery	3 (3.0)
APGAR SCORES	
1-minute	8 (3-9)
5-minute	9 (8-10)
Singleton, n (%)	101 (97%)
Antenatal Risk Factors, n (%)	
GBS colonization	3 (2.9)
Gestational Diabetes Mellitus	1 (0.96)
PPROM	1 (0.96)
Amniotic Fluid, n (%)	
Clear	92 (88.5)
Meconium Stained	12 (11.5)
Resuscitation Measures, n (%)	
Suction and Stimulation	65 (62.5)
CPAP	6 (5.8)
Mask PPV	2 (1.9)

Results

Participant enrolment

One hundred and ninety-two expectant women were approached and consented. Of these, 81 deliveries occurred before arrival of the investigators, hence, 111 newborns were included (Figure 1). Seven newborns were excluded from the analysis; 2 for incomplete data and 5 for poor quality of data.

Participant characteristics

One-hundred and four infants analyzed were born to women aged 19 to 41 years old; 3 were born to women who were carrier for group B Streptococcal bacteria, 1 had gestational diabetes, 1 had preterm premature rupture of membranes and 2 had non-reassuring

fetal status on CTG during labor.

Ninety (86.5%) infants were born term with a median gestational age of 38 weeks. Thirty-two (30%) infants required no support at delivery, and the remaining (70%) needed resuscitation in the form of suction, Positive Pressure Ventilation (PPV) and/or Continuous Positive Airway Pressure (CPAP). The mean Apgar score of the 104 infants were 8 and 9 at 1 and 5 min respectively (Table 1).

Heart rate and pulse rate measurements of study participants

The mean difference in time taken to apply ECG leads *vs.* POX sensors was -5.3 (SD=11.6) seconds with median (IQR) of 27 (22.0 to 34.0) *vs.* 33.5 (24.0 to 41.0) sec respectively, (p<0.001). The mean difference in time to display of 1st reliable ECG HR *vs.* POX PR was 25.5 (SD=60.5) sec with median (IQR) of 10 (5.0 to 20.0) compared to 30.5 (22.8 to 53.0) sec respectively, (p<0.001). The 1st reliable HR measured using electrocardiogram was higher than PR measured using POX with mean difference of 4 (SD=13) bpm and median of 170 (156 to 185) bpm *vs.* 167 (153 to 178) bpm respectively (p=0.002).

Effect on skin integrity

There were no reported cutaneous concerns in enrolled newborns up to time of discharge.

Intra-class correlation coefficient (ICC)

The Intra-class Correlation Coefficient (ICC) on time taken to display of 1st reliable HR on ECG by 2 investigators was excellent with ICC of 0.93 (95% CI 0.84, 0.97).

Discussion

In our study, the time taken to apply the ECG leads on the chest compared with the POX sensor over the right wrist was significantly different with the latter being significantly longer at 27.0 (22.0 to 34.0) *vs.* 33.5 (24.0 to 41.0) sec respectively (p<0.001). Our finding compares favorably with report by Katheriaet al. [12] which showed a significant difference in the time taken to apply both the ECG and POX sensor with median time of 26 and 38 sec respectively.

In our cohort of infants, the use of alcohol swabs to remove the vernix and blood followed by tissue to dry the skin resulted in good adherence of the ECG leads to the chest wall with no observed or reported cutaneous injury to the skin. Poor adherence of the chest leads accounted in part for the failure to achieve reliable ECG trace and readings in 5 infants leading to appearance of "noisy" signals. This observation suggests that vernix must be removed and skin dried to ensure optimal contact and signal transmission.

In addition, the time to display of 1st reliable HR occurred earlier than that of first reliable PR at a median time (IQR) of 10.0 (5.0 to 20.0) sec as compared to 30.5 (22.8 to 53.0) sec respectively, (p<0.001). This finding is consistent with that reported by Van Vonderen et al. [8] which involved largely male newborns at median gestational age of 37 weeks delivered *via* caesarean section with good Apgar scores. In their study, the ECG leads were connected to an ECG monitor (Intellivue MP5; Philips, Eindhoven, The Netherlands) and the Masimo POX sensor (M-LNCS NeoPt-500) attached to the Masimo Radical 7 (Masimo, Irvine, California). Stable HR and PR readings were documented at 1 sec compared to 12 sec (p<0.001) using electrocardiography and peripheral pulse oximetry respectively.

Similarly, Mizumotoet al. [7] in their study on 20 newborns with a mean gestational age of 36 weeks (mean birth weight of 2338 grams) reported a shorter time to acquiring reliable HR on ECG compared to PR measured using the POX with median (IQR) of 38 (34 to 43) *vs.* 122 (101 to 146) sec respectively, (p<0.001).

While it is widely accepted that the POX may take longer duration in the first few minutes of life to achieve a quality signal, the variation in time for appearance of reliable PR and oxygen saturation reported in different studies may be related to variation in sensitivities amongst different brands of pulse oximeters as well as the state of perfusion of the infants studied.

Reports on agreement between HR measured on electrography versus PR determined on pulse oximetry showed inconsistent results. Kamlin et al. [6] and Dawson et al. [13] showed minor difference in heart rate measured on electrocardiogram compared with pulse rate measured using pulse oximetry, with a mean difference of -2 (SD, 26) and 0.2 (SD, 9) bpm, respectively. Report by Van Vonderen et al. [8] on 48 newly born infants with gestational age of 27 to 41 weeks showed that the POX underestimated the HR in the first few minutes of life. This is consistent with our findings which showed that HR measured on ECG is higher than PR measured using the POX with mean difference of 4 (SD, 13) bpm. While this difference could be in part be due to poor perfusion in the first few minutes of life, or hypothermia, accurate absolute heart rate reading is important as values of <100 bpm is the recommended reading used in neonatal resuscitation protocol guidelines worldwide to determine the need for resuscitative interventions. In the event when the POX value is low, reading should be interpreted simultaneously with other methods of HR assessment such as continuous ECG monitoring.

Differences in agreement between HR and PR readings among studies may be related to the differences in sensitivities across different brands of equipment. In our study, we used the Philips 13953D Neonatal ECG Electrodes connected to a Phillips IntelliVue MX500 monitor for continuing ECG monitoring, and a Philips Reusable Neonatal Wrap (M1193A) POX sensor. Other studies have used different equipment, inclusive of the Philips IntelliVue MP5 monitor with Masimo M-LNCS NeoPt-500 [8], Escort II ECG Monitor with Masimo L-NOP Neo [6] and the Philips Agilent M3046A Monitor with Masimo L-NOP Neo [14-17]. These different modalities have not been standardized, thereby limiting comparisons amongst studies.

Limitations

Our results were derived using the Phillips IntelliVue MX500 monitor. Thus, findings obtained from other studies using different devices should be addressed with caution.

In addition, our study included mainly term infants; hence, findings cannot be extrapolated to extreme preterm neonates. None of the babies enrolled required advanced resuscitation and none of our enrolled newborns had HR of ≤100 bpm.

Conclusion

It is feasible and easy to apply the ECG leads on the chest of the term and late preterm newborn at delivery. The use of alcohol swabs to clean and tissue to dry the skin are sufficient to ensure adequate adherence of the ECG leads. It is faster to apply ECG leads as compared with pulse oximetry sensor. Use of electrocardiography provides reliable HR readings earlier than pulse oximetry. Therefore, ECG can be used to aid in monitoring of HR at resuscitation. Its

application and safety in extreme preterm newborns require further evaluation.

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