Improving neonatal resuscitation at birth : technique and devices

Schilleman, K.

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Breathing during mask ventilation of preterm infants at birth

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Submitted

Abstract

Objective

To evaluate breathing during mask ventilation of preterm infants at birth and how it related to inflations.

Methods

Breathing was studied in infants < 32 weeks' gestation receiving positive pressure ventilation (PPV) with sustained inflations (SIs), and consecutive inflations (CIs) via a facemask in the first five minutes of respiratory support. Airway pressure, gas flow, tidal volume, heart rate and oxygen saturation were measured and the resuscitation was video-recorded. Breathing was identified and waveforms were divided into independent breaths or breaths coinciding with an inflation. Expired tidal volume (V_{Te}) was compared.

Results

In 27 infants (median (IQR) gestational age 29 (27–31) weeks) breathing occurred in 24/27 infants (89%); 18/27 (67%) during SIs and 18/22 (82%) during CIs. Per infant, we analysed a median (IQR) of 50 (15–97) inflations, 2 (0–4) breaths between inflations and 4 (2–7) breaths coinciding with an inflation. During SIs the V_{Te} of breaths, breaths coinciding with inflations, and inflations were 2.8 (0.7–4.6) mL/kg, 3.9 (0.0–7.7) mL/kg and 0.8 (0.0–5.6) mL/kg. During CIs the V_{Te} were 3.3 (2.1–6.6) mL/kg, 4.6 (2.1–7.8) mL/kg and 3.7 (1.4–6.7) mL/kg, respectively.

Conclusion

Most preterm infants breathe during PPV after birth and the V_{Te} of breaths was similar to the inflations. The presence of breathing contributed to the resuscitation.

Introduction

Very preterm infants with impaired lung liquid clearance may have difficulties creating adequate lung volume and gas exchange.[1,2] Approximately 60% of very preterm infants require resuscitation at birth,[3] at which time adequate ventilation is crucial.[4,5] Positive pressure ventilation (PPV) given via a facemask is frequently used as the primary intervention. The technique of mask ventilation requires considerable practice and experience to apply it safely and effectively.[6,7] Studies in manikins[6-8] and infants[9,10] have shown that mask ventilation is often impeded by large mask leak which leads to low tidal volumes.

Sustained inflations (SIs) can be given during the initial support to help aerate the preterm lung at birth,[11] followed by consecutive inflations (CIs) of shorter duration if required.

We know that most very preterm infants breathe immediately after birth.[12] Breathing at birth has also been shown in infants with congenital diaphragmatic hernia.[13] Breathing in preterm infants is very difficult to observe when solely judged by chest excursions.[14,15] Their breaths might either contribute to the effect of resuscitation or counteract the inflations.

The aim of this study was to evaluate how often preterm infants' breathing occurred during PPV and how it related to inflations.

Methods

This prospective observational study was performed at the department for neonatal intensive care of the Leiden University Medical Center, a tertiary level perinatal care centre in Leiden, the Netherlands, with an average of 400 intensive care admissions per year.

Infants with a gestational age < 32 weeks were included if time allowed to set up the recording equipment. Infants were included in the study if PPV was given via a face mask immediately after birth. We excluded recordings of infants who received CPAP only or no respiratory support, and infants who received PPV via nasopharyngeal tube. Both face mask and nasal tube are frequently used interfaces for PPV in the delivery room and the choice of interface was made by the caregiver according to personal preference.

Recording equipment

PPV was given with a T-piece infant resuscitator (Neopuff, Fisher & Paykel Healthcare, Auckland, New Zealand) in combination with a round silicone facemask in the appropriate size for infant weight (Laerdal, Stavanger, Norway). All included infants received heated and humidified gas using a MR850 heated humidifier (Fisher & Paykel Healthcare, Auckland, New Zealand). PPV was performed according to Dutch guidelines, starting with five initial SIs lasting 2–3 seconds using a peak inflating pressure (PIP) of 20 cm H_2O and a positive

end expiratory pressure (PEEP) of 5 cm H_2O, a gas flow rate of 8 L/min and air.[4,16]
Respiratory interventions and parameters were recorded using a webcam for video monitoring and a Florian neonatal respiratory function monitor (Acutronic Medical Systems, AG, Switzerland). It has a small hot wire anemometer (dead space < 1 mL), placed between the T-piece and the mask, to measure gas flow in and out of the mask. This signal was automatically integrated to measure inspired and expired tidal volume. The difference equals the leak from the mask. It also measured respiratory rate, minute volume and all ventilation pressures. The monitor was always turned on to prevent electronic drift. The flow sensor was calibrated each time recordings were made. Pressure was measured from the distal section of the T-piece tubing. Using a respiratory monitor was in our local guidelines, if time allowed it to be set up. The resuscitators were not blinded to the respiratory monitor but our experience was that they almost never looked carefully at the monitor during the resuscitation. The clinicians were not told by the research team what the monitor showed to minimise bias to the study.
Oxygenation and heart rate were measured with a Masimo SET pulse oximeter (Masimo Radical, Masimo Corporation, Irvine CA, USA). A probe was placed around each infant's right wrist. The signals of gas flow, tidal volume, ventilatory pressure, oxygen saturation and heart rate were digitised and recorded at 200 Hz using a neonatal respiratory physiological recording program (Spectra, Grove Medical Limited, Hampton, UK).

Data collection

Demographic data were collected from hospital records. The first five minutes of respiratory support were analysed using airway pressure, gas flow and tidal volume. A breath-by-breath analysis was performed manually to identify one of the three following respiratory patterns:

Inflation

An inflation was characterised by an inspiratory flow simultaneous with an obvious increase in airway pressure from an inflation. The start of expiratory flow was synchronous with the end of the inflation when airway pressure starts to return to the PEEP pressure (figure 1).[13]

Breath

A breath was characterised by an inspiratory and expiratory flow in absence of a concurrent pressure wave from an inflation. These breaths occurred in between inflations and during CPAP. They were often associated with a simultaneous reduction in PEEP (figure 2).[13]

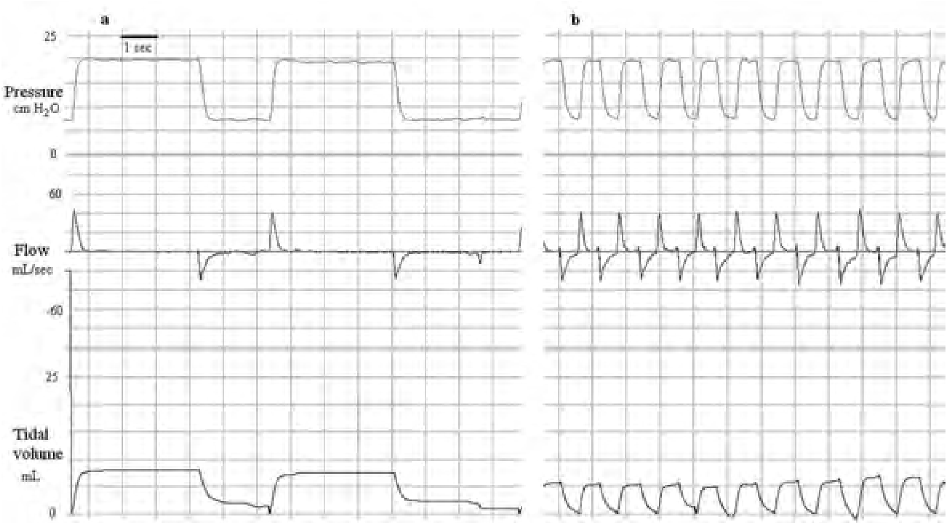

Figure 1. Two examples of manual inflations. (a) The first SI is characterised by an expired tidal volume (V_{Te}) of 7 mL/kg and a facemask leak of 22%, the second SI by a V_{Te} of 7.2 mL/kg and a facemask leak of 11%. (b) In this recording ten consecutive inflations can be seen. In this CI the V_{Te} varies between 5–7 mL/kg and there is minimal facemask leak.

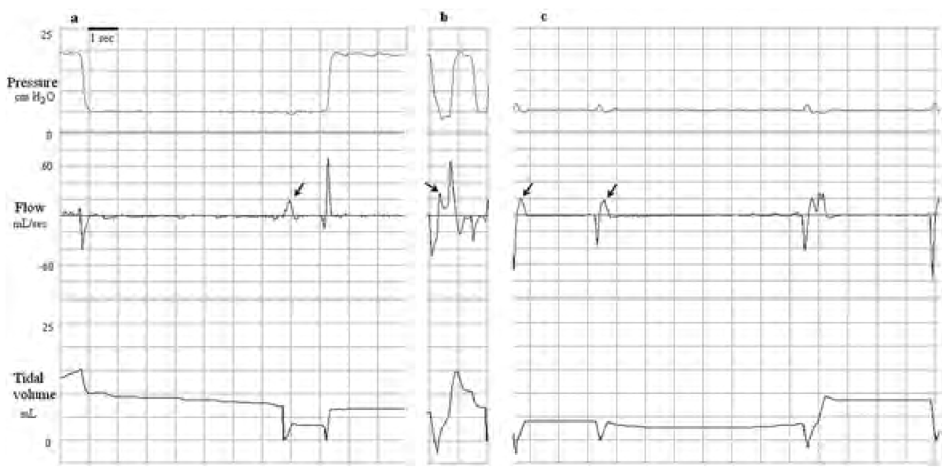

Figure 2. Three examples of breaths. (a) A breath occurs between sustained inflations (arrow) with an expired tidal volume (V_{Te}) of 8.1 mL/kg and a facemask leak of 0%. (b) A breath is taken between consecutive inflations (arrow) with a V_{Te} of 3.2 mL/kg and a facemask leak of 53%. (c) An infant is breathing while on CPAP (arrows) of 5 cm H_2O. The first and second breaths have a V_{Te} of 3.2 and 5.1 mL/kg, respectively, and a facemask leak of 0%.

Breath coinciding with an inflation

A breath coinciding with an inflation was characterised by a breath adjacent to an inflation, or by a breath during an inflation. There were two coincidental inspiratory flow patterns resulting in one volume wave (figure 3).[13]

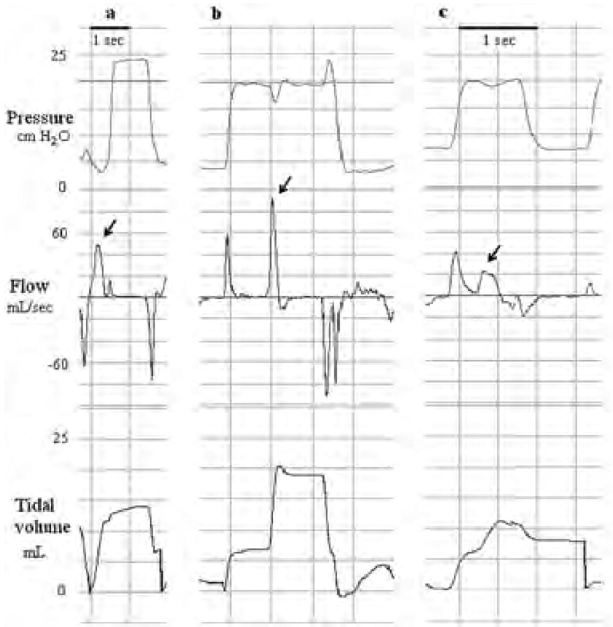

Figure 3. Three examples of breaths coinciding with an inflation, adjacent to, or synchronised with an inflation. (a) Inspiratory flow starts before the inflation, the PEEP is reduced, when the inflation starts this produces a small second peak in inspiratory flow. The expired tidal volume (V_{Te}) is 7.7 mL/kg and the facemask leak is 46%. (b) A breath occurred during a 2.5 s sustained inflation (arrow) observed as a second peak in inspiratory flow and decrease in pressure, but resulting in one volume wave with a V_{Te} of 21 mL/kg. (c) Breathing occurs during a one second inflation (arrow), with a V_{Te} of 4.2 mL/kg and a facemask leak of 62%.

Each recording was analysed for the occurrence and timing of breaths with or without coinciding inflations during the first five minutes of resuscitation. The number of breaths during SIs was noted. The amount of breaths during CIs was investigated according to the following categories; none (no breaths per 10 inflations), occasionally (< 3 breaths per 10 inflations), obvious/irregular (3–7 breaths per 10 inflations) and regular (> 7 breaths per 10 inflations).

Statistical analysis

Data were analysed using SPSS (SPSS for windows, version 16.0, 2008, Chicago, Ill., USA). Results are presented as mean (standard deviation (SD)) or median (interquartile range (IQR)) where appropriate. Expired tidal volumes of the three different types of breaths were compared using Kruskal-Wallis test and Mann-Whitney U test for post hoc comparison. Statistical significance was defined as $p < 0.05$. Reported p values are two-sided.

The study was approved by the Institutional Review Board of the hospital. When possible, parental consent to record the resuscitation was obtained antenatally. Otherwise, a waiver of consent was used to record the resuscitation and parental consent to use the data was obtained afterwards.

Results

From March 2009 to October 2010 we recorded 57 resuscitations of very preterm infants. Thirty were excluded because they did not meet the inclusion criteria for this study: in 14 infants (25%) a nasopharyngeal tube was used as interface, 8 received only CPAP and 3 infants did not require resuscitation/respiratory support. In 4 infants recordings were incomplete due to technical problems during the recordings and 1 infant had a gestational age > 32 weeks. Thus, 27 infants were included in the study. The baseline characteristics of these infants are presented in table 1 and 2.

Table 1. Baseline characteristics of the infants

Infant characteristics (n=27)	
Birth weight (grams)*	1200 (985–1418)
Gestational age (weeks)*	29 (27–31)
Male gender†	14 (52%)
Caesarean section†	18 (67%)
Apgar score 1 min*	5 (3–6)
Apgar score 5 min*	7 (6–8)
Antenatal steroids†	17 (63%)

Data are presented as * median (IQR) or † n (%)

Table 2. Apgar score, heart rate and oxygen saturation, if recorded

Apgar score, heart rate and oxygen saturation (n=27)				
	1 min	**3 min**	**5 min**	**10 min**
Apgar score	5 (3–6)	N/A	8 (6–8)	9 (8–9)
Heart rate (/min)	60 (49–111)	140 (103–154)	146 (110–164)	N/A
Oxygen saturation (%)	54 (41–64)	57 (45–66)	82 (53–90)	N/A

Data are presented as median (IQR). N/A = not available

Respiratory support

All 27 infants received initial SIs. In 21/27 (77%) inflations were continued (CIs) and the other 6 infants only received CPAP after SIs. The median PIP was 20.6 (19.3–24.9) cm H_2O and PEEP was 3.9 (3.2–4.6) cm H_2O. In two infants PIP was increased by 5 cm H_2O during the resuscitation. All infants started in air, but received oxygen at five minutes because the oxygen saturation was below the 25th centile of target range.[17] After this, oxygen saturation increased in all infants and oxygen could be reduced to 21–30% before transport to the NICU. Four infants were intubated in the delivery room. A flow chart showing the type of respiratory support the infants received is shown in figure 4.

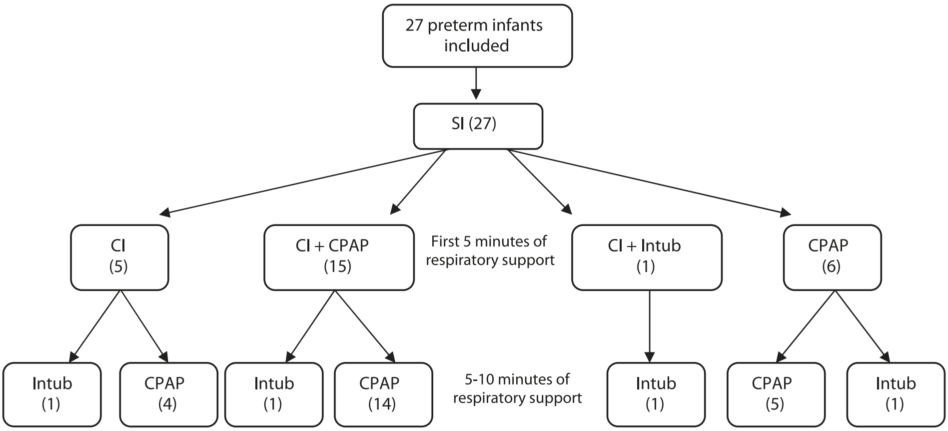

Figure 4. Flow chart of early respiratory management in the delivery room. CIs: consecutive inflations, CPAP: continuous positive airway pressure, Intub: Intubation.

Breathing patterns

A total of 3562 inflations and breaths were recorded, with a median of 137 (86–172) per infant. A total of 1643 inflations were analysed, with a median (IQR) of 50 (15–97) per infant. The remaining 1919 waveforms were breaths, of which 133 coincided with an inflation, 110 were between inflations and 1676 on CPAP.

During the period of PPV we analysed per infant 4 (2–7) breaths coinciding with an inflation, and 2 (0–4) breaths between inflations, within a total recording time of five minutes per infant. Breathing during inflations was observed in 23/27 infants (85%). The first breath occurred at a median of 10 (9–30) seconds after start of ventilation.

During the SIs breathing occurred in 18/27 infants (67%) coinciding with or in between SIs with a median of 3 (2–4) breaths per infant. In total, 60 breaths were analysed during SIs of which 41/60 (68%) were breaths between inflations and 19/60 (32%) breaths that coincided with an inflation.

During CIs breathing occurred in 18/22 infants (82%) coinciding with or in between CIs. In most infants (15/18) breathing was observed in an occasional pattern (< 3 breaths per 10 inflations) and in 3 infants in an obvious/irregular pattern (3–7 breaths per 10 inflations). Breathing was not observed in a regular pattern (> 7 breaths per 10 inflations) during CIs.

Within the five minutes of recording, 21/27 infants (78%) received CPAP without inflations. During CPAP we analysed a median (IQR) of 44 (4–110) breaths per infant.

Expired tidal volumes of breaths and inflations

The median V_{Te} of all breaths between inflations, breaths coinciding with inflations and inflations alone was 3.2 (1.6–6.3) mL/kg, 4.5 (1.0–7.8) mL/kg and 3.6 (1.2–6.6) mL/kg, respectively. The median V_{Te} of these patterns in each infant are shown in table 3.

Table 3. Schematic overview of the median expired tidal volume (V_{Te}) (IQR) during inflations, breaths in between inflations and breaths coinciding with an inflation, per infant.

Inf	Inflations†	Inflations V_{Te} (mL/kg)*	Breaths†	Breaths V_{Te} (mL/kg)*	Breaths coinciding with inflation†	Breaths coinciding with inflation V_{Te} (mL/kg)*
1	20	0 (0–0)	2	2.3 (0–4.6)	4	0 (0–0)
2	214	0 (0–2.4)	0		1	0
3	97	0 (0–4.4)	0		0	
4	45	1.9 (0–2.5)	3	4.2 (2.2–4.9)	21	3.7 (0.2–6.6)
5	77	0 (0–4.3)	0		9	0 (0–0)
6	15	0 (0–0)	0		2	0 (0–0)
7	57	7.6 (6.0–10.3)	16	5.2 (2.6–8.2)	5	4.9 (4.6–10.9)
8	1	0	2	2.6 (0.7–4.6)	4	6.0 (3.3–9.2)
9	3	2.1 (0–2.5)	1	3.3	4	0 (0–1.9)
10	35	4.4 (3.6–5.4)	0		3	3.3 (0.5–6.5)
11	65	2.4 (0–6.6)	12	2.8 (1.3–7.0)	10	3.3 (1.1–8.6)
12	39	0 (0–7.6)	4	4.2 (1.6–12.0)	6	13.5 (7.0–15.5)
13	26	5.9 (4.9–6.3)	1	4.7	0	
14	102	4.0 (2.8–4.9)	13	3.3 (2.1–4.6)	11	3.9 (3.2–4.5)
15	2	0.3 (0–0.6)	2	1.9 (0.7–3.1)	2	6.3 (5.7–6.9)
16	52	2.3 (1.9–2.8)	3	2.1 (1.3–3.0)	5	4.2 (3.3–8.5)
17	200	3.0 (2.1–4.3)	0		0	
18	4	2.7 (0–6.3)	0		2	7.7 (5.8–9.5)
19	133	4.4 (2.2–6.2)	14	3.2 (1.4–6.7)	7	6.0 (1.2–7.2)
20	50	4.4 (3.3–6.7)	2	2.5 (2.2–2.8)	3	7.6 (6.1–7.9)
21	1	0	0		0	
22	109	7.1 (3.1–8.5)	0		4	4.8 (3.4–9.8)
23	66	6.8 (4.8–9.7)	1	4.7	4	6.6 (5.1–7.5)
24	60	5.6 (3.6–8.6)	15	1.7 (1.3–3.5)	9	6.5 (3.0–13.7)
25	0		0		1	0
26	20	2.2 (0.7–2.8)	4	1.9 (0.2–4.5)	9	5.8 (1.0–9.9)
27	150	15.5 (10.9-17.6)	15	8.2 (2.9-14.5)	7	9.9 (8.0-16.3)

Data are presented as * = median (IQR) or † = n. Inf: infant.

During SIs, the median V_{Te} of breaths between inflations, breaths coinciding with inflations and inflations alone was 2.8 (0.7–4.6) mL/kg, 3.9 (0.0–7.7) mL/kg and 0.8 (0.0–5.6) mL/kg respectively (not significantly different between groups; p = 0.14).
During CIs, the median V_{Te} of breaths between inflations, breaths coinciding with inflations and inflations alone was 3.3 (2.1–6.6) mL/kg, 4.6 (2.1–7.8) mL/kg and 3.7 (1.4–6.7) mL/kg respectively (not significantly different between groups; p = 0.14).
During CPAP, the median V_{Te} of breaths was not significantly different from those between SIs (3.7 (1.2–5.3) mL/kg vs. 2.8 (0.7–4.6) mL/kg; p = 0.36) and not significantly different to breaths between CIs (3.7 (1.2–5.3) mL/kg vs. 3.3 (2.1–6.6) mL/kg; p = 0.08).

Discussion

This is the first study investigating breathing in very premature infants during mask PPV in the delivery room. We observed that breaths occurred in preterm infants receiving mask ventilation during the initial SIs and during CIs. In the first part of this study, investigating the effect of inflations alone, we showed in a companion article that although mask ventilation is often hampered by large leak and low tidal volumes, in most preterm infants heart rate and saturation quickly improved. We think this must be because most infants started breathing soon after the start of resuscitation and left the delivery room on CPAP with low oxygen need.
This study has showed that the V_{Te} of breaths did not differ from V_{Te} of inflations. It is therefore likely that breathing contributes to the effectiveness of stabilisation of preterm infants at birth. It is possible that breathing was already present or breathing started in response to the PPV given. O'Donnell et al. showed that most preterm infants breathe immediately after birth.[12]
Breathing could also be initiated in response to an inflation inducing Head's paradoxical reflex.[18,19] Boon et al. observed that during initial ventilation of asphyxiated term infant lung expansion became much more efficient when infants began their own respiratory efforts, possibly in response to a Head's paradoxical reflex.[18] Consequently, if inflations initiate breathing this might have positively influenced the effect of manual ventilation.
Breathing immediately after birth can be difficult to observe in preterm infants and clinicians often misjudge the adequacy of breathing. Often CIs were given after the initial SIs, as caregivers thought that breathing was absent. The infants who were intubated in the delivery room did breathe. A respiratory function monitor may add objectivity to the assessment of breathing. In this study caregivers were not blinded to the respiratory function monitor. This could have influenced the results. However, our experience was that the resuscitators hardly used the extra parameters for evaluation. More studies are

needed to investigate whether the use of a respiratory function monitor in the delivery room can be of additional value.

Clinicians have been reluctant to use SIs because they are afraid injuriously high tidal volumes might occur when a breath coincides an inflation. However, this study has shown that high or potentially dangerous tidal volumes did not occur when infants breathed spontaneously during the inflation, even for inflations with minimal mask leak.

International guidelines recommend initially evaluating the infants heart rate and breathing.[4] One study showed that after birth the median heart rate of healthy term infants needing no intervention was often below 100/min in the first two minutes after birth.[20] Oxygen saturation of these infants at one and two minutes was around 65% and 70%, respectively.[17] Heart rate and oxygen saturation of preterm infants started lower and rose slower than in term infants.[17,20] This suggests that a heart rate <100/min may not be pathological and is probably not enough to decide whether ventilatory support is necessary in the first few minutes after birth. Other clinical indicators, such as the presence of breathing and muscle tone, are important in the decision whether to start PPV in the delivery room.

When a set pressure is used during ventilation, the compliance of the lung and the inspiratory effort of the infant are the major contributors to the delivered tidal volume.[13] The use of ventilation that is not synchronised with an inspiration could be counterproductive.[21] On the contrary, the placement of a mask on the infant's face may stimulate the trigeminal area and increase tidal volume.[22,23] It is not known whether ventilation stimulates or counteracts the infants' breathing. One study showed that ventilation strategies that are synchronised with the infant's inspiratory efforts improved ventilation and led to a shorter duration of ventilation.[24] We found that infants were breathing coinciding with and between inflations. From these results it is likely that breathing supports resuscitation and contributes to the effectiveness of stabilisation of preterm infants at birth. The development of more efficient ventilation techniques during resuscitation should focus on the presence of breathing during ventilation and should coincide inflations with inspiration.

Conclusion

This study shows that many very preterm infants breathe during and between initial sustained inflations and subsequent consecutive inflations immediately after birth. Most infants left the delivery room on CPAP with low oxygen need. The expired tidal volume of breaths was similar to that of inflations. It is likely that the presence of breathing contributes to ventilation of preterm infants immediately after birth. More research is needed to determine the role of breathing during manual ventilation and how this can be used to develop optimal resuscitation techniques.

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