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ORIGINAL ARTICLE

Newborns requiring resuscitation: Two thirds have heart rate ≥100 beats/minute in the first minute after birth

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Abstract

Aim: The aim was to study the prevalence of bradycardia at birth in newborns requiring positive pressure ventilation (PPV), distribution of first measured heart rate (HR), changes in HR before start of PPV and HR response to PPV.

Methods: A population-based study including newborns ≥30 weeks' gestation receiving PPV at birth. HR was captured immediately after birth and continuously throughout resuscitation using the dry-electrode ECG device NeoBeat. Time of birth was registered in the Liveborn app. Provision of PPV was captured by video.

Results: We included 98 newborns receiving PPV at birth. Among newborns with HR measured within 60 s after birth, median (quartiles) first HR was 112 (84, 149) bpm recorded 19 (14, 37) s after birth, of which 33% had first HR <100 and 10% had first HR <60 bpm respectively. First HR was widely distributed. Median HR at start PPV 69 s after birth was 129 bpm. In newborns with an initial low HR, HR typically remained low for 20 s of PPV before increasing rapidly over the next 20–30 s.

Conclusions: First measured HR was ≥100 bpm in two thirds of newborns receiving PPV. In bradycardic infants, HR did not increase until after 20 s of PPV.

KEYWORDS
dry-electrode ECG, heart rate, neonatal resuscitation, positive pressure ventilation, resuscitation guidelines

1 | INTRODUCTION

Newborn heart rate (HR) is considered one of the most important markers of need for, and response to, resuscitation after birth.[1] Yet, there is no accurate data on distribution of HR from birth and during the first 60 s after birth in newborns requiring resuscitation. This is the critical time frame when decisions should be made on whether to clamp and cut the cord, transfer the newborn to the resuscitation table and initiate positive pressure ventilation (PPV).

According to guidelines, PPV should be initiated within 60 s if the newborn fails to establish spontaneous and effective breathing following drying and stimulation, and/or if HR is <100 beats/minute (bpm), if HR does not increase if initially low, or if HR decreases if initially fast.[2] Chest compressions are indicated if HR is <60 bpm

Abbreviations: bpm, beats per minute; ECG, electrocardiogram; HCP, healthcare provider; HR, heart rate; PPV, positive pressure ventilation.

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after at least 30 s of good quality ventilation.[1,2] These recommended HR thresholds are based on animal studies and expert consensus.[3] Although a prompt increase in HR is considered the most sensitive indicator of effective ventilation,[2] there is limited knowledge on what rise in HR should be expected.[4,5]

Dry-electrode electrocardiogram (ECG) has recently been shown to display an accurate newborn HR more rapidly and continuously than standard ECG and pulse oximetry immediately after birth, during the first 60 s and throughout resuscitation.[6–11]

The overall aim was to study the prevalence of bradycardia at birth in newborns requiring PPV and HR response to ventilation. We describe: (i) the proportion of newborns with HR <60 and <100 bpm, (ii) the distribution of first HR, (iii) changes in HR before start of PPV and (iv) HR changes in response to PPV.

Key Notes

- Evidence on heart rate (HR) during the first minute after birth in newborns requiring positive pressure ventilation (PPV) is scarce.
- Two thirds of newborns requiring PPV had HR ≥100 bpm in the first minute. Median HR at start PPV was 129 bpm. In bradycardic newborns, HR did not increase until after 20 s of PPV.
- These findings emphasise that the main indication for starting PPV is lack of spontaneous breathing, irrespective of HR.

2 | METHODS

2.1 | Study design and setting

This descriptive study was performed at Stavanger University Hospital in Norway between 6 June 2019 and 21 September 2021. The hospital provides tertiary level obstetric and newborn services for a population of 370 000, with approximately 4300 annual deliveries. The hospital is the only hospital in the region, and well suited for population-based studies. The prematurity rate is 5.5% and overall caesarean section rate 16.5%. The incidence of PPV at birth is 3.6%, and newborns born by caesarean section are overrepresented among those receiving PPV.[12] Healthcare providers (HCPs) undergo regular training on newborn resuscitation according to National and European guidelines on newborn resuscitation.[2]

2.2 | Equipment and data collection

During the study period, exact time of birth and time of cord clamping was registered by midwife assistants in the Liveborn application (Laerdal Medical) on a portable tablet. The wireless dry-electrode ECG device NeoBeat (Laerdal Medical) was applied to the thorax or upper abdomen of all newborns by the midwife assistants immediately after birth for HR feedback. During resuscitation, additional HR assessment was performed by auscultation, 3-lead gel-electrode ECG and pulse oximetry. For caesarean sections, NeoBeat was applied when the newborn was clear of the operation field or when placed on the resuscitation table. The device samples ECG at 500 Hz, and the calculated HR is transmitted continuously every second and stored in the Liveborn application.

In newborns requiring PPV, the umbilical cord was clamped, and the newborn transferred to the resuscitation table with the NeoBeat in place. HCPs were advised to initiate PPV within 60 s after birth if (i) the newborn failed to establish spontaneous and effective breathing following drying and stimulation, and/or (ii) HR was <100 bpm, (iii) HR did not increase if initially low or (iv) HR decreased if initially fast, in line with newborn resuscitation guidelines.[2] PPV was mostly performed using the T-piece resuscitator NeoPuff (Fisher & Paykel Healthcare) at recommended settings 30/5 cmH_2O starting at room air for newborns of ≥32 weeks gestation, and 25/5 cmH_2O starting at FiO2 0.30 for newborns of <32 weeks gestation or alternatively by self-inflating bag (Upright, Laerdal Medial). In newborns receiving chest compressions, NeoBeat was if needed repositioned to the abdomen of the newborn. Videos of the resuscitations were recorded using motion sensor cameras placed above the resuscitation tables, capturing the newborn and the hands of the HCPs. The timestamp in the video server and Liveborn application was automated synchronised daily. Video recordings were used to validate the respiratory efforts of the newborn (spontaneously breathing, gasping or non-breathing), and need for intubation and chest compressions. Patient characteristics (gestational age, birth weight, gender, mode of delivery, Apgar score and umbilical arterial pH), management and short-term outcomes (intubation, chest compressions, admission to the neonatal intensive care unit, therapeutic hypothermia treatment, hypoxic ischaemic encephalopathy and death before discharge) were automatically extracted from the digital medical records.

2.3 | Inclusion and exclusion criteria

At the time of the study, NeoBeat was only available in a size equivalent to a minimum approximate birth weight of 1500 grams. Newborns with gestational age (GA) ≥30 weeks who received PPV within the first 5 min after birth were included if: (i) HR signal data were captured by NeoBeat within the first 120 s after birth, (ii) exact time of birth was registered in the Liveborn app and (iii) video of the resuscitation was available. Newborns were excluded if they had congenital malformations that interfered with the application of NeoBeat or if they were breathing sufficiently when PPV was started as determined by video.

2.4 | Calculations and statistical analysis

'First HR' was defined as median of the first 5 s of HRs reported from NeoBeat, 'HR at initiation of PPV' as median of the 5 s of HR before

PPV was started, and 'last HR' median of the last 5s of HR registered. Video recordings of the resuscitations were reviewed by two investigators (AK, SR) using XProtect Smart Client software2016 (Milestone). Respiratory effort, the time of initiation and discontinuation of PPV, intubation and chest compressions were registered from the video recordings. Time to initiation of PPV was defined as time from birth to the first positive pressure inflation. Duration of PPV was defined as time from first to last positive pressure inflation, or if intubated, when the newborn was moved from the resuscitation table to the transport incubator. Management and short-term outcomes included admission to the neonatal intensive care unit, therapeutic hypothermia, hypoxic ischaemic encephalopathy and death before discharge. HR data processing, data point extraction and statistical analysis were done using MATLAB R2021a (MathWorks) and R version 4.1.2 (R Development Core Team, Vienna, Austria). Continuous data were summarised by median and quartiles, unless otherwise stated.

3 | RESULTS

We included 98 newborns with gestational age ≥30 weeks that received PPV within 5 min of birth and had HR signal data obtained by NeoBeat within the first 120 s after birth, exact time of birth registered in the Liveborn app and video capture of the resuscitation, Figure 1. Median gestational age (quartiles) was 40.0 (38.4, 41.1) weeks, and 13 of the 98 (13%) newborns were born preterm at gestational age 30+0 to 36+6 weeks. Cord clamping was done at median 37 (18, 133) s after birth (n = 56). PPV started 69 (44, 116) s after birth (n = 98), with a duration of 147 (72, 253) s (n = 86). Analysis of video recordings confirmed that all included newborns were not breathing (n = 72) or insufficiently breathing (n = 26) when PPV was started; and 30 newborns had additional bradycardia as indication for providing PPV. In total, 90 (92%) of newborns were ventilated with t-piece alone, the remaining with bag-mask or a combination of t-piece and bag-mask. Characteristics of the newborns are presented in Table 1.

3.1 | The proportion of newborns with HR <100 and <60 bpm at birth and distribution of first HR

Among 81 newborns with first measured HR within 60 s after birth median HR was 112 (84, 149) bpm at 19 (14, 37) s, of which 27 (33%) and eight (10%) had first HR <100 and <60 bpm respectively. When including all 98 newborns with HR within 120 s after birth, median first measured HR remained the same at 112 (80, 146) bpm at 30 (15, 52) s, of which 36 (37%) and 11 (11%) had a first HR <100 and <60 bpm respectively. The distribution of first measured HR, HR at start of PPV and last measured HR are shown in Figure 2.

3.2 | Physiological HR response after birth before start PPV

HR at start PPV was median 129 (78, 165) (n = 72) at 69 (44, 116) (n = 98) s after birth, shown in Figure 2C,D. At start of PPV, one third (30 newborns) had HR <100 bpm. However, there was a wide variation in HRs in the first minute after birth before starting PPV, and in 65 newborns with both first HR and HR at start PPV measured at least 5 s apart the changes in HR could be defined as increasing ≥10 bpm (n = 29), stable (n = 16) or decreasing ≥10 bpm (n = 20), as shown in Figure 3.

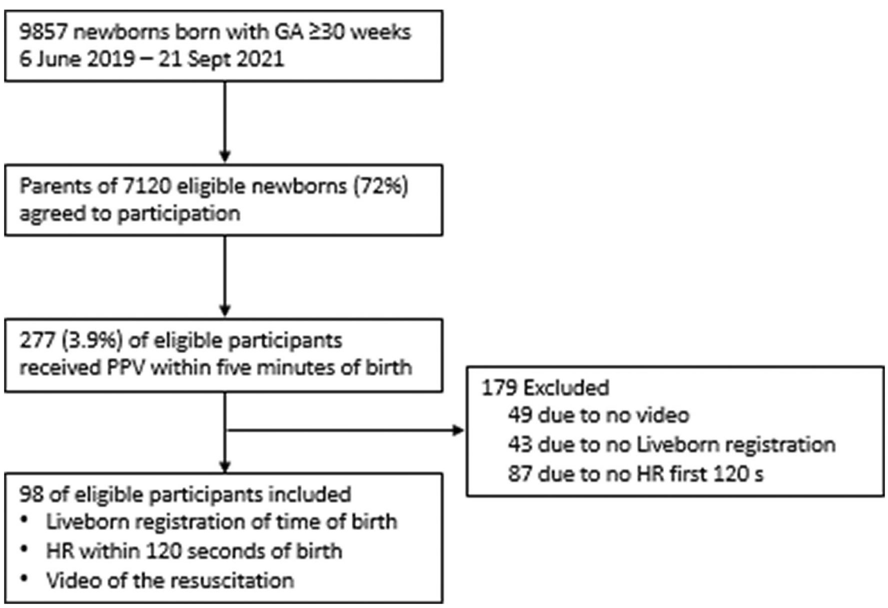

FIGURE 1 Flow chart showing study participants.

TABLE 1 Patient demographics

	Total ($n = 98$)
Gestational age (weeks)	
Mean	39.4 ± 2.5
Median	40.0 (38.4, 41.1)
Birth weight (grams)	
Mean	3396 ± 777
Median	3507 (2963, 3851)
Gender	
Female	46 (47%)
Male	52 (53%)
Mode of delivery	
Spontaneous vaginal	19 (19%)
Vacuum	31 (32%)
Forceps	4 (4%)
Acute caesarean section	33 (34%)
Elective caesarean section	3 (3%)
Apgar	
1 min	4 (3, 6)
5 min	7 (6, 9)
10 min	9 (8, 10)
Umbilical arterial pH	7.19 ± 0.09
Intubated	2 (2%)
Chest compressions	3 (3%)
Admission NICU	53 (54%)
Therapeutic hypothermia treatment	4 (4%)
Hypoxic ischaemic encephalopathy	5 (5%)
Death before discharge	1 (1%)

Note: The table shows the characteristics of the 98 newborns. Gender, mode of delivery, intubation and chest compressions are given as *n* (%), Apgar score is given as median (IQR) and umbilical pH is given as mean (SD).

Abbreviations: IQR, Inter-quartile range; NICU, Neonatal intensive care unit; SD, Standard deviation.

3.3 | Heart rate response to PPV

HR responses to PPV followed different courses; low to high HR (PPV started at median 60 [36, 115] s), high to high HR (PPV started at 61 [42, 80] s), stable high HR (PPV started at 116 [65, 154] s) and unstable HR (PPV started at 69 [54, 105] s), as illustrated in Figure 4A,D. In newborns with low to high transition from a HR <100 bpm at start PPV ($n = 30$), the transition started 20 (12, 37) s after initiation of PPV, followed by a rapid HR increase over the following 20–30 s to around 150 bpm and a further increase of 10–30 bpm during the next minutes before stabilising, as shown in Figure 5. Among the subgroup of newborns with HR <100 bpm at start of PPV, 93% were not breathing and 7% insufficiently breathing, compared to 62% and 38% among the newborns with HR ≥100 bpm respectively.

Last measured HR was 175 (151, 191) bpm at 675 (468, 861) s after birth, shown in Figure 2E,F. At 5 min after starting PPV, only two newborns had HR <100 bpm. Three newborns received chest compressions, all three had HR <60 bpm.

4 | DISCUSSION

Data on accurate HR during the first minute after birth among an unselected cohort of newborns requiring PPV are lacking, despite HR being an important marker in resuscitation algorithms.

This population-based study conducted in a high-resource setting demonstrates that the immediate HR among newborns in need of PPV was distributed over a wide range. Importantly, two thirds of the resuscitated newborns had a first measured HR ≥100 bpm, and median HR was 129 bpm at start of PPV. In newborns who were bradycardic at start of PPV, HR typically remained low through the first 20 s of PPV, but thereafter increased rapidly to approximately 140–150 bpm over the next 20–30 s.

We believe our results are representative for most high-resource settings. The proportion of newborns receiving PPV, proportion of late preterms requiring PPV and median duration of PPV after birth was in line with previous reports.[12–14] As expected in these settings, most newborns were moderately asphyxiated, with an umbilical arterial pH 7.19, and few newborns required advanced resuscitation with intubation and/or chest compressions. These factors may explain why a minority of newborns had first measured HRs <100 bpm.

4.1 | Distribution of first HR and proportion with low HR

The European newborn resuscitation guidelines define a HR ≥100 bpm in the first minute of life as fast and satisfactory.[2] However, resuscitated newborns in our cohort had a median first measured HR of 112 bpm in the first minute after birth, well within the so-called normal range. Furthermore, in a study from a high-resource settings including 898 vaginally born term newborns not requiring resuscitation, a much higher median HR of 168 bpm were observed 30 s after birth. In that study, HRs <100 and <120 bpm were relatively rare and corresponded to the third and 10th centile respectively.[7] Therefore, a HR <120 bpm beyond 30 s after birth should alarm HCPs that the newborn may be compromised and in need of resuscitation. Notably, a study from a low-resource setting showed that for every bpm increase in first detected HR after birth, the risk of death was reduced by 2%.[15]

Importantly, any newborn not breathing within 60 s after birth should be ventilated irrespective of their measured HR. None of the newborns who received PPV in this study were breathing sufficiently when placed on the resuscitation table and therefore required PPV. Timely initiation of PPV is essential, as demonstrated in a study from a low-resource setting where every 30-s delay in starting PPV among apnoeic newborns increased the risk of morbidity and mortality by 16%.[16] In this study, PPV was initiated at median

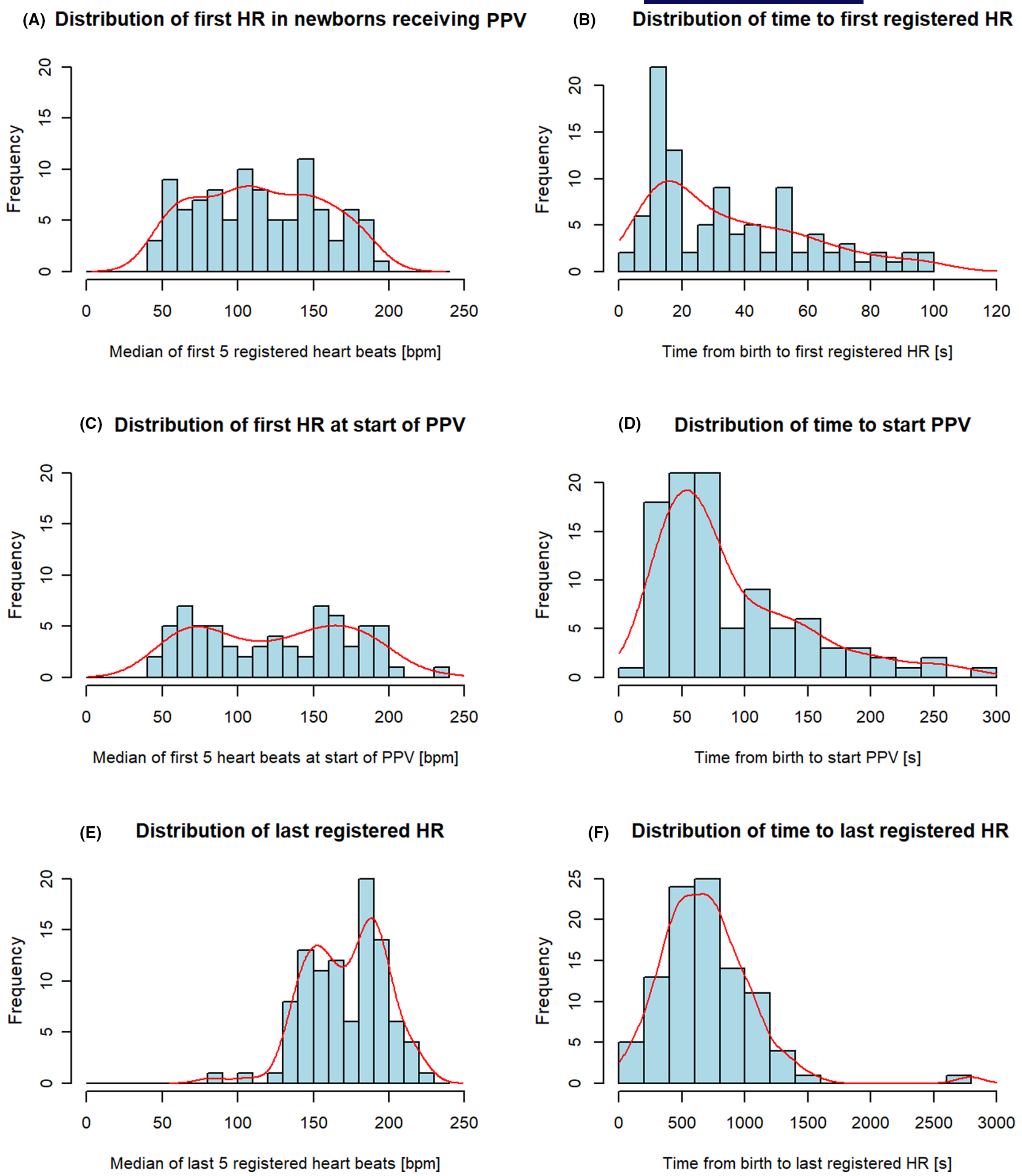

FIGURE 2 Histograms presenting the distribution of Panels (A) first HR (left) and (B) time to measurements from birth (right), Panels (C) distribution of HR at start of PPV (left) and (D) time to measurements from birth (right), Panels (E) HR at end of PPV (left) and (F) time to measurements from birth (right). HR = heart rate, PPV = positive pressure ventilation.

69 s after birth, not in line with recommendations. However, we believe non-compliance with guidelines and delay in initiating PPV during newborn resuscitation to be a frequent occurrence also in high-resource settings.[14,17,18] Although high-resource settings can offer advanced post-resuscitation care when indicated and mortality rates are low, delay in effective ventilation in apnoeic newborns may cause unnecessary organ damage due to the ongoing hypoxic-ischaemic process.

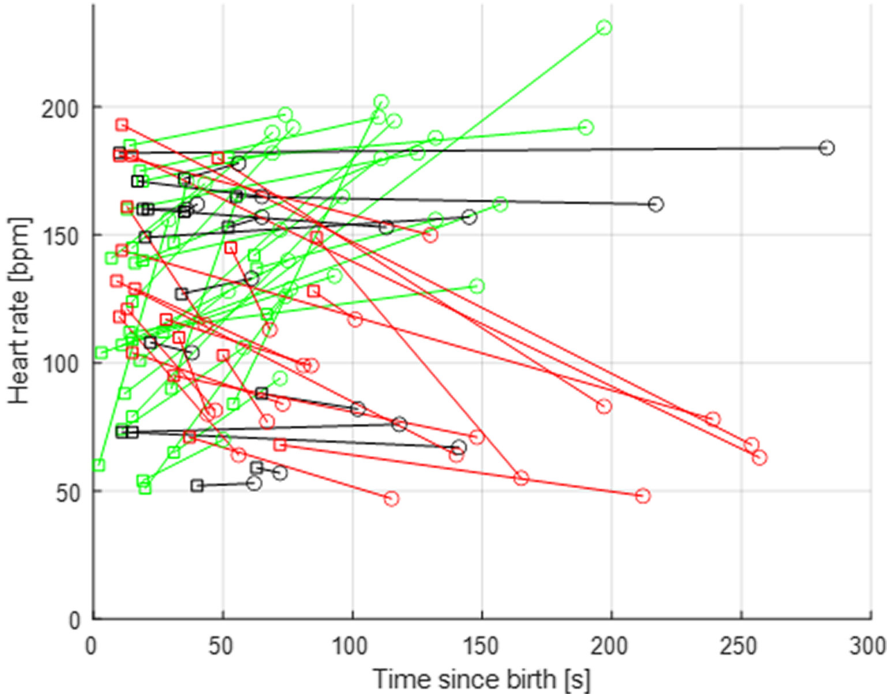

FIGURE 3 Changes in HR from the first HR (squares) to HR at start of PPV (circles) for $n = 65$ where both HR points exist and is at least 5 s apart. Green represents HR increasing ≥10 bpm ($n = 29$), black represents stable HR ($n = 16$) and red represents HR decreasing ≥10 bpm ($n = 20$). HR = heart rate, PPV = positive pressure ventilation and bpm = beats per minute.

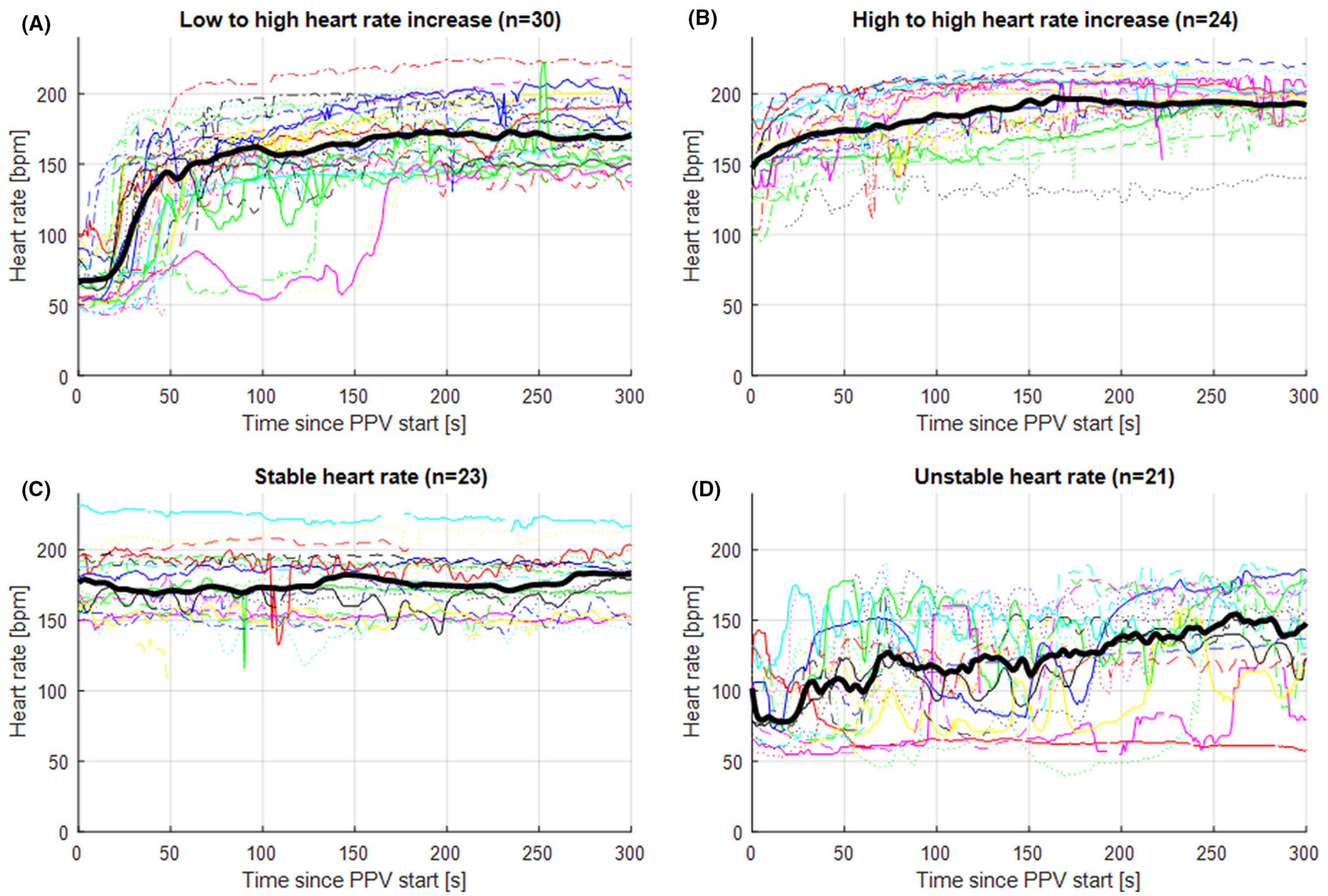

FIGURE 4 Illustration of different HR courses after starting PPV, Figure 4A shows the low to high HR increase where PPV started at median 60 (36, 115) s, Figure 4B shows high to high HR increase where PPV started at 61 (42, 80) s, Figure 4C shows stable HR where PPV started at 116 (65, 154) s and Figure 4D shows unstable HR courses where PPV started at 69 (54, 105) s. HR = heart rate, PPV = positive pressure ventilation.

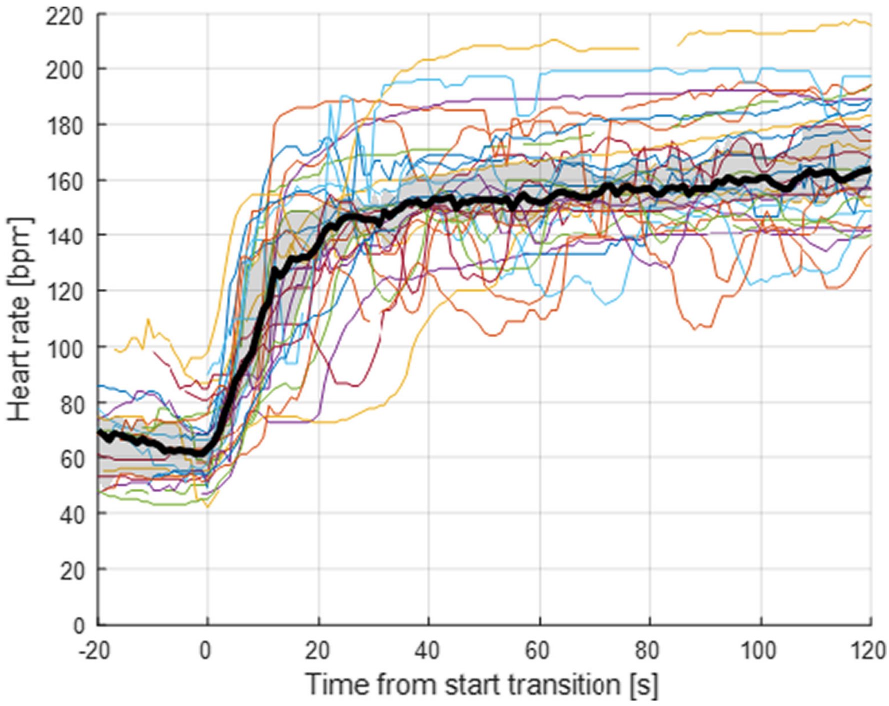

FIGURE 5 Changes in HR during PPV among newborns with HR <100 bpm at start PPV (*n* = 30). Time point 0 shows the time when HR transition starts. HR remains low median (quartiles) 20 (12, 37) s after starting PPV, before increasing rapidly over the next 20–30 s. HR = heart rate, PPV = positive pressure ventilation, bpm = beats per minute. HR = heart rate and PPV = positive pressure ventilation.

4.2 | HR changes in the first minutes of life

We describe large variations in HR courses over the first minutes of life, as shown in (Figure 2; Figure 4). Interestingly, the HR at start of PPV resembles the same two-peak distribution as described in a large study of 1237 apnoeic newborns receiving bag-mask ventilation in a low-resource setting. In that study, first HR after drying and stimulation but before start of PPV at median 102 s after birth was distributed in two peaks with centres around 60 and 165 bpm.[5] We demonstrated similar peaks around 70 and 170 bpm at median 69 s after birth at start of PPV in our cohort, shown in Figure 2C. We speculate that the two-peak distribution may reflect different degrees of asphyxia in these non-breathing newborns. The highest peak with HRs at 170 bpm may represent a hypoxia state with catecholamine drive, whereas the lowest peak with HRs at 70 bpm may represent more severely asphyxiated newborns. These observations from both low- and high-resource settings are in line with animal studies from Dawes, where increasing duration of asphyxia resulted in a sudden decompensation with a steep decline in HR. This may explain the low number of newborns with HRs in the normal range 100–160 bpm at start of PPV in our study.[3]

Figure 3 shows the variation in HR courses in individual newborns between first measured HR, and HR at start of PPV. In half of newborns, HR increased spontaneously or in response to stimulation before receiving PPV (illustrated with green lines). We speculate that these newborns largely contribute to the high median HR 129 bpm at start of PPV. Newborns with a decreasing HR course after birth are illustrated in red, and these newborns often drop to a HR <100 bpm at start PPV, and likely represent a more compromised cohort.

4.3 | Heart rate responses to PPV

A prompt increase in HR is considered the most sensitive indicator of resuscitation efficacy. This was confirmed in our study, with an increasing HR response after initiation of PPV unless HR was stable high. Guidelines do not indicate timing or the extent of HR acceleration one should expect. In one study, HR increased on average 23 beats between 60 and 90 s after birth in newborns receiving PPV and the HR response was dependent on the severity of asphyxia.[19] Based on our data, it was natural to divide HR responses to PPV into four groups. Newborns in the low to high HR group, responded after 20 s of ventilation with a rapid increase in HR over 20–30 s to approximately 150 bpm, as shown in (Figure 4A; Figure 5). This is in line with findings from the study of 1237 bag-mask ventilated newborns in a low-resource setting, where at least one low–high HR transition crossing 100 bpm was noted in 44% of newborns. The HR increase occurred over median 9 (6, 13) s, was 60 (43, 77) bpm, and 86% followed a ventilation sequence of 23 (16, 34) s duration.[5] Moreover, we have recently documented that establishment of functional residual lung capacity takes about 20 s.[20] The stable HR group shown in Figure 4C distinguish itself from the others, since PPV was started almost 2 min after birth, probably representing a less compromised cohort. The unstable HR group shown in Figure 4D were somewhat unexpected, and we will investigate in more detail the potential causes (e.g., vulnerability of the newborn) and specifically the relationship with delivered PPV in a subsequent study. From a recent study including 129 term newborns resuscitated with a t-piece resuscitator, we described a substantial variation in delivered tidal volumes at the lower end of the recommended range at median 4.5 ml/kg for the initial inflations.[21] Much higher tidal volumes were delivered by bag-mask ventilation (no PEEP) in a study of 215 newborns in a low-resource setting, were tidal volumes of 9.3 ml/kg produced the most rapid increase in HR during PPV.[22] Furthermore, in a study including 757 ventilated newborns, pauses in PPV during resuscitation were in some newborns followed by a decrease in HR to <100 bpm, associated with an almost twofold increased risk of death.[15]

In this study, one newborn had a HR <100 bpm for the entire first 5-min period despite provision of PPV and even chest compressions, and video analysis indicates that it was difficult to ventilate the newborn adequately. Our team is currently analysing resuscitation videos and signal data (ECG and PPV) to better understand reasons why some resuscitations progress to advanced resuscitations with chest compressions, intubation and adrenaline.

Limitations in this study included loss of participants due to incomplete data sets, which occurred at random and should not affect the results. The manual registration of exact time of birth and cord clamping is prone to human error. The European Resuscitation Council states that the presence or adequacy of breathing effort in especially preterm infants can be difficult to assess as breathing can be very subtle and is often missed, however, most included newborns were born at or near term. The results are representative for high resource settings with moderately asphyxiated newborns. This study included 98 newborns in need of PPV at birth, and the findings should be confirmed in larger studies.

5 | CONCLUSIONS

Almost two thirds of newborns in need of PPV had a first measured HR ≥100 bpm. There was a wide variation in HR courses from first measured HR to HR at start of PPV among individual newborns. At start of PPV, only one third had HR <100 bpm and median HR was 129 bpm. In newborns with a low HR at start of PPV, HR typically remained low for 20 s of PPV, and then increased rapidly.

AUTHOR CONTRIBUTIONS

All authors have made substantial contributions and are accountable for all aspects of the manuscript. AK, SR and HE conceptualised and designed the study. AK and SR was responsible for data curation. AK, SR, JE and JTK were responsible for data analysis, and all authors for the interpretation of the data. JTK provided statistical expertise and analysis. AK wrote the first draft of the manuscript, and all authors revised and approved the final version.

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CONFLICT OF INTEREST

Siren Rettedal has an unconditional research grant from Laerdal Foundation. Joar Eilevstjønn is a Laerdal Medical employee. The other three authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are not publicly available due to their containing information that could compromise the privacy of research participants, but are available from the corresponding author [SR] upon reasonable request.

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REFERENCES

1. Wyckoff MH, Wyllie J, Aziz K, et al. Neonatal life support: 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation. 2020;142(16_Suppl_1):S185-S221.
2. Madar J, Roehr CC, Ainsworth S, et al. European resuscitation council guidelines 2021: newborn resuscitation and support of transition of infants at birth. Resuscitation. 2021;161:291-326.
3. Dawes GS. Birth Asphyxia, Resuscitation and Brain Damage. Foetal Neonatal Physiol. 1968;141-159.
4. Saugstad OD, Soll RF. Assessing heart rate at birth: auscultation is still the gold standard. Neonatology. 2016;110(3):238-240.
5. Eilevstjonn J, Linde JE, Blacy L, Kidanto H, Ersdal HL. Distribution of heart rate and responses to resuscitation among 1237 apnoeic newborns at birth. Resuscitation. 2020;152:69-76.
6. Linde JE, Schulz J, Perlman JM, et al. Normal newborn heart rate in the first five minutes of life assessed by dry-electrode electrocardiography. Neonatology. 2016;110(3):231-237.
7. Bjorland PA, Ersdal HL, Eilevstjonn J, Oymar K, Davis PG, Rettedal SI. Changes in heart rate from 5s to 5 min after birth in vaginally delivered term newborns with delayed cord clamping. Arch Dis Child Fetal Neonatal Ed. 2021;106(3):311-315.
8. Bush JB, Cooley V, Perlman J, Chang C. NeoBeat offers rapid newborn heart rate assessment. Arch Dis Child Fetal Neonatal Ed. 2021;106(5):550-552.
9. Pike H, Eilevstjonn J, Bjorland P, Linde J, Ersdal H, Rettedal S. Heart rate detection properties of dry-electrode ECG compared to conventional 3-lead gel-electrode ECG in newborns. BMC Res Notes. 2021;14(1):166.
10. Rettedal S, Eilevstjonn J, Kibsgaard A, Kvaloy JT, Ersdal H. Comparison of heart rate feedback from dry-electrode ECG, 3-Lead ECG, and pulse oximetry during newborn resuscitation. Children-Basel. 2021;8(12):1092.
11. van Twist E, Salverda HH, Pas ABT. Comparing pulse rate measurement in newborns using conventional and dry-electrode ECG monitors. Acta Paediatr. 2022;111:1137-1143.
12. Bjorland PA, Oymar K, Ersdal HL, Rettedal SI. Incidence of newborn resuscitative interventions at birth and short-term outcomes: a regional population-based study. BMJ Paediatr Open. 2019;3(1):e000592.
13. Skare C, Kramer-Johansen J, Steen T, et al. Incidence of newborn stabilization and resuscitation measures and guideline compliance during the first minutes of life in Norway. Neonatology. 2015;108(2):100-107.

14. Niles DE, Cines C, Insley E, et al. Incidence and characteristics of positive pressure ventilation delivered to newborns in a US tertiary academic hospital. Resuscitation. 2017;115:102-109.
15. Linde JE, Perlman JM, Oymar K, et al. Predictors of 24-h outcome in newborns in need of positive pressure ventilation at birth. Resuscitation. 2018;129:1-5.
16. Ersdal HL, Mduma E, Svensen E, Perlman JM. Early initiation of basic resuscitation interventions including face mask ventilation may reduce birth asphyxia related mortality in low-income countries: a prospective descriptive observational study. Resuscitation. 2012;83(7):869-873.
17. McCarthy LK, Morley CJ, Davis PG, Kamlin CO, O'Donnell CP. Timing of interventions in the delivery room: does reality compare with neonatal resuscitation guidelines? J Pediatr. 2013;163(6):1553-1557.e1.
18. Bjorland PA, Ersdal HL, Oymar K, Rettedal SI. Compliance with guidelines and efficacy of heart rate monitoring during newborn resuscitation: a prospective video study. Neonatology. 2020;117(2):175-181.
19. Saugstad OD, Rootwelt T, Aalen O. Resuscitation of asphyxiated newborn infants with room air or oxygen: an international controlled trial: the Resair 2 study. Pediatrics. 1998;102(1):e1.
20. Ersdal HL, Eilevstjonn J, Perlman J, et al. Establishment of functional residual capacity at birth: observational study of 821 neonatal resuscitations. Resuscitation. 2020;153:71-78.
21. Bjorland PA, Ersdal HL, Haynes J, Ushakova A, Oymar K, Rettedal SI. Tidal volumes and pressures delivered by the NeoPuff T-piece resuscitator during resuscitation of term newborns. Resuscitation. 2022;170:222-229.
22. Linde JE, Schulz J, Perlman JM, et al. The relation between given volume and heart rate during newborn resuscitation. Resuscitation. 2017;117:80-86.

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