Physiological measurements of the effect of cord clamping strategies

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CHAPTER 3

Umbilical cord pulse oximetry for measuring heart rate in neonates at birth: a feasibility study

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Manuscript submitted

ABSTRACT

OBJECTIVE

To determine the feasibility of measuring heartrate (HR) by umbilical pulse oximetry (PO) after cord clamping and whether reliable HR signals can be obtained faster when compared to preductal PO in infants needing stabilisation at birth.

METHODS

Preductal and umbilical HR measurements were obtained in infants >25 weeks gestational age. During stabilisation and after cord clamping, a PO sensor was placed around the umbilical cord in addition to the standard preductal PO measurements. Umbilical PO measurements were not visible to caregivers. Video of the infant was recorded as part of standard care. HR data of the first ten minutes after birth were reviewed and compared. HR signal was considered reliable when signal identification and quality >30% and a stable plethysmograph pulse wave was observed.

RESULTS

In total, 18 infants needing respiratory support at birth were included (median [IQR] gestational age 32 [31-33] weeks, birthweight 1723 [1019-2130] grams). Reliable HRs from umbilical PO were obtained in all infants, but the time between sensor application and obtaining a reliable HR signal was longer than with preductal PO (19 [16-55] seconds vs. 15 [11-17] seconds; p= 0.01). Umbilical HR was consistently lower than preductal HR (mean(±SD) difference 36(±22) bpm; Intraclass Correlation Coefficient (95% CI): 0.1 (0.03-0.22)).

CONCLUSION

In infants needing stabilisation at birth, it is feasible to obtain reliable HRs when using umbilical PO, but takes longer when compared to preductal PO. Although both PO signals were reliable, umbilical cord measurement produced lower HRs than preductal PO, which warrants further investigation.

INTRODUCTION AND RATIONALE

Heart rate (HR) is considered the most important parameter to evaluate the infant's condition and the effect of interventions during transition at birth.[1-3] Although auscultation of the heart and palpation of umbilical cord pulses are still practiced, these methods are reportedly inaccurate and often lead to underestimation of HR.[4, 5] International guidelines recommend either electrocardiogram (ECG) or pulse oximetry (PO) of the right hand (preductal) if available.[2] However, there is still uncertainty whether evaluating HR using electrical activity (ECG) or pulsatility following contraction of the heart (PO) is more indicative of cardiac output. In addition, ECG has some disadvantages as electrodes can injure the fragile skin, cause pain or distress, and cleaning the skin can prolong electrodes placement as they do not adhere well to a wet or vernix covered skin.[6-8]

Although preductal PO has been recommended, it is recognised that obtaining a reliable HR can be difficult.[2] Several studies have shown a delay in obtaining a reliable HR signal after placing a preductal PO sensor on the right hand,[8-16] which takes from 12(9-30) to 87.28(±12.11) seconds.[11-13, 17] Factors contributing to the delay in HR assessment of preductal PO include; time needed to dry neonates after delivery, skin fragility in preterm neonates and presence of vernix or edema within the right hand.[2, 9, 18] Motion artefacts and peripheral vasoconstriction can also reduce preductal PO accuracy.[9]

The delay in obtaining a reliable HR signal can influence the steps taken during resuscitation, which prompted researchers to develop alternative methods for obtaining a faster HR signal.[19] While umbilical pulsatility can be palpated, this method leads to underestimation of the HR which has been attributed to caregiver miscalculation.[4, 5] Measuring pulsatility by placing the PO sensor around the umbilical cord could provide a more objective assessment. Additionally, umbilical arteries are less subjected to peripheral vasoconstriction, the umbilical cords central position could decrease sensitivity for motion artefacts and less vernix or edema is present around the cord than the hand. Cardiac generated pressure pulses continue to reach the umbilical cord whether or not arterial blood flow has ceased and are therefore still detectable after umbilical cord clamping.[20] For these reasons, we hypothesised it is feasible to measure HR using umbilical PO and that a reliable signal can be obtained faster when compared to preductal PO. In this study we aimed to investigate whether it is feasible to measure HR by umbilical PO in infants needing stabilisation and determine whether a reliable signal can be obtained faster when compared to the standard preductal PO.

METHODS

A prospective observational study was performed at the Leiden University Medical Center (LUMC, Netherlands) and was approved by the accredited Medical Research Ethics Committee of Leiden-Den Haag-Delft (P19.108) and registered in the Dutch Trial Register (NL8316). Infants of >25 weeks gestational age who needed stabilisation at birth were enrolled from January 2020 until July 2020. Infants were eligible if stabilisation was anticipated, if they were placed on the standard resuscitation table and if preductal PO measurements were obtained. Parents were approached for study participation and written informed consent was obtained antenatally.

A Masimo SET PO (Masimo Radical-7, Masimo Corporation, Irvine, California, USA) was used to feature continuous numerical values of HR, SpO_2, signal identification and quality (SIQ) and plethysmograph signals. The Masimo PO contains a multisite low noise cabled Neonatal PO sensor which was placed on the infants right hand.[21] A (non-)adhesive sensor was used for preductal HR measurements depending on birthweight: RD SET NeoPt if <1kg and RD SET Neo if ≥1kg to <3kg. For umbilical PO measurements a non-adhesive sensor for birth weight <1kg (RD SET NeoPt-500) was used. Sensors did not differ in accuracy and used the same light sensor.[21] Both Masimo's were set to acquire data with maximum sensitivity.

Preductal PO measurements and a video recording of the infant were digitised using the NewLifeBox-E physiological recording system (Advanced Life Diagnostics, Weener, Germany) and recorded by the NewLifeBox Neo-RSD computer system (Advanced Life Diagnostics) using Polybench physiological software (Applied Biosignals, Weener, Germany). Umbilical PO measurements were obtained using a designated laptop containing the same Polybench physiological software.

Recordings of both PO signals were started as soon as the infant was born. All infants were placed on the resuscitation table after cord clamping, then dried or covered in a wrap. The umbilical PO sensor was placed by the investigator (on the base of the umbilical cord, where it was covered with skin) and the preductal PO sensor by a neonatal nurse. After placing the sensors, they were simultaneously connected to the devices. Umbilical PO measurements were shielded and alarms were muted, so caregivers were not informed or distracted by umbilical measurements. HR measurements of the umbilical PO were continued until 10 minutes postpartum. Preductal HR measurements could continue for standard of care. Study procedures did not interfere with standard of care at any time.

The recording on the resuscitation monitor was started at the time of birth, conform our departments standard procedure during neonatal stabilisation at birth. To

synchronise HR measures from both devices, time of recording on the designated laptop was corrected using the recording time on the resuscitation monitor.
A reliable HR signal was defined as a SIQ >30% and/or a stable plethysmograph pulse wave, which is consistent with previous studies.[12, 22, 23] The Masimo PO was set to average HR measurements over 8-12 seconds and the plethysmograph pulse waveform was displayed over 10 second intervals for analysis. This waveform was considered stable when a regular waveform was visible for at least 2/3 of each 10 second period that was displayed (figure 1).

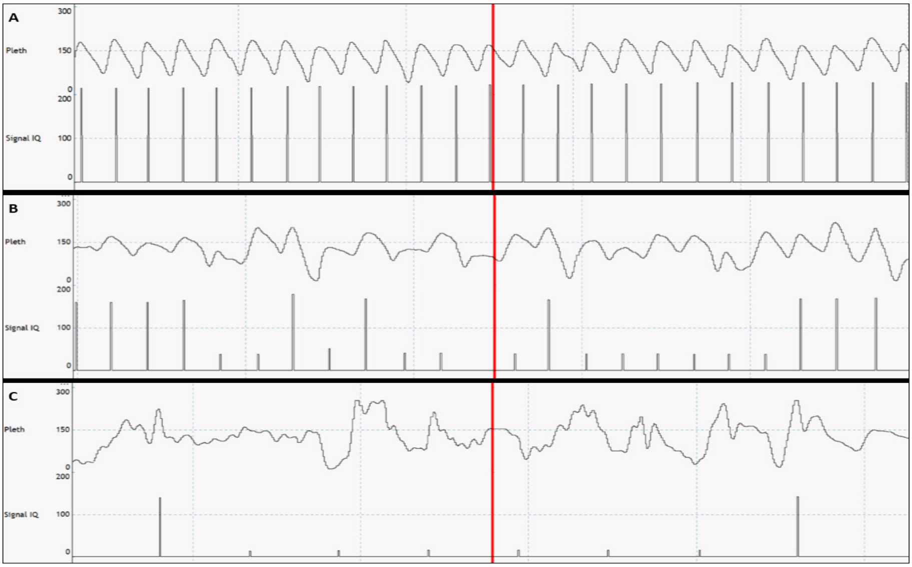

Figure 1 | plethysmograph wave patterns and the corresponding SIQ peaks
1a. Reliable signal with regular plethysmograph wave patterns and corresponding SIQ peaks.
1b. A reliable signal, despite the low SIQ peaks, as a regular plethysmograph wave pattern is shown.
1c. An unreliable signal is shown with low SIQ peaks and an irregular plethysmograph wave pattern.

HR data were obtained at 0.5 second-intervals during the first 10 minutes after birth and analysed for stability at each 10-second interval. HR measurements were considered valid for analysis if both pulse rates (umbilical and preductal) were present at that specific time interval. Furthermore, the time between touching the right hand or the umbilical cord for sensor placement and complete sensor placement was recorded. The total time of HR signal loss and the percentage of reliable HR signal after the first reliable HR signal appeared were calculated. The occurrence of replacing and reattaching the sensors were noted.

The primary outcome was feasibility; the proportion of infants with a reliable HR signal obtained from the umbilical cord. Secondary outcomes were the time needed to obtain an reliable umbilical HR signal after sensor placement and the proportion of infants where reliable umbilical PO signals were obtained for at least 20 seconds earlier than the preductal PO.

We calculated a sample size for the difference in time to obtain a reliable signal. Previous studies have shown that the time needed to display reliable HR measurements after complete preductal PO sensor placement varies between 12 (9-30) and 87.28 (±12.11) seconds.[11-13, 17] To identify a 20-second difference between the two methods (preductal versus umbilical), using a standard deviation of 20 seconds with a 2-sided α error of 5% and power of 80%, a total sample size of 32 paired measurements (16 infants) were needed. Assuming a 10% loss of patient data due to failure of measuring a HR signal, we decided to include a total of 18 infants. We considered 18 infants to be sufficient to test whether it is feasible to measure reliable umbilical HR.

Data analysis was performed using SPSS Statistics for Windows (IBM SPSS Statistics 25, Chicago, Illinois). Descriptive statistics were used for all baseline variables and secondary outcomes of umbilical PO. Normally distributed data are presented as mean (± standard deviation; SD), whereas not normally distributed data are presented as median [interquartile range; IQR]. Categorical variables are presented as numbers and percentages. A Bland Altman plot was computed to assess agreement between umbilical and preductal HR measurements. Limits of agreement were calculated by two standard deviations (SD±1.96) around the mean difference. A p-value of <0.05 was considered statistically significant. Continuous data were analysed using the Student's paired t test for data with normal distribution and a Wilcoxon signed-rank test for skewed continuous data. An intraclass correlation coefficient was calculated to assess the agreement between the two methods.

RESULTS

A total of 120 parent couples were screened for eligibility of which 60 parent couples could not be approached, mostly due to restrictions imposed by the COVID-19 pandemic. Sixty eligible parent couples were approached for study participation. In total, 36 parent couples consented, but for various reasons 18 measurements were not obtained (figure 2). Thus, the study was conducted in 18 infants with a median gestational age of 32 [31-33] weeks and a birth weight of 1723 [1019-2130] grams (table 1). Due to malfunctions of the recording software we were able to record umbilical HR measurements in 17 of 18 infants, whereas preductal measurements were recorded in 14 infants. In all 18 infants (100%), the umbilical sensor was applied successfully and in all 17 infants with umbilical HR recordings a reliable HR could be measured.

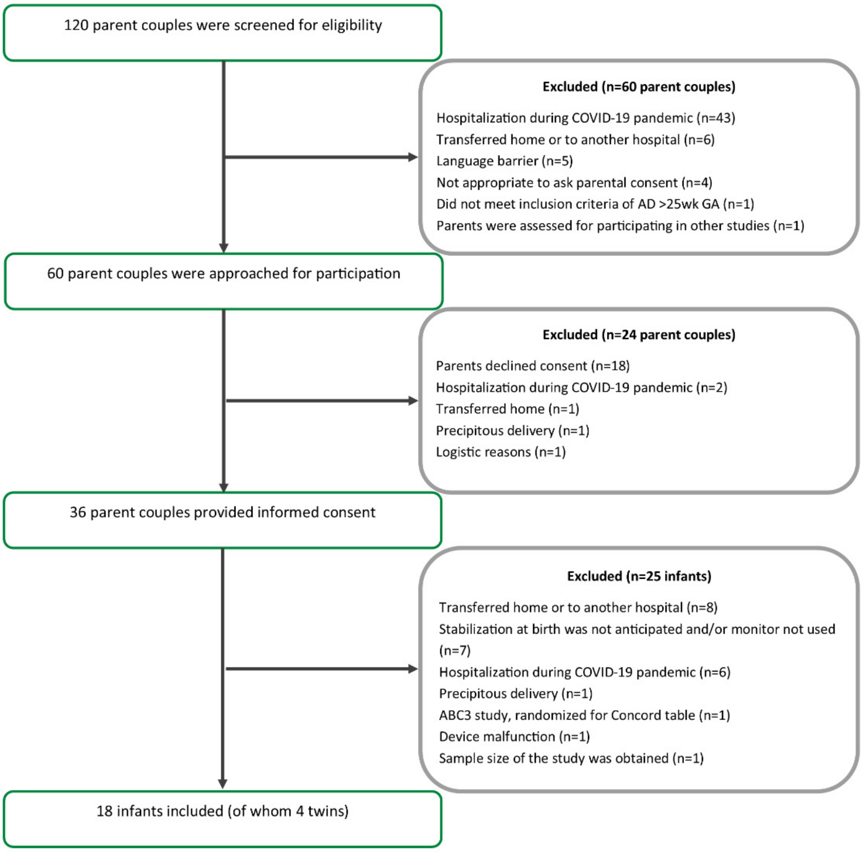

Figure 2 | Consort flowchart of patients in the study

Table 1 | Patient characteristics

Characteristics	N=18
Gestational age (weeks)	32 [31-33]
Birth weight (grams)	1723 [1019-2130]
Male sex	9 (50%)
Caesarean section	14 (78%)
Antenatal use of steroids	17 (94%)
Completed course*	14 (78%)
Incomplete course	3 (17%)
Gravidity	
1	5 (28%)
2	12 (67%)
3	1 (6%)
Parity	
0	8 (44%)
1	10 (56%)
Apgar score after 1 minute#	7 [6-9]
Apgar score after 5 minutes#	9 [8-10]
Apgar score after 10 minutes#	9 [9-10]
Respiratory support	
Tactile stimulation	18 (100%)
CPAP	14 (78%)
5 inflations given	9 (50%)
PPV ventilation	3 (17%)
Intubation	0 (0%)
Maximum FiO_2 (%)	75 [38-100]

Characteristics displayed as median [IQR] or as n (%).

* Completed course described as 2 doses of steroids completed 48 hours prior to birth, within 2 weeks before delivery.

Data available from 17/18 infants

The median time required for sensor placement was not different between PO's (umbilical vs. preductal: 18 [11-21] seconds vs. 14 [9-27] seconds; p=0.5). The median time needed to obtain a reliable HR after the sensor was connected to the PO device was a few seconds longer for umbilical PO (19 [16-55] seconds vs. 15 [11-17] seconds; p= 0.01). Total time to acquire a reliable HR signal from birth was not different between PO's (183 [150-306] seconds vs. 179 [150-238] seconds; p=0.1). When using umbilical PO, no infant attained a reliable HR at least 20 seconds earlier (birth to reliable HR signal) than with preductal PO. After the first reliable signal, HR remained reliable in 96% [83-100] versus 99% [96-100] of the first 10 minutes (p=0.2), for umbilical and preductal PO respectively.

The umbilical sensor needed reattachment in five infants, while the preductal sensor was reattached in one infant (p=0.3). The umbilical sensor did not need to be replaced, whereas the preductal sensor needed to be replaced once.

When comparing all reliable HR measurements (11924 umbilical HR and 10409 preductal HR; 8902 paired (both present)), umbilical HR was lower when compared to preductal HR (125 [73-146] bpm vs. 147 [136-155] bpm; p=0.001). Although umbilical HR was consistently lower, the difference became smaller in time mostly due to increase in umbilical HR (figure 3). Reliable HRs of both PO's were compared in a Bland-Altman plot. The mean (±1.96 SD) difference between all HR data pairs (preductal PO–umbilical PO) was 36(±22) bpm with a 95% limit of agreement between -7 up to 79 bpm (figure 4). The intraclass correlation coefficient (95% CI) was 0.1 (0.03-0.22) which indicates a poor agreement between the two PO measurements.

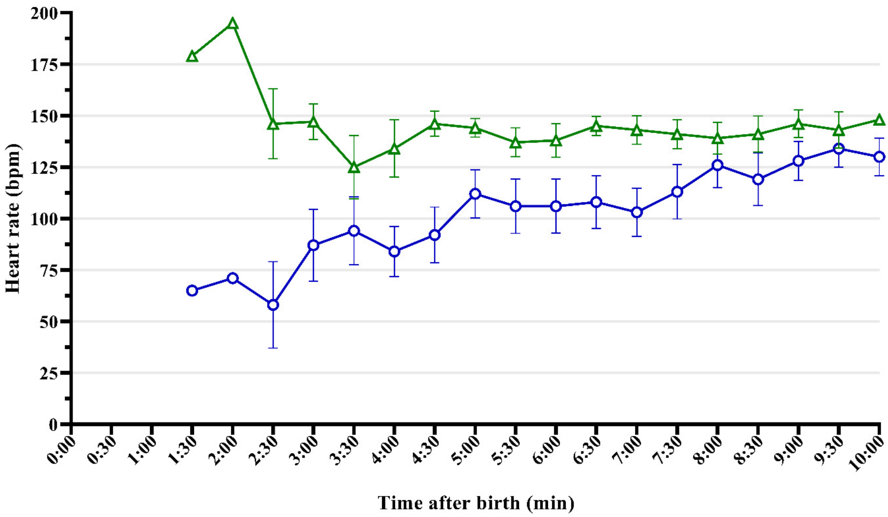

Figure 3 | Mean HR (SEM) in the first 10 minutes after birth measured by umbilical PO (blue) and preductal PO (green)

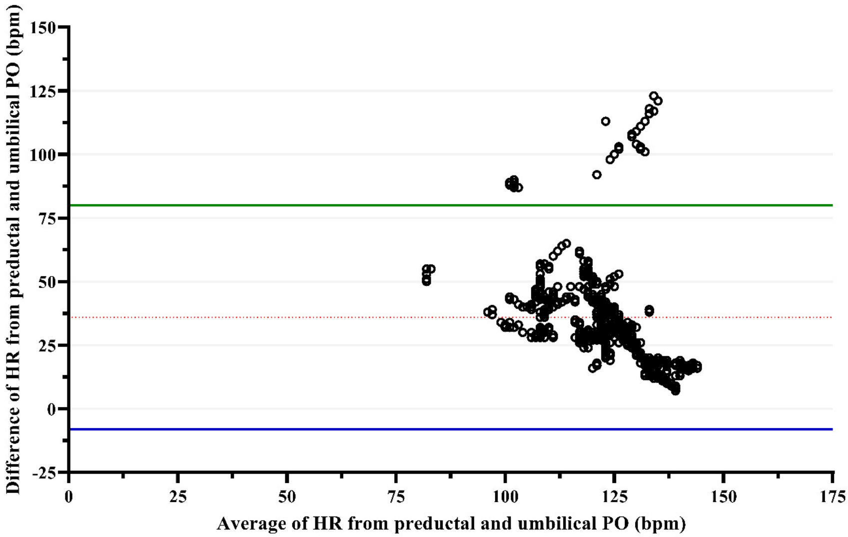

Figure 4 | Bland-Altman plot showing 95% limit of agreement in preductal and umbilical HR measurements (bpm)

DISCUSSION

In this study we observed it was feasible to obtain reliable HR measurements in infants at birth using PO with the sensor attached around the umbilical cord. We were able to obtain a reliable umbilical HR rapidly (on average within 20 seconds of sensor placement), but this was not faster than the standard preductal PO. This is largely because we were able to obtain preductal HR faster than in previous studies,[11, 13, 17] which questions the necessity for an alternative method. Although it was possible to obtain reliable HRs from both locations, the umbilical sensor measured a consistently lower HR than the preductal sensor. There is consensus that when ECG is not possible, HR of infants can be evaluated using PO. Our findings demonstrate that HR can be estimated by both umbilical and preductal PO, but given the discrepancy between umbilical and preductal measured HR, it raises the question as to which method best reflects the infants clinical condition. We could measure reliable HR preductally faster (from sensor attached to first reliable HR) than described in previous studies.[10, 16, 17] This can be explained by a different method in the use of PO that was recently implemented in our unit. In a recent observational study we observed that motion artefact is the predominant reason for a delay in obtaining a reliable pulse wave (unpublished data). When the hand is gently contained and motion is prevented after sensor application, a reliable HR is obtained earlier. Additionally, once a reliable HR signal is obtained it remains reliable, even when the hand is released and motion occurs. This suggests that once a reliable signal has been detected, the Masimo PO algorithm is able to filter out motion artefacts. In contrast to our initial assumption, we observed that the umbilical cord is still subject to motion, which is not caused by movements of the infant, but by handling of the caregiver.

The consistent discrepancy in HR, with a lower HR measured at the umbilical cord, was a surprising finding. Since we only used HR data obtained from reliable signals and the HR from the umbilical cord and hand were synchronised in time, it is unlikely the difference is caused by the measuring methods. Previous studies demonstrated that counting HR by palpation of the cord led to underestimation of the HR.(4, 5) Kamlin *et al.* compared calculating HR by manual palpation of the cord with ECG and observed that caregivers counted a similar lower HR (-21 (21) bpm difference) than measured by ECG.(4) Since then it has been assumed that caregivers have difficulty counting HR in such a short time frame. This was supported by simulation studies where they observed that HR assessment by palpation was inaccurate when HR was above 100 bpm, but more accurate when HR was lower.(24-26) However, based on our findings it is possible that the observed difference in clinical studies was a true physiological phenomenon and that less pulse waves are transmitted to the umbilical cord.

Studies have shown that lung aeration at birth is the primary trigger for the decrease in pulmonary vascular resistance leading to an increase in pulmonary blood flow.(27-29) We recently demonstrated that this leads to a change in ductal shunting, from a right to left shunt in the fetus to a bidirectional shunt following lung aeration.(30, 31) While a left to right shunt through the ductus arteriosus predominates during diastole, a right to left shunt is briefly restored during systole.(31) Thus, during systole the right ventricle contributes to the pulse wave passing down the descending aorta, whereas during diastole, the left to right shunt diminishes the blood flow down the descending the aorta. Indeed, a difference in pulse waves between pre- and post-ductal blood vessels has been observed in experimental studies, with less pulse waves in the aorta.(32) All infants included in our study were breathing spontaneously with or without the need for CPAP at the time of measurements. We speculate that breathing effort at birth disrupts blood flow to the lower body when the ductus arteriosus is still open, with the sub-atmospheric pressure during inspiration increasing the left to right shunt.(33) This would then lead to a reduced volume change associated with the beat that is not detected by the plethysmograph algorithm. While this is a matter of speculation, this would probably explain why we observed difference in plethysmography waveforms between the preductal and umbilical oximetry measurements.

This is a small observational study and findings are not conclusive but create rationale for further investigation. The sensor and algorithm of the oximeter are not designed to measure HR at the umbilical cord and this could have influenced our findings. The feasibility of HR signal acquisition through the Wharton jelly was unknown until this study. Wharton jelly is considered to be a mucoid polysaccharide predominantly comprised of hyaluronin and chondroitin sulfate which are highly hygroscopic, providing vascular support that prevents kinking of the vessels during fetal movements.[29] However, the PO algorithm might have difficulties detecting a signal through other tissues than skin and subcutaneous fat of the hand and feet. Nevertheless, when using umbilical PO we were able to detect reliable HRs in all infants within a few seconds of preductal HR measurements. It is possible that a purpose built umbilical sensor and adjusted algorithm would lead to obtaining reliable signals much faster.

In conclusion, it is feasible to measure HR at the umbilical cord in preterm infants at birth using plethysmography of an oximeter, but this is currently not faster than the standard preductal measurement. The lower HR measured at the umbilical cord as compared to the preductal HR warrants further studies to confirm this but, if correct, evaluation of the infants clinical condition using HR by palpating the cord should be reconsidered.

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