Corrective steps to enhance ventilation in the delivery room

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ABSTRACT

Objective The clinical impact of ventilation corrective steps for delivery room positive pressure ventilation (PPV) is not well studied. We aimed to characterise the performance and effect of ventilation corrective steps (MRSOPA (Mask adjustment, Reposition airway, Suction mouth and nose, Open mouth, Pressure increase and Alternative airway)) during delivery room resuscitation of preterm infants.
Design Prospective observational study of delivery room PPV using video and respiratory function monitor recordings.
Setting Tertiary academic delivery hospital.
Patients Preterm infants <32 weeks gestation.
Main outcome measure Mean exhaled tidal volume (Vte) of PPV inflations before and after MRSOPA interventions, categorised as inadequate (<4 mL/kg); appropriate (4–8 mL/kg), or excessive (>8 mL/kg). Secondary outcomes were leak (>30%) and obstruction (Vte <1 mL/kg), and infant heart rate.
Results There were 41 corrective interventions in 30 infants, with a median duration of 15 (IQR 7–29) s. The most frequent intervention was a combination of Mask/Reposition and Suction/Open. Mean Vte was inadequate before 16/41 interventions and became adequate following 6/16. Mean Vte became excessive after 6/41 interventions. Mask leak, present before 13/41 interventions, was unchanged after 4 and resolved after 9. Obstruction was present before five interventions and was subsequently resolved only once. MRSOPA interventions introduced leak in two cases and led to obstruction in one case. The heart rate was <100 beats per minute before 31 interventions and rose to >100 beats per minute after 14/31 of these.
Conclusions Ventilation correction interventions improve tidal volume delivery in some cases, but lead to ineffective or excessive tidal volumes in others. Mask leak and obstruction can be induced by MRSOPA manoeuvres.

What is already known on this topic?

- Positive pressure ventilation (PPV) is a critical component of delivery room resuscitation but is challenging to perform.
- Neonatal resuscitation guidelines include ventilation corrective steps to troubleshoot common impediments to delivery room PPV, but the clinical impact of these steps is undefined.

What this study adds?

- Ventilation corrective steps improve tidal volume delivery in some cases but worsen exhaled tidal volumes in others.
- Mask leak and airway obstruction can be induced by ventilation corrective manoeuvres during PPV.

INTRODUCTION

Approximately 4%–10% of newborns require initial resuscitation in the delivery room, and positive pressure ventilation (PPV) is the most critical step of neonatal resuscitation.[1] However, effective PPV is challenging to perform in neonates. Reasons for inadequate ventilation in manikin and clinical studies of preterm infants include mask leak, flow obstruction and inadequate pressures.[2–9] Further, these parameters vary widely between providers during simulated and delivery room resuscitation, and clinicians' self-assessments of mask leak are often inaccurate.[7]

Visual assessment of chest rise is poorly predictive of tidal volume and inspiratory pressure delivery.[10 11] Despite this, current Neonatal Resuscitation Program (NRP) recommendations include assessment chest rise to evaluate ventilation delivery.[1] According to the NRP algorithm, if the infant's heart rate (HR) remains less than 100 beats per minute after 15 s of PPV without presence of chest rise, corrective steps for PPV are indicated. NRP proposes using 'MRSOPA' mnemonic as an approach to these steps, standing for Mask adjustment, Reposition airway, Suction mouth and nose, Open mouth, Pressure increase and Alternative airway. However, these steps are empirically defined and may not target the specific impediment to PPV.

To date, few studies have described clinicians' approach to ventilation corrective steps in the delivery room. Furthermore, no studies have assessed delivered tidal volumes prior to MRSOPA manoeuvres and the impact of MRSOPA manoeuvres on measured tidal volume delivery. Our objective was to systematically characterise the approach to MRSOPA manoeuvres during delivery room resuscitation and to assess the impact of these interventions on measures of tidal volume delivery of PPV performed in preterm infants.

METHODS

Setting and design

This was a prospective observational study performed in the Hospital of the University of Pennsylvania (HUP) in Philadelphia, Pennsylvania,

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an academic tertiary hospital with approximately 4000 deliveries annually. All infants born at <32 weeks gestation in our hospital are resuscitated in a dedicated resuscitation room equipped with the recording equipment used for this study. All preterm deliveries are attended by a team of NRP-trained providers with a dedicated team leader (neonatal fellow or attending neonatologist). Airway management is performed by an experienced neonatal provider, usually a neonatal nurse practitioner, physician assistant or neonatal fellow. All deliveries in the present study were led by an attending neonatologist.

We enrolled inborn infants with gestational age between $23^{0/7}$ and $31^{6/7}$ weeks who received PPV during initial delivery room stabilisation and had complete video and respiratory function monitor (RFM) files. Infants with major congenital anomalies, deemed non-viable at delivery or who were enrolled in the concurrent MONITOR trial and randomised to RFM visible were excluded.[12] The targeted sample size was 30 infants, consistent with other delivery room studies of PPV.[2 4 5 10]

Equipment

Videos of resuscitations were recorded with B-line LiveCapture Ultraportable unit (B-Line Medical, Washington, DC, USA). This integrates video and audio feed from two mounted cameras and video stream from the vital sign monitor, which includes pulse oximetry and ECG data.

An RFM is a research tool used to objectively assess ventilation in the delivery room.[2–4 6 13–15] Data about respiratory interventions were recorded with a New Life Box RFM (Advanced Life Diagnostics, Weener, Germany), which uses an in-line flow sensor (Avea VarFlex Flow Transducer; CareFusion, Yorba Linda, California, USA) placed between the facemask and T-piece respiratory device to detect air flow to and away from the infant. The signal is integrated to generate data on flow, pressure, and tidal volume of delivered inflations. In our hospital, a New Life Box RFM is used to record data about respiratory support provided during facemask ventilation of preterm infants for quality improvement purposes. The display is not visible to providers during clinical resuscitation outside of the MONITOR trial.[12] Video and RFM recordings were commenced by the clinical teams prior to resuscitation and stopped after facemask PPV was discontinued.

Study definitions

MRSOPA manoeuvres: Video recordings were reviewed by one investigator (KCY). Visual and auditory cues in the video recordings were reviewed to identify when MRSOPA manoeuvres were performed during PPV. MRSOPA manoeuvres were categorised as (1) Mask/Reposition, (2) Suction/Open mouth, (3) Increase pressure or (4) Alternative airway, either singly or in combination. The manoeuvres were grouped in this fashion according to the 2015 NRP algorithm, which recommends performing MRSOPA in these combinations. In addition, single manoeuvres are difficult to distinguish from one another on video or RFM, such as mask adjustment and repositioning. The type, number, and combination of MRSOPA manoeuvres in each intervention period were recorded.

MRSOPA intervention periods: The time periods where MRSOPA manoeuvres occurred were referred to as 'intervention periods' and were defined as the time starting from when the first manoeuvre was commenced and ending when PPV was recommenced and continued for at least 30 s. If PPV was performed for less than 30 s before subsequent MRSOPA manoeuvres were performed, the following manoeuvres were included in the initial intervention period. Intervention periods were synched with the RFM output by linking the time stamps on the RFM record and video and confirmed by visual inspection of expected waveform patterns on the RFM recordings (ie, persistent positive flow when the mask was removed, or increased pressures with pressure changes).

The HR range from the ECG 30 s before and after each intervention period were recorded. The duration of each intervention period based on the RFM were recorded. RFM recordings of the 10 PPV inflations immediately before and after each intervention period were analysed on a breath-by-breath basis by one investigator (KCY). Only delivered inflations (ie, not spontaneous breaths) were analysed for the following measures: mean exhaled tidal volume (Vte), presence of leak and presence of obstruction. Mask leak was calculated as [(inhaled tidal volume − exhaled tidal volume)/inhaled tidal volume × 100]. There is no clear agreement in the literature for defining meaningful mask leak. Therefore, mask leak in this study was empirically defined as ≥30% leak occurring in ≥50% PPV inflations. Obstruction was defined as Vte <1 mL/kg, which is approximately a 75% reduction from expected 4 mL/kg tidal volume.[3] Obstruction was considered to be present if ≥50% of the PPV inflations within the epoch had Vte <1 mL/kg.

Summary statistics were used to report the types and sequence of MRSOPA manoeuvres performed, the presence of bradycardia (HR <100 beats per minute at any point in the 30 s before or after the intervention period) and the RFM measurements of the 10 PPV inflations before and after each intervention period. Data were analysed using Stata V.15.1 (Stata, College Station, Texas, USA).

RESULTS

Between September 2017 and November 2018, 129 infants born at HUP were screened and 30 eligible infants were included in the study. Of 99 excluded, 86 did not have complete video and RFM files available, 8 had congenital anomalies, 4 were randomised to RFM visible in the MONITOR trial and 1 was non-viable at birth. There were 41 intervention periods identified in 25 infants; 5 infants received PPV without MRSOPA manoeuvres performed. The infant characteristics are shown in table 1. The median number of MRSOPA manoeuvres per intervention period was 2 (IQR 1–2, range 0–4). The median duration of each intervention period was 15 s (IQR 7–29, range 1–70).

The type and combination of MRSOPA manoeuvres performed across all intervention periods are shown in figure 1. All alternative airways were endotracheal intubations. The most frequent combination of manoeuvres within each intervention period was Mask/Reposition with Suction/Open. The most common first,

Table 1 Infant and intervention period characteristics

	No of infants (%), n=30
Male, %	17 (57)
Birth weight, g, mean±SD	886±393
Gestation, weeks, mean±SD	27±3
Caesarean section, %	23 (77)
Complete steroids, %	19 (63)
1 min Apgar, median (IQR)	2 (1–4)
5 min Apgar, median (IQR)	6 (5–8)
Intervention periods per infant, median (IQR)	1 (1–2)

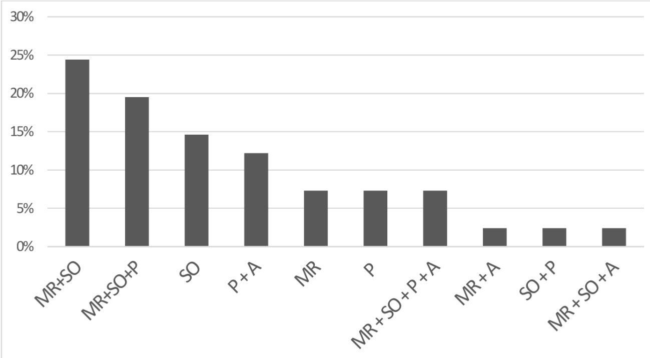

Figure 1 Type and combination of MRSOPA (mask adjustment, reposition airway, suction mouth and nose, open mouth, pressure increase and alternative airway) manoeuvres performed during corrective ventilation intervention periods (n=41). MR, mask/reposition; SO, suction/Open; P, pressure increase; A, alternative airway.

second, third, and fourth manoeuvres performed within each individual resuscitation are shown in figure 2.

The mean Vte was inadequate before 16/41 (39%) intervention periods (table 2). Of these, mean Vte became adequate after MRSOPA interventions in 6/16 (38%), had no change after 8/16 (50%) and became excessive in 1/16 (6%). Among 22/41 (54%) cases with adequate Vte prior to the corrective steps, Vte worsened after four intervention periods and became excessive following five. Mask leak, present prior to 13/41 (32%) intervention periods, was resolved following ventilation corrective interventions in 9/13 (69%) cases and remained unchanged after 4/13 (31%) interventions. Obstruction was present before 5/41 (12%) intervention periods and was resolved after the intervention in only one case. MRSOPA interventions induced mask leak on two occasions and introduced airway obstruction in one.

Bradycardia (HR <100 beats per minute) occurred before 31/41 (76%) of intervention periods, and resolved after corrective steps in 14/31 (45%). Inadequate mean Vte (<4 mL/kg) was observed during 10/31 episodes of bradycardia. The corrective interventions led to improved Vte in four of these cases, but the HR rose >100 in only two of these. Conversely, in two cases, bradycardia resolved after the corrective intervention while the mean Vte delivered was actually lower following the intervention. Performing MRSOPA did not worsen the HR in any occasion.

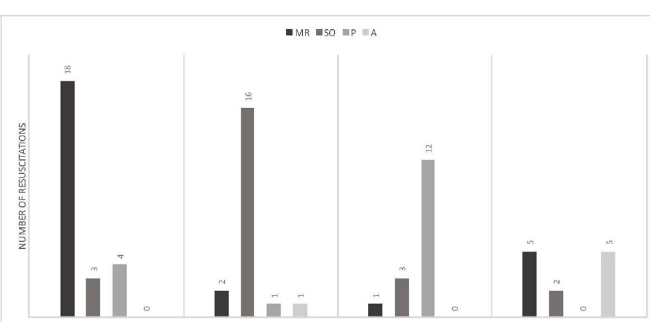

Figure 2 Sequence of first four MRSOPA (mask adjustment,reposition airway, suction mouth and nose, open mouth, pressure increase and alternative airway) manoeuvres performed across each resuscitation (n=25). MR, mask/reposition; SO, suction/open; P, pressure increase; A, alternative airway.

Table 2 Impact of ventilation corrective interventions on Vte of PPV inflations

		Mean Vte during 10 PPV inflations after intervention period			
		<4 mL/kg	**4–8 mL/kg**	**>8 mL/kg**	**N/A***
Mean Vte during 10 PPV inflations before intervention period	<4 mL/kg (n=16)	8	6	1	1
	4–8 mL/kg (n=22)	4	12	5	1
	>8 mL/kg (n=3)	0	2	0	1

*PPV discontinued after intervention period.
PPV, positive pressure ventilation; Vte, exhaled tidal volume.

DISCUSSION

We characterised the approach and outcome of ventilation corrective steps during PPV for delivery room resuscitation of preterm infants. Among 30 delivery room resuscitations involving PPV, the number, sequence and combination of MRSOPA manoeuvres performed during resuscitation were variable. In some cases, these manoeuvres led to resolution of bradycardia and/or more effective PPV delivery as measured by Vte. In other cases, the MRSOPA manoeuvres had no impact on bradycardia, induced mask leak or obstruction, or resulted in excessive tidal volume delivery.

Optimising ventilation is a mainstay in delivery room resuscitation, but little is known about clinicians' approach and outcomes of ventilation corrective steps in the delivery room setting. Kilmartin described the approach to MRSOPA and various mask holds during PPV in delivery room resuscitation of 46 preterm infants.[16] The authors found that Opening the mouth was used in all resuscitations, with Mask/Reposition being the next most frequent intervention. In contrast, we found that Mask/Reposition were the most common manoeuvres, followed by Suction/Open. They also found that the MRSOPA steps were not consistently applied, including some resuscitations where infants were intubated prior to completing all steps. In our study, providers largely adhered to the proposed NRP sequence, with Mask/Reposition being the most common first, Suction/Open the most common second, Increase Pressure the most common third and Alternative Airway the most common fourth manoeuvres per infant.

In a delivery room study of mostly full-term infants, Skåre *et al* demonstrated a median pause of 6 s (IQR 4–13) in PPV to perform MRSOPA manoeuvres.[17] Our study showed a longer median pause of 15 s (IQR 7–29). One possible explanation is that MRSOPA manoeuvres are technically more challenging to perform in preterm neonates.

Mask leak and obstruction are common impediments in both clinical and simulated PPV.[2–9] In the present study, mask leak was present before 32% of intervention periods and obstruction was present prior to 12%. The corrective manoeuvres did not consistently resolve these impediments, and in some cases the interventions introduced leak or obstruction. In the instances where leak or obstruction were introduced, performing MRSOPA worsened the ability to deliver adequate ventilation.

Potential explanations for failure of ventilation corrective interventions to improve Vte are that the chosen manoeuvres did not address the actual impediment, for example adjusting the facemask when the problem was insufficient pressure. In addition, static impediments such as inappropriate facemask size may not be corrected by MRSOPA steps. Further, attempts to correct existing impediments may have created new ones, such as readjusting a mask and creating an obstruction. Thus, a one-size-fits all approach to ventilation corrective steps may not be appropriate. Given that clinicians' subjective assessment of chest rise, Vte, and mask leak is poor,[7 10 11] more objective monitoring may be needed to correctly identify and troubleshoot specific impediments during PPV.

Similar to other studies,[10] we observed important variability in Vte during PPV. Importantly, Vte became excessive (>8 mL/kg) following 15% of corrective interventions. Mian *et al* recently reported a significantly higher rate of IVH among infants who received tidal volumes >6 mL/kg during delivery room resuscitation, suggesting the potential negative impact of excessive tidal volume delivery during PPV.[18]

Bradycardia was present prior to 76% of the intervention periods, with the remainder of intervention periods initiated despite HR >100. We did not elucidate the reason for performing MRSOPA manoeuvres in these situations. It is possible that providers performed manoeuvres for other perceived impediments during PPV such as inadequate oxygenation or poor chest rise. Interestingly, bradycardia was resolved following 45% of corrective interventions. In addition, only a minority of infants had 'low' tidal volumes while bradycardic, and some episodes of bradycardia resolved even though Vte decreased after the corrective interventions. These observations suggest that these defined tidal volume ranges may not account for the whole clinical picture during ventilation of the preterm infant.

We acknowledge study limitations. Our single-centre academic setting may not be representative of other institutions. The sample size was small but consistent with other delivery room studies of PPV. We used video recordings to identify the performance of MRSOPA manoeuvres and were not able to delineate each manoeuvre individually. Additionally, we only analysed infants who had MRSOPA manoeuvres performed, but not those who may have needed them but did not have them. Potential RFM limitations include calibration error and need for manual waveform interpretation; the inter-reliability and intra-reliability of these assessments have not been established. Last, we empirically defined ranges for 'low' versus 'excessive' tidal volumes (<4 mL/kg and >8 mL/kg, respectively) and dichotomous definitions for leak and obstruction. While these values are consistent with the literature,[3 6 17] optimal tidal volumes to support lung aeration during PPV after birth are not yet defined.

Study strengths include the use of an RFM to directly measure the impact of performing MRSOPA manoeuvres on tidal volume delivery, mask leak and obstruction. The study supports the feasibility of using an RFM to assess delivery room resuscitation.

CONCLUSION

Ventilation correction interventions improve tidal volume delivery in some cases, but lead to ineffective or excessive tidal volumes in others and do not consistently resolve bradycardia. Mask leak and obstruction can be induced by corrective interventions. This study supports the role for more objective monitoring of PPV during delivery room resuscitation.

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