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Clinical paper

Newborn resuscitation timelines: Accurately capturing treatment in the delivery room

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Abstract

Objectives: To evaluate the use of newborn resuscitation timelines to assess the incidence, sequence, timing, duration of and response to resuscitative interventions.

Methods: A population–based observational study conducted June 2019–November 2021 at Stavanger University Hospital, Norway. Parents consented to participation antenatally. Newborns ≥28 weeks' gestation receiving positive pressure ventilation (PPV) at birth were enrolled. Time of birth was registered. Dry-electrode electrocardiogram was applied as soon as possible after birth and used to measure heart rate continuously during resuscitation. Newborn resuscitation timelines were generated from analysis of video recordings.

Results: Of 7466 newborns ≥28 weeks' gestation, 289 (3.9%) received PPV. Of these, 182 had the resuscitation captured on video, and were included. Two-thirds were apnoeic, and one-third were breathing ineffectively at the commencement of PPV. PPV was started at median (quartiles) 72 (44, 141) seconds after birth and continued for 135 (68, 236) seconds. The ventilation fraction, defined as the proportion of time from first to last inflation during which PPV was provided, was 85%. Interruption in ventilation was most frequently caused by mask repositioning and auscultation. Suctioning was performed in 35% of newborns, in 95% of cases after the initiation of PPV. PPV was commenced within 60 s of birth in 49% of apnoeic and 12% of ineffectively breathing newborns, respectively.

Conclusions: Newborn resuscitation timelines can graphically present accurate, time-sensitive and complex data from resuscitations synchronised in time. Timelines can be used to enhance understanding of resuscitation events in data-guided quality improvement initiatives.

Keywords: Newborn resuscitation, Positive pressure ventilation, Dry-electrode ECG, Compliance with guidelines, Heart rate, Newborn resuscitation timelines

Introduction

Ventilation is considered the single most important step in newborn resuscitation.[1,2] Between 3–10% of newborns fail to initiate spontaneous breathing and receive positive pressure ventilation (PPV) at birth.[1–5] Advanced resuscitation including intubation, cardiac compressions or drugs is rare.[2,6] Initiation of PPV is time-critical and the risk of mortality and morbidity rises with prolonged apnoea.[7] Newborn resuscitation algorithms and guidelines begin at the time of birth, and are focused on the sequence, timing and duration of interventions.[2,8]

Although clinical research on newborn resuscitation has accelerated over recent decades to inform resuscitation algorithms and guidelines,[9–12] automated capture, storage, and synchronisation of objective data from resuscitations are limited. Documentation of resuscitations is often inaccurate or incomplete,[13–16] and this leads to gaps in the literature on newborn resuscitation. Prospective population-based studies including timing and duration of events and evaluation of physiological responses to treatment are needed.[1]

Since 2019, the Safer Births Stavanger research consortium has systematically captured data from consecutive delivery room resuscitations, including audio–video recordings of the resuscitation table

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

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and HR data captured by dry-electrode electrocardiogram (ECG).[17] Dry-electrode ECG correlates well to standard 3-lead ECG, and provides heart rate (HR) faster and more continuously during resuscitation.[18–21] Using automated objective data capture, individual resuscitations can be presented graphically as "newborn resuscitation timelines", to contextualise resuscitation actions and responses for easy evaluation, debrief, and learning.

The objectives were to use newborn resuscitation timelines to visualise and describe the incidence, sequence, timing and duration of resuscitative interventions, physiological responses to treatment, as well as evaluate compliance with guidelines.

Methods

Study design and setting

This prospective population-based observational study was conducted from 6 June 2019 through 16 November 2021 at Stavanger University Hospital, Norway. The rate of prematurity (<37 weeks' gestation) is 5.5%. The caesarean section and vacuum assisted delivery rates are 16% and 11%, respectively.

Newborns in need of resuscitation are carried on average 10 m to adjacent resuscitation rooms in the labour ward and the operating theatre. Resuscitation algorithms recommend starting PPV no later than 60 s after birth if (i) the newborn fails to establish effective breathing following tactile stimulation, (ii) the HR is <100 beats per minute (bpm) and does not increase, or (iii) the HR decreases if initially acceptable.[2] If the HR decreases to <100 bpm, ventilation corrective steps or advanced airway placement should be performed. Chest compressions are recommended if HR is <60 bpm despite at least 30 s of adequate ventilation.[2,9]

Healthcare providers (HCPs) undergo yearly off-site neonatal resuscitation training, in addition to fortnightly in-situ multidisciplinary team training sessions for the team on call. Anticipated resuscitations are attended by a paediatric resident, with the addition of a neonatologist and a neonatal nurse for complicated resuscitations. For unanticipated resuscitations, PPV is initiated by midwifery or anaesthetic staff. PPV is mostly provided using a flow-driven T-piece resuscitator (NeoPuff, Fischer and Paykel, Auckland, New Zealand). A self-inflating bag (Laerdal Medical, Stavanger, Norway) is occasionally used as an alternative due to clinician preference or if the infant fails to respond to T-piece. Humidified gas is not available in the delivery room. Initial pressures and fraction of inspired oxygen are set at 30/5 cm H_2O and 0.21 in term newborns, and 25/5 cm H_2O and 0.30 in newborns <32 weeks gestation.

Inclusion and exclusion

Informed parental consent was obtained during the visit for routine ultrasound screening week 18–20 during pregnancy or on admission at the onset of labour. Newborns with gestational age $\geq$28 weeks who received PPV within 10 min of birth, whose resuscitation was captured on video and exact time of birth registered, were eligible for inclusion. Exclusion criteria were congenital malformation interfering with placement of the dry-electrode HR sensor NeoBeat (Laerdal Global Health, Stavanger, Norway) or if HCPs requested the resuscitation video to be deleted.

Data collection

Time of birth was registered by the midwife assistant using the Liveborn app (Laerdal Medical, Stavanger, Norway) on a portable tablet. Late cord clamping ($\geq$30–60 s) was standard care.[2,8] NeoBeat was placed on all newborns in the delivery room immediately after birth and remained in place throughout the resuscitation. HR was recorded every second and stored for later analysis in the Liveborn app. In apnoeic or ineffectively breathing newborns not responding to drying and stimulation, the umbilical cord was clamped and cut, and the newborn carried to the resuscitation room with the wireless NeoBeat attached. HCPs were instructed to apply additional standard monitoring with 3-lead gel-electrode ECG and pulse oximetry in ventilated newborns. Videos of the resuscitations were recorded using motion sensor cameras placed above the resuscitation tables, capturing images of the newborn and hands of the HCPs. The timestamp in the video server and Liveborn app were synchronised daily. Video recordings of the resuscitations were reviewed by one or more investigators (VK, SR, HP) using ELAN 5.8 tool (The Language Archive, Nijmegen, Netherlands). The time of initiation and discontinuation of PPV, as well as those of stimulation, suction, intubation, chest compression, and administration of epinephrine were extracted from the video recordings. The breathing efforts at the start of PPV were evaluated from the video recordings, and categorised as adequate, ineffective (grunting or severe retractions), or absent. Patient characteristics were extracted from the digital medical records.

Definitions

The domains for reporting neonatal resuscitations were adapted from those recently published in "Recommended Guideline for Uniform Reporting of Neonatal Resuscitation: The Neonatal Utstein Style".[11] For the purpose of this study, we included resuscitations involving the provision of PPV within 10 min of birth. Stimulation was defined as repetitive, tactile rubbing of the newborn's torso. Suctioning was defined as the time from the tip of the catheter first being passed into the nostril or mouth until its' exit. Ventilation fraction during PPV was defined as the cumulative number of seconds of PPV, divided by the total duration from the first to the last inflation. An advanced neonatal resuscitation was defined as one including any of endotracheal intubation, chest compression or epinephrine. The duration of intubation was defined as the time between the laryngoscope entering the mouth and its' removal.

Statistical analyses

NeoBeat HR data processing, data point extraction and statistical analysis were performed, and newborn resuscitation timelines generated using MATLAB R2023a (MathWorks, Natick, MA) and R version 4.2.2 (R Core Team). Continuous data were summarised using median and quartiles, categorical data using numbers and proportions. The Wilcoxon Rank Sum test was used for continuous variables and the Fisher exact test for categorical variables to test for differences between patient groups. Tests with a p-value <0.05 were considered statistically significant.

Ethical approvals

The study was approved by the Norwegian regional ethical committee (ref. 2018/338 and 222455)) and was registered in ClinicalTrials.gov (NCT03849781).

Results

Consent for participation was provided from parents of 7466 newborns of $\geq$28 weeks gestation, of whom 289 (3.9%) received PPV.

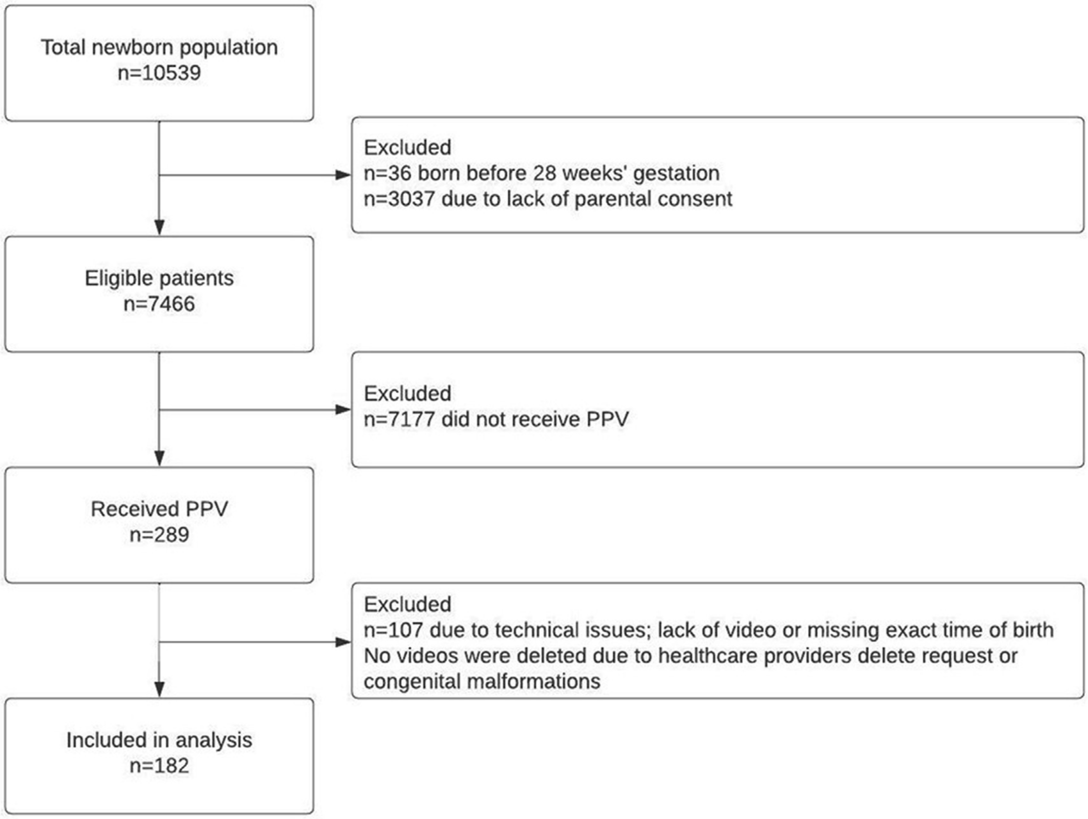

Fig. 1 – Flow diagram showing enrolment of participants. PPV = positive pressure ventilation.

Table 1 – Patient characteristics of the 182 newborns included in the analysis. Characteristics are reported as median (quartiles) or count (%).

Breathing status at start PPV	Apnoeic n = 125	Ineffectively breathing n = 57	p-value
Gestational age (Weeks)	40 (38, 41)	39 (38, 40)	0.4
Birth weight (g)	3584 (2960, 3984)	3358 (2954, 3680)	0.063
Mode of delivery			0.004
Vaginal delivery	24 (19%)	12 (21%)	
Vaginal assisted delivery	52 (42%)	13 (23%)	
Planned caesarean section	16 (13%)	19 (33%)	
Acute caesarean section	33 (26%)	12 (21%)	
Sex female	54 (43%)	31 (54%)	0.2
APGAR			
APGAR 1	4 (3, 6)	6 (5, 7)	<0.001
APGAR 5	7 (6, 9)	7 (6, 8)	0.8
APGAR 10	9 (8, 10)	9 (8, 10)	0.4
Umbilical cord values			
Arterial pH	7.18 (7.11, 7.25)	7.22 (7.14, 7.26)	0.2
Arterial BE	4.80 (2.36, 6.26)	2.84 (0.88, 6.22)	0.035
Arterial pCO2	8.15 (7.06, 9.84)	8.16 (7.24, 9.19)	0.8

1 Median (quartiles); n (%)
2 PPV = Positive pressure ventilation

In total, 182 (63%) newborns had their resuscitation captured on video and time of birth registered in the Liveborn app and were included (Fig. 1). The majority were near-term or term newborns, with 155 (85%) born at term, 17 (9.3%) born between week 34 + 0–36 + 6 and 10 (5.5%) <34 weeks gestation. Patient characteristics are presented in Table 1. Newborn resuscitation timelines visualising key interventions such as stimulation, provision of PPV, suctioning, chest compressions, and intubation in the first ten minutes relative to the time of birth among apnoeic and ineffectively breathing newborns are presented in Fig. 2a and b, respectively. In Fig. 3, physiological HR response to treatment has been added to the resuscitation timelines.

Stimulation and assessment of heart rate

The newborns were placed on the resuscitation table at median (quartiles) 44 (29, 70) seconds after birth. Stimulation preceded PPV in 146 (80%) newborns after placement on the resuscitation table. HR was assessed by clinicians using NeoBeat, standard ECG, pulse oximetry or auscultation in 167 (92%) newborns before starting PPV. NeoBeat HR signals at 60 ± 5 s were median (quartiles) 145 (90, 166) bpm. HR immediately before starting PPV was 122 (77, 160) bpm.

Positive pressure ventilation

Based on review of 182 video recordings, 125 (69%) of ventilated newborns were apnoeic, and 57 (31%) were breathing ineffectively immediately before commencement of PPV. PPV was commenced at a median (quartiles) 72 (44, 141) seconds after birth, 61 (40, 89) seconds among apnoeic and 141 (91, 223) seconds among ineffectively breathing newborns, $p < 0.001$. Among apnoeic and ineffectively breathing newborns 37 (30%) and 34 (60%) respectively received CPAP before provision of PPV. PPV continued for 135 (68, 236) seconds from the start of the first to the end of the last inflation. The median ventilation fractions for apnoeic and ineffectively breathing newborns were 85% (69%, 94%) and 70% (49%, 89%),

Fig. 2 – a) Resuscitation practices among newborns apnoeic at start ppv (n = 125). b) Resuscitation practices among newborns breathing ineffectively at start PPV (n = 57). Resuscitation practices among 182 newborns. Each horizontal row represents an individual newborn from the time of birth and for the first consecutive ten minutes. Newborns are sorted by time from birth to start PPV, the vertical orange line representing 60 s. Time before the newborn was placed on the resuscitation table is marked in grey. Provision of PPV is illustrated in orange, stimulation in green, suctioning in blue, chest compressions in red and intubation in pink lines. Fig. 2a) Apnoeic newborns at start PPV, and b) ineffectively breathing newborns at start PPV. PPV= positive pressure ventilation.

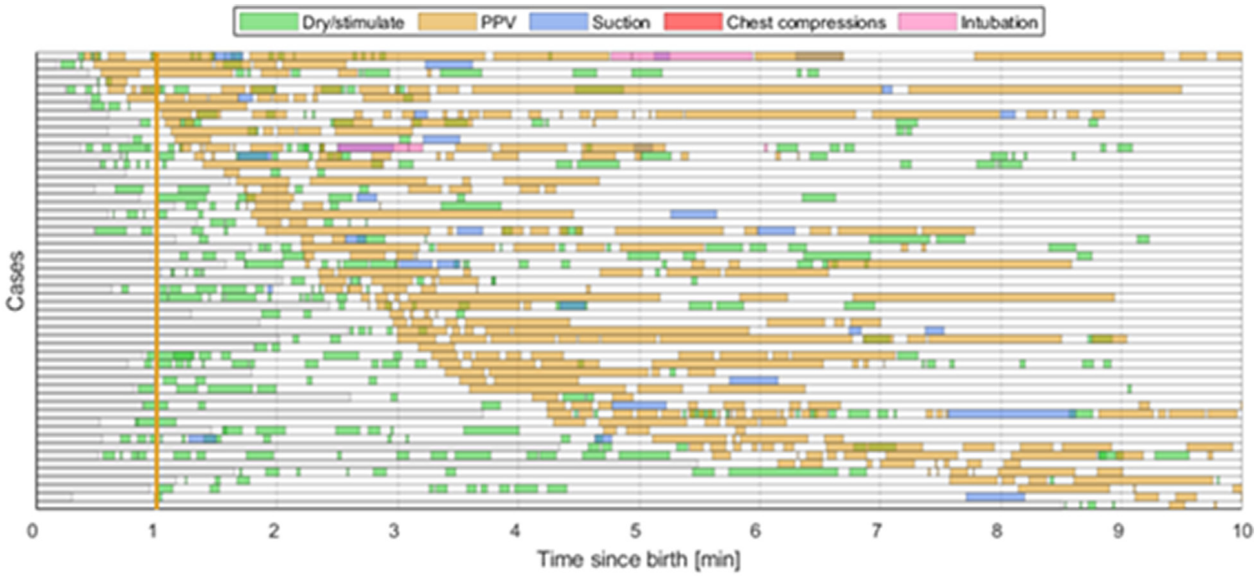

Fig 2. (continued)

respectively. In 68 (37%) newborns, PPV was started within 60 s after birth. Among apnoeic newborns 61 (49%) started PPV within 60 s, compared to 7 (12%) of ineffectively breathing newborns.

In 156 (86%) newborns, PPV was interrupted. Interruptions were mainly due to mask repositioning (59%), cardiac auscultation (19%), and CPAP (17%). Differences between apnoeic and ineffectively breathing newborns are shown in Table 2.

Suctioning

Suctioning was performed on 64 (35%) newborns. The median (quartiles) duration of each suctioning episode was 28 (18, 48) seconds. Total duration of suctioning ranged from 5 to 430 s. In 61 (95%) newborns, PPV preceded suctioning.

Advanced resuscitation

Advanced resuscitation was performed on 16 (8.7%) newborns. In total, 8 were intubated and did not receive chest compressions, 5 received chest compression without intubation and 3 were both intubated and received chest compressions. Chest compressions started at a median (quartiles) 152 (142, 313) seconds from birth, after 107 (95, 198) seconds of PPV, and lasted for 49 (37, 88) seconds. HR signal at the start of chest compressions was available for 6/8 newborns, with median (quartiles) 56 (56, 132) bpm. In 2 of these 6 cases, HR was $\geq$60 bpm when chest compressions were commenced. The HR immediately after chest compressions were ceased was 83 (64, 169) bpm in the five cases where HR was available. Intubation was performed in 11 newborns. Median (quartiles) intubation attempts per newborn was 2 (1, 2), with duration per attempt being 23 (8, 40) seconds. One newborn received epinephrine. In 4 of 16 cases, advanced resuscitation commenced more than ten minutes from birth, and these are not shown in Fig. 2.

Discussion

In this population-based study, innovative newborn resuscitation timelines were generated from 182 consecutive resuscitations to graphically present incidence, sequence, timing, duration of, and HR responses to resuscitative interventions, as well as compliance with guidelines. Timelines may represent a useful strategy for recording and reviewing complex situations such as newborn resuscitations.[18,22,23]

Incidence

The incidence of PPV was 3.9%, similar to reports from other high resource settings.[1–5] Although the proportion of newborns who receive ventilation increases at lower gestations, the majority of resuscitated newborns are late-preterm or term.[4,5,24,25] Respiratory failure at birth may be due to several causes. Term newborns are more likely to have apnoea secondary to birth asphyxia, whereas immature newborns more often breathe spontaneously but fail to establish effective ventilation.[1,8,12] We report a large variability in the interval between birth to commencement of PPV overall and particularly between apnoeic (Fig. 2a) and ineffectively breathing (Fig. 2b) newborns. These cohorts may require different resuscitation algorithms.

Stimulation and assessment of heart rate

Treatment recommendations for newborns who are not breathing within the first minute of life include tactile stimulation, largely based on expert opinions.[2,8,26] The most recent publication from ILCOR 2022 concluded that tactile stimulation should not delay the initiation of PPV for newborns who continue to have absent, intermittent, or shallow respirations after birth.[8] We found that the majority of newborns were stimulated on the resuscitation table prior to PPV, but we do not have information on the extent of stimulation in the delivery room.

HR is one of the main drivers in the newborn resuscitation algorithm and should be assessed early. At our hospitals, newborns have NeoBeat placed in the delivery room, providing continuous HR data from birth and throughout the resuscitation.[27] Almost all newborns had HR assessed prior to commencing PPV. It is not known if early feedback on newborn HR improves outcomes.[9,17]

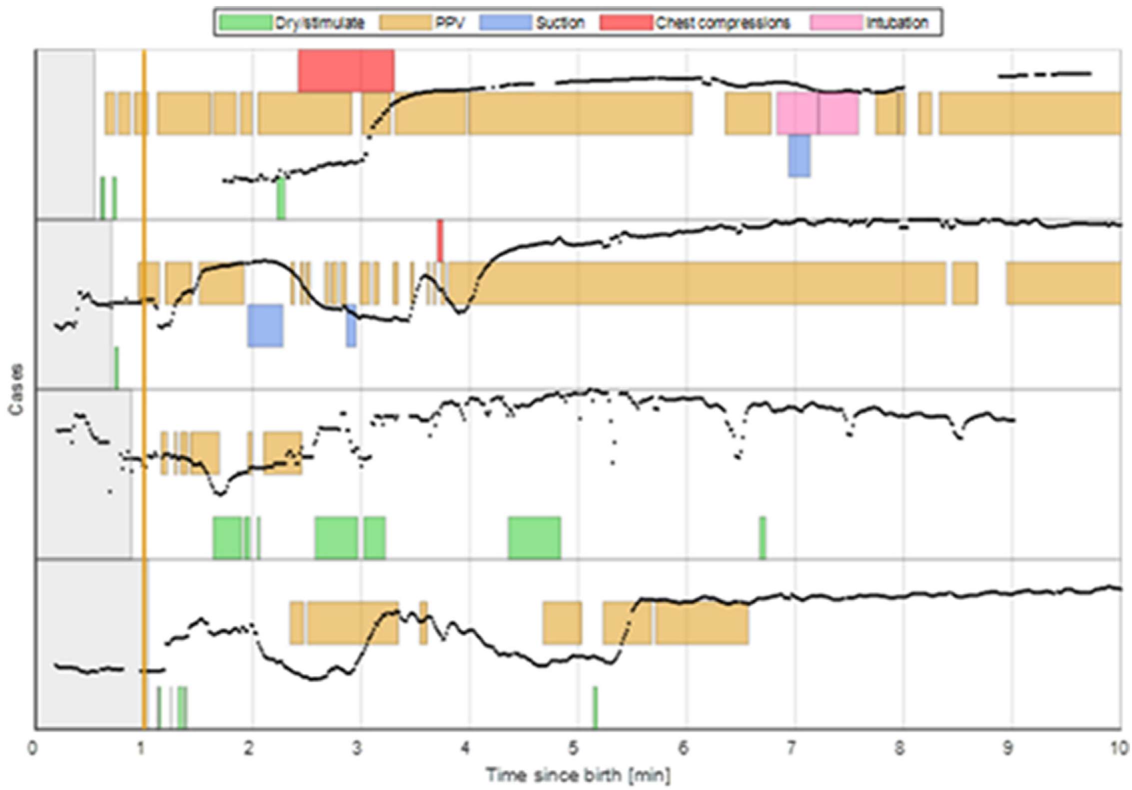

Fig. 3 – Visualisation of resuscitation timelines in four individual cases. Physiological heart rate response shown in black lines, ranging from 0–200, with the horizontal centre representing 100 bpm. Case 1. Apnoeic newborn that remains bradycardic after relatively continuous ventilation for more than two minutes. Chest compressions started on indication with an announced effect on HR. Compressions ceased when HR normalised. Intubation followed to secure airway due to continued need for ventilation. Case 2. Apnoeic newborn with HR approximately 100 bpm one minute after birth. HR increased initially during ventilation, followed by a significant drop during suction. Interrupted ventilation with frequent mask repositioning after suctioning was accompanied by bradycardia. A few chest compressions provided, although not indicated. After another 20 s of continuous PPV, a response with increase in HR was observed. Case 3. Initially high HR in the first minute after birth, ventilation started due to apnoea. Ineffective ventilations initially with a drop in HR. After stimulation and 20 s of continuous PPV the HR increased rapidly over the next 30 s. Case 4. Initially HR <100 bpm in an ineffectively breathing newborn. HR increased rapidly after 30 s of continuous PPV. However, when PPV was paused for evaluation of spontaneous breathing, the newborn again became bradycardic. The newborn responded with rapid increase in HR after PPV was started again. Case examples of how timelines from newborn resuscitations can be used to understand timing, duration, and effect of resuscitative interventions. Same colour definitions as Fig. 2.

Table 2 – Associations between breathing status at start of PPV and resuscitation characteristics.

Breathing status at start PPV	Apnoeic	*n*	Ineffectively breathing	*n*	*p*
Time to cord clamp [s]	53 (18, 186)	76	36 (16, 84)	37	0.24
Time to placement on resuscitation table [s]	41 (28, 65)	125	53 (32, 97)	57	0.024
Time to first HR [s]	31 (15, 53)	110	42 (19, 96)	49	0.043
First measured HR [bpm]	120 (86, 156)	110	140 (102, 172)	49	0.050
HR at 60 s [bpm]	135 (85, 161)	69	158 (128, 170)	28	0.058
HR at start PPV [bpm]	118 (74, 158)	62	136 (80, 166)	36	0.34
Newborns receiving PPV within 60 s of birth [%]	49 (61 of 125)	125	12 (7 of 57)	57	<0.001
Time to start PPV [s]	61 (40, 89)	125	141 (91, 223)	57	<0.001
Duration of PPV [s]	129 (69, 226)	125	155 (63, 346)	57	0.42
Ventilation fraction [%]	85 (69, 94)	125	70 (49, 89)	57	0.01
1 Median (IQR); n (%)					

The variation in n is due to missing data at the respective timepoints. HR was not registered by NeoBeat in 23 of the resuscitated newborns. s = seconds.

Positive pressure ventilation

Niles et al studied 64 resuscitations in a tertiary academic hospital in the US where the median time to be moved to the resuscitation table was 20 seconds after birth. In newborns receiving PPV, assistance was initiated within 60 s after birth in only 45%. The duration of PPV was <120 s in 60% of newborns.[5] It is interesting that we identified different treatment approaches in apnoeic and ineffectively breathing newborns, with 49% and 12% receiving PPV within 60 s after birth, respectively. Although no effect of delayed initiation of PPV on mortality has been demonstrated in high-resource settings, rates of mortality/morbidity increased by 16% for each additional 30 s delay in starting of PPV in a study performed in a low resource setting.[7] We cannot speculate to events prior to placement on the resuscitation table, but to better understand evaluation and initial steps, while upholding privacy protection, we have now implemented thermal video in the delivery room.[28]

The median duration of PPV was relatively short at 135 s, probably indicating that most newborns were not severely asphyxiated. Interruptions to ventilation were common, and mostly caused by mask repositioning, auscultation, or CPAP. We observed that CPAP was probably offered during evaluation of the newborn and as a step-down treatment after PPV. This was in contrast to a low-resource setting, where excessive suctioning and stimulation caused delayed initiation of and interruption to ventilation.[22] In that study, newborn resuscitation timelines indicated that median time from birth to start bag-mask ventilation was more than five minutes.

Suctioning

Recommendations from the International Liaison Committee on Resuscitation (ILCOR) suggest that suctioning of clear amniotic fluid from the nose and mouth should not be routine but should be considered if airway obstruction is suspected.[8,29] In our population, one-third of newborns received suctioning. Ninety-five per cent of suctioning occurred after the initiation of PPV and hence did not delay the commencement of ventilation.

Advanced resuscitation

Yamada et al. studied audio–video recordings of 23 advanced resuscitations and concluded that errors were common during neonatal resuscitation and were potentially harmful.[30] In the current study, chest compressions were performed after at least 30 s of ventilation, and in four of six cases HR was <60 bpm in line with the algorithm. The median duration of compressions was short at 49 s, and in all five cases for which HR was available when chest compressions ceased, HR was >60 bpm. Newborn cardiac compression recommendations are primarily based on physiologic plausibility, data from adults, and experimental neonatal simulation and animal models.[31]

The indications for intubation remain a knowledge gap. Routine intubation for meconium-stained amniotic fluid or prior to commencing respiratory support is not recommended but may be considered if airway obstruction is suspected.[8] Half of the newborns receiving advanced resuscitations in our population were intubated. Intubation attempts were always preceded by ventilation. The time taken to intubate, corresponding to the duration of interruption of ventilation, was similar to those reported in other studies.[32,33]

Potential uses of newborn resuscitation timelines

Deviation from guidelines has been demonstrated in several studies both from high- and low-resource settings, using video- [3,28–31] or direct observations of newborn resuscitations.[5,7,22] Traditionally, newborn resuscitations have been documented after the event, often inaccurately.[13–16 22,34] When work-as-done does not align with work-as-imagined, the potential learning opportunity from each resuscitation is limited. Although newborn resuscitation occurs frequently, each individual HCP is exposed to a limited number of events, and it is crucial “to make every resuscitation a learning event”.[35] Debriefs and audits using video and physiological recordings from newborn resuscitations are shown to improve performance.[13,36] Capturing and storing physiological parameters in a more accurate, consistent and systematic manner may be the first step to data-guided continuous quality improvement. Vadla et al. documented improved time to start PPV and more continuous PPV after implementation of targeted simulation trainings based on real-life resuscitation data.[37,38]

In contrast to adult cardiac arrest registries, no global newborn resuscitation register exists.[39] This lack of accountability and benchmarking may represent a missed opportunity to improve a culture of safety.[35] Newborn resuscitation timelines generated from manual annotations of video recordings have recently been used to uncover delay and interruption in ventilation due to excessive suctioning, and for evaluation of HR monitoring practices during newborn resuscitation.[18,23,35] In order to apply data-guided learning at a system level, data capture must be generic and automated without the need for complex pre-processing. Newborn resuscitation timelines can be used to contextualise performance and outcomes, aid in closing the knowledge-do gaps, drive new insight that inform guidelines, be used for case reviews, in clinical debriefs, targeted in-situ simulations, benchmarking, trending and documentation to potentially change the experiences of providing and receiving care.

Limitations and generalisability

A limitation to this study was the loss of data due to technical challenges with missing video frames and server failure. These occurred at random and should not bias the overall results. Times of birth were registered manually by a HCP, making them prone to human error. The incidence of PPV was similar to that previously reported in high-resource settings, however, the number of severely compromised and asphyxiated newborns requiring advanced resuscitation was low. The results may be less generalisable to settings with higher rates of birth asphyxia.

Conclusions

Newborn resuscitation timelines can graphically present a large dataset of objective, time-sensitive and complex data from resuscitations, time-synchronised and starting at birth. Timelines can be used to enhance understanding and the evaluation of the resuscitation process in data-guided quality improvement initiatives.

CRediT authorship contribution statement

Hanne Pike: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Vilde Kolstad:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis, Data curation. **Joar Eilevstjønn:** Writing – review & editing, Visualization, Resources, Formal analysis, Data curation. **Peter G. Davis:** . **Hege Langli Ersdal:** Writing – review & editing, Visualization, Supervision, Methodology, Funding acquisition, Conceptualization. **Siren Irene Rettedal:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Joar Eilevstjønn is a Laerdal Medical employee. Siren Rettedal and Hanne Pike had unconditional research grants from Laerdal Foundation, Stavanger, Norway [grant numbers 5007, 2023-0087]. The other authors have no conflicts of interest to disclose. The funder had no role in the design and conduct of the study.].

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