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# Respiratory Function During Chest Compressions

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## Abstract

Chest compression (CC) is an infrequent event (0.08%) in newborns delivered at near-term and term gestation, and occurs at a higher frequency (10%) in preterm deliveries. In addition, outcome studies of deliveries requiring resuscitation or chest compression have reported high rates of mortality and neurodevelopmental impairment in surviving children. A respiratory function monitor (RFM) can help guide a resuscitator during cardiopulmonary resuscitation (CPR) in a neonate and help assess the quality and efficacy of chest compression. Utilizing a non-invasive respiratory function monitor during chest compression may decrease high mortality rates in addition to having many distinct advantages, which will benefit both the newborn and the resuscitators. There are several different ways that a respiratory function monitor can assist a resuscitator during chest compression; these include confirming and ensuring adequate lung ventilation, analyzing the efficacy and quality of chest compression and exhaled CO<sub>2</sub> monitoring.

**Keywords:** infants, newborn, delivery room, neonatal resuscitation, chest compression

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## 1. Introduction

Fortunately, the need for chest compression (CC) or medications in the delivery room is rare. Only about 0.1% of term infants receive these interventions, resulting in approximately 1 million newborn deaths annually worldwide. In addition, chest compression or medications is more frequent in the preterm population (~15%) due to birth asphyxia [1, 2]. Fortunately, the majority

of newborn infants successfully make the transition from fetal to neonatal life without any help [3]. An estimated 10% of newborns need help to establish effective ventilation (e.g., positive pressure ventilation, PPV), which remains the most critical step of neonatal resuscitation [3]. However, clinicians struggle to deliver an adequate tidal volume ( $V_T$ ) [4]. In addition, mask positive pressure ventilation is often impaired by either mask leak or airway obstruction [5]. Manikin studies have further demonstrated that initiation of chest compression increases mask leak and therefore impedes effective ventilation [6, 7]. It is imperative to give optimal ventilation during chest compression to maximize efficacy [8]. Recently, a respiratory function monitor (RFM) has been described to be support the clinical team during simulated [9, 10] and real-time neonatal resuscitation [11–14]. This chapter discusses how an RFM can aid during neonatal resuscitation.

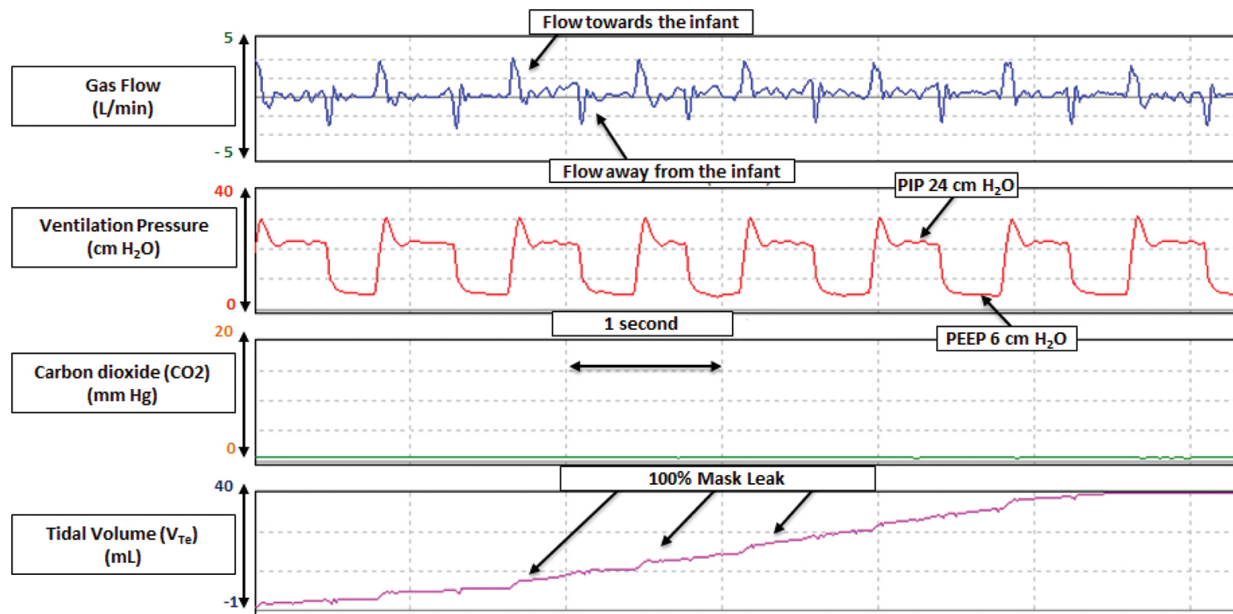
## 2. Respiratory function monitor

### 2.1. $V_T$ , gas flow, airway pressure, and exhaled $\text{CO}_2$ monitor

Gas flow,  $V_T$ , airway pressure, and *exhaled*  $\text{CO}_2$  ( $\text{ECO}_2$ ) can be measured by any respiratory function monitor using a flow sensor placed between a ventilation device and facemask or endotracheal tube [11, 14]. Inspiratory and expiratory tidal volume passing through the sensor can be calculated by any flow sensor (e.g., fixed orifice pneumotach or a hot wire anemometer) by integrating the flow signal [11, 14]. Airway pressure is measured by directly connecting a line to the circuit, which displays peak inflation pressure and positive end expiratory pressure. Any respiratory function monitor continuously displays waves (e.g., pressure, flow, and tidal volume) and numerical values (e.g., airway pressure, tidal volume, and respiratory rate) [11, 14]. In addition, the percentage of mask leak or around a tracheal tube is calculated and displayed.  $\text{ECO}_2$  is measured using a non-dispersive infrared absorption technique. According to manufacturers, the accuracy for gas flow is  $\pm 0.125$  L/min and for  $\text{ECO}_2$  is  $\pm 2$  mmHg.

## 3. Mask leak

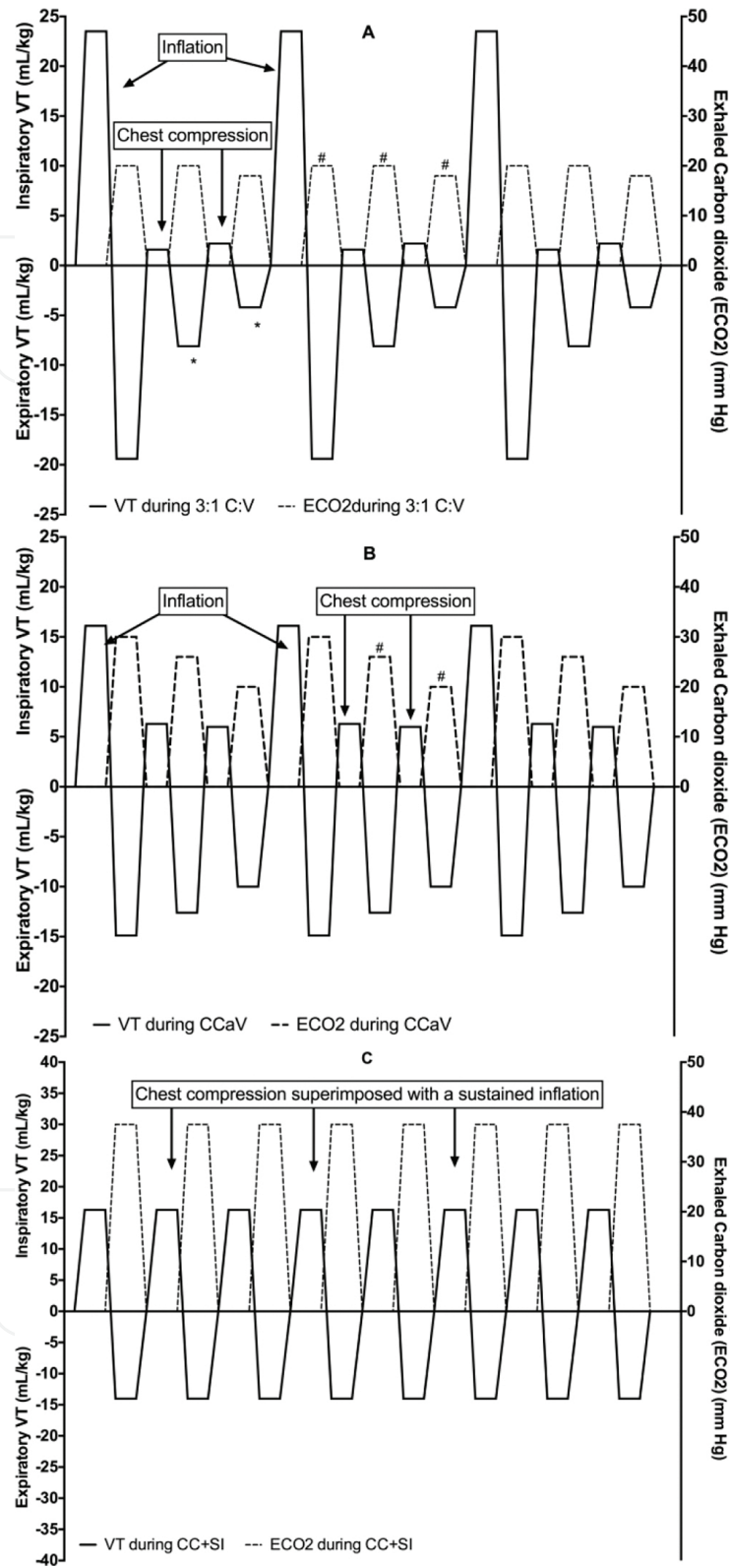
Mask ventilation studies in the delivery room have reported variable mask leak during positive pressure ventilation [4], which can be significantly decreased if mask leak is displayed on an RFM [13]. Using a manikin, Binder-Heschl et al. reported that mask leak significantly increased from 15% during positive pressure ventilation to 32% after chest compression was started [6]. This is further supported by a study by Solevåg et al. who reported that tidal volume delivery is significantly decreased using continuous chest compression with non-synchronized ventilation compared to the current 3:1 cardiopulmonary resuscitation (CPR) [7]. However, when a resuscitation used an RFM to assess mask leak, it was significantly reduced [6]. Unfortunately, the data in newborn infants are sparse and limited to a case report by Li et al. [12]. During chest compression, mask leak was 100% and did not result in an increase in heart rate, suggesting that adequate tidal volume was not delivered (**Figure 1**) [12].



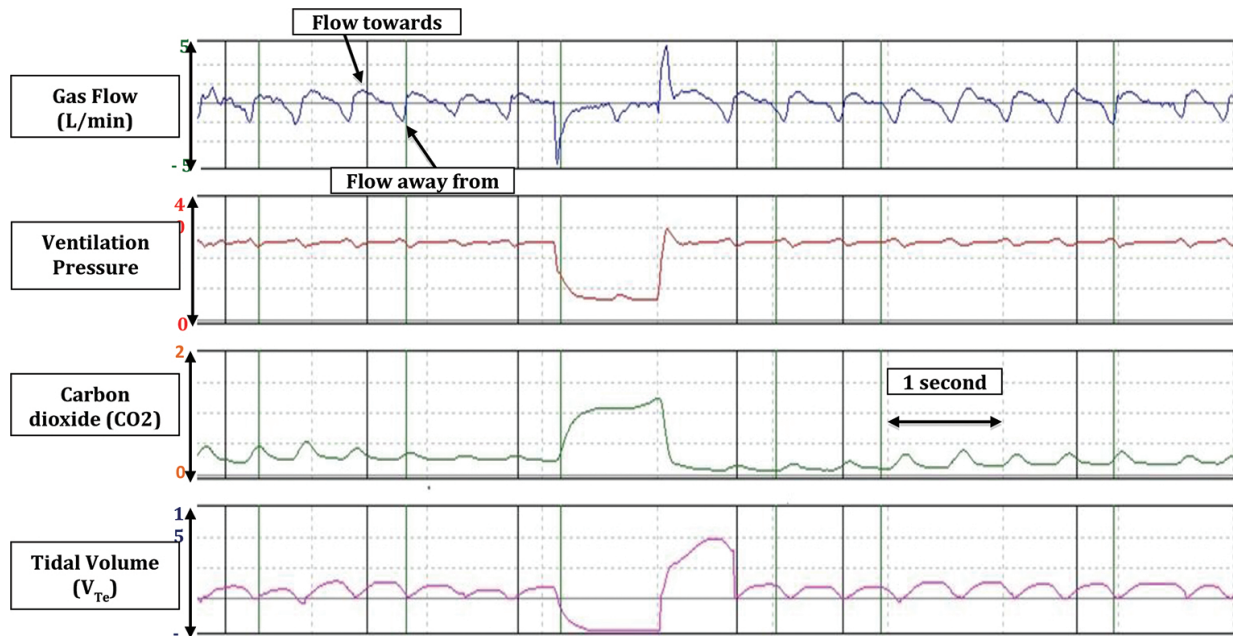
**Figure 1.** As CC is initiated in an extremely preterm infant, the traces indicate large mask leak. This results in ineffective ventilation and no  $V_T$  delivered, which could lead to failure of achieving ROSC.

#### 4. Tidal volume

The purpose of inflations during chest compression is to deliver an adequate tidal volume to facilitate gas exchange [3]. A manikin study reported that tidal volume increases once chest compression was started compared to mask ventilation alone [7]. Interestingly, a further manikin study examined different auditory prompts during simulated neonatal cardiopulmonary resuscitation and reported higher tidal volumes in all groups compared to baseline [15]. These studies suggest a change in tidal volume once chest compressions are initiated. An increase or decrease in tidal volume could cause lung derecruitment, which could hamper oxygenation and therefore return of spontaneous circulation (ROSV) [12]. In a porcine model of neonatal resuscitation, Li et al. recently described that using the current recommendation of 3:1 chest compression to ventilation ratio (**Figure 2**) [3], lung derecruitment occurs [8]. The study further compared continuous chest compressions with asynchronous ventilations and found similar results [8], however, when chest compression superimposed by sustained inflation (CC + SI) (**Figure 3**) [16] improved tidal volume delivery and continuous lung recruitment was observed, potentially leading to better alveolar oxygen delivery and lung aeration.



**Figure 2.**  $V_T$  (mL/kg) changes during 3:1 chest compression:ventilation ratio (3:1 C:V) (A), continuous chest compressions and asynchronous ventilations (CCaV) (B), and continuous chest compressions superimposed by sustained inflations (CC + SI) (C). # $p < 0.05$  exhaled  $CO_2$  (ECO<sub>2</sub>) compared with CC + SI [8] (with permission).



**Figure 3.** CC superimposed by sustained inflation; adequate lung ventilation and  $V_T$  delivery are displayed: (i) adequate gas flow towards and away from the infant; (ii) average  $V_T$  of 4 mL/kg is delivered without leak.

## 5. Exhaled carbon dioxide ( $ECO_2$ )

There is increasing evidence that continuous monitoring of exhaled carbon dioxide ( $ECO_2$ ) can predict rise of heart rate during neonatal transition [17], monitor lung aeration at birth [11, 18–20], and predict return of spontaneous circulation during neonatal cardiopulmonary resuscitation (**Figure 4**) [21]. Blank et al. used a Pedi-Cap during mask positive pressure ventilation and reported a significant increase in heart rate once the Pedi-Cap turned yellow [17]. Similar results have been described in animal models and a further delivery room study [18]. During neonatal cardiopulmonary resuscitation  $ECO_2$  is a reliable parameter to examine return of spontaneous circulation. Chalak et al. reported that an  $ECO_2$  of 14 mmHg was the most reliable indicator for return of spontaneous circulation with 92% sensitivity and 81% specificity [21]. This study suggests that monitoring  $ECO_2$  during cardiopulmonary resuscitation would allow uninterrupted chest compression and potentially could be an indirect indicator of the CC effectiveness. This has been further supported by a recent animal study by Li et al., suggesting that either  $ECO_2$ , rate of elimination of  $CO_2$  ( $VCO_2$ ) or partial pressure of exhaled ( $PeCO_2$ ) could be used to monitor the return of spontaneous circulation [12]. A recent case report of neonatal cardiopulmonary resuscitation in an extremely preterm infant supports this hypothesis where a significant increase in  $ECO_2$  preceded an increase in heart rate and return of spontaneous circulation [12].  $ECO_2$  monitoring is a non-invasive tool

that can be used to predict the return of spontaneous circulation during cardiopulmonary resuscitation.

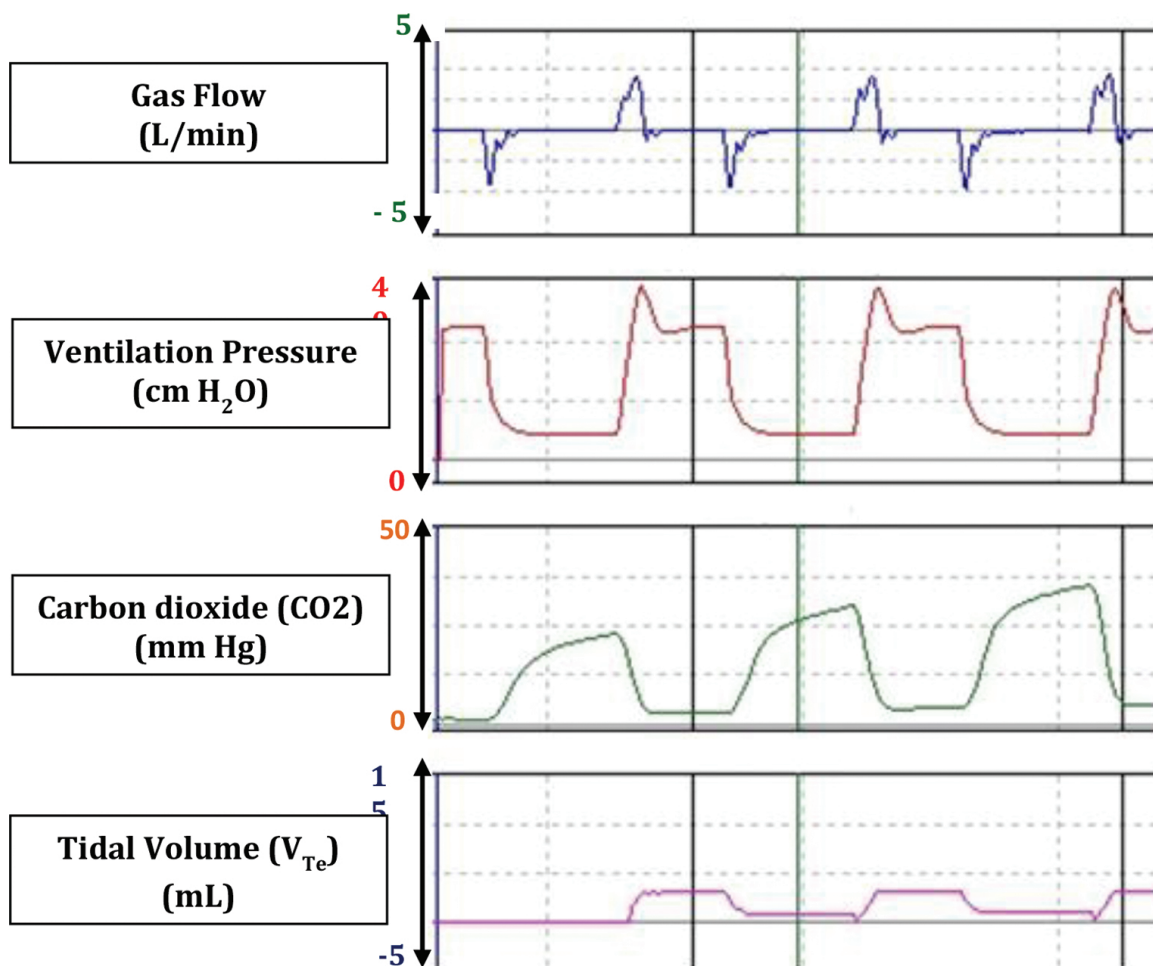


Figure 4. Increasing  $ECO_2$  values suggesting imminent ROSC.

### 5.1. Partial pressure of exhaled ( $PeCO_2$ ) and rate of elimination of $CO_2$ ( $VCO_2$ )

A recent animal study described  $VCO_2$  and  $PeCO_2$  values as a clinical indicator during chest compression to achieve the return of spontaneous circulation.  $VCO_2$ , or the volume of expired  $CO_2$ , reflects changes in both ventilation and perfusion, and therefore ventilation/perfusion (V/Q) matching [22]. Palme-Kilander et al. reported that low  $VCO_2$  values could be due to residual lung fluid, very low tone, or deficient perfusion of the lungs [23]. A recent study in preterm infants reported that higher  $VCO_2$  levels were associated with lung aeration and successful establishment of functional residual capacity [19]. During chest compression, increasing  $VCO_2$  values reflects adequate ventilation, perfusion, and lung aeration [22]. Thus,  $VCO_2$  potentially provides valuable information during neonatal resuscitation.

PeCO<sub>2</sub> is a continuous, non-invasive measurement. Since the physiological dead space/tidal volume ( $V_D/V_T$ ) ratio is never zero, PeCO<sub>2</sub> is always lower than the ETCO<sub>2</sub> [22]. During resuscitation, there is poor ventilation to perfusion matching, and therefore dead space/tidal volume increases, independent of whether mismatching is either due to impaired perfusion, impaired ventilation, or a mixture of impaired perfusion and ventilation, causing lower PeCO<sub>2</sub> [22]. Therefore, PeCO<sub>2</sub> is decreased under all conditions of impaired ventilation/perfusion. In the case of ventilation mismatch, PeCO<sub>2</sub> is dilute relative to ETCO<sub>2</sub>, and the PeCO<sub>2</sub>/ETCO<sub>2</sub> ratio is reduced. In the case of reduced or maldistributed pulmonary blood flow without airway defects, both PeCO<sub>2</sub> and ETCO<sub>2</sub> would be reduced, resulting in a near normal PeCO<sub>2</sub>/ETCO<sub>2</sub> ratio. A recent animal study described PeCO<sub>2</sub> for the first time in the neonatal population. Newborn piglets who successfully achieved return of spontaneous circulation had significantly higher PeCO<sub>2</sub> levels in the latter portion of cardiopulmonary resuscitation, indicating sufficient gas exchange was occurring [22]. Low levels of PeCO<sub>2</sub> can only be attributed to poor or low quality of ventilation during cardiopulmonary resuscitation, while decreased levels of both PeCO<sub>2</sub> and ETCO<sub>2</sub> may signify inadequate pulmonary perfusion due to poor circulation [22]. These findings suggest that monitoring PeCO<sub>2</sub> and ETCO<sub>2</sub> continuously during cardiopulmonary resuscitation, the clinical team would be able to determine changes in ventilation or perfusion and adjust ventilation to improve either.

## 6. Conclusion

Using a respiratory function monitor to assess mask leak and tidal volume delivery during neonatal cardiopulmonary resuscitation can help improve mask ventilation. In addition, using exhaled carbon dioxide can predict return of spontaneous circulation during neonatal cardiopulmonary resuscitation.

## Abbreviations

CPR	cardio pulmonary resuscitation
CC	chest compression
CC+SI	continuous chest compressions with sustained inflations
ECO <sub>2</sub>	exhaled carbon dioxide
PPV	positive pressure ventilation
ROSC	return of spontaneous circulation
V <sub>T</sub>	tidal volume
VD/VT	physiological dead space/tidal volume



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## References

- [1] Kapadia V, Wyckoff MH. Chest compressions for bradycardia or asystole in neonates. *Clin Perinatol* 2012;39:833–42.
- [2] Wyckoff MH, Perlman J. Cardiopulmonary resuscitation in very low birth weight infants. *Pediatrics* 2000;106:618–20.
- [3] Perlman J, Wyllie JP, Kattwinkel J, Wyckoff MH, Aziz K, Guinsburg R, et al. Part 7: Neonatal resuscitation: 2015 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. *Circulation* 2015;132:S204–41.
- [4] Schmölzer GM, Kamlin COF, O'Donnell CP, Dawson JA, Morley CJ, Davis PG. Assessment of tidal volume and gas leak during mask ventilation of preterm infants in the delivery room. *Arch Dis Child Fetal Neonatal* 2010;95:F393–7.

- [5] Schmölzer GM, Dawson JA, Kamlin COF, O'Donnell CP, Morley CJ, Davis PG. Airway obstruction and gas leak during mask ventilation of preterm infants in the delivery room. *Arch Dis Child Fetal Neonatal* 2011;96:F254–7.
- [6] Binder-Heschl C, Schmölzer GM, O'Reilly M, Schwabegger B, Pichler G. Human or monitor feedback to improve mask ventilation during simulated neonatal cardiopulmonary resuscitation. *Arch Dis Child Fetal Neonatal* 2014;99:F120–3.
- [7] Solevåg AL, Madland JM, Gjørnum E, Nakstad B. Minute ventilation at different compression to ventilation ratios, different ventilation rates, and continuous chest compressions with asynchronous ventilation in a newborn manikin. *Scand J Trauma Resusc Emerg Med* 2012;20:73.
- [8] Li ES-S, Cheung P-Y, O'Reilly M, Schmölzer GM. Change in tidal volume during cardiopulmonary resuscitation in newborn piglets. *Arch Dis Child Fetal Neonatal* 2015;100:F530–3.
- [9] Schilleman K, Witlox RS, Lopriore E, Morley CJ, Walther FJ, te Pas A. Leak and obstruction with mask ventilation during simulated neonatal resuscitation. *Arch Dis Child Fetal Neonatal* 2010;95:F398–402.
- [10] Schmölzer GM, Roehr C. Use of respiratory function monitors during simulated neonatal resuscitation. *Klin Padiatr* 2011;223:261–6.
- [11] van Os S, Cheung P-Y, Pichler G, Aziz K, O'Reilly M, Schmölzer GM. Exhaled carbon dioxide can be used to guide respiratory support in the delivery room. *Acta Paediatr* 2014;103:796–806.
- [12] Li ES-S, Cheung P-Y, Pichler G, Aziz K, Schmölzer GM. Respiratory function and near infrared spectroscopy recording during cardiopulmonary resuscitation in an extremely preterm newborn. *Neonatology* 2014;105:200–4.
- [13] Schmölzer GM, Morley CJ, Wong C, Dawson JA, Kamlin COF, Donath S, et al. Respiratory function monitor guidance of mask ventilation in the delivery room: a feasibility study. *J Pediatr* 2012;160:377–381.e2.
- [14] Schmölzer GM, Kamlin COF, Dawson JA, te Pas A, Morley CJ, Davis PG. Respiratory monitoring of neonatal resuscitation. *Arch Dis Child Fetal Neonatal* 2010;95:F295–303.
- [15] Roehr C, Schmölzer GM, Thio M, Dawson JA, Dold SK, Schmalisch G, et al. How ABBA may help improve neonatal resuscitation training: auditory prompts to enable coordination of manual inflations and chest compressions. *J Paediatr Child Health* 2014;50:444–8.
- [16] Schmölzer GM, O'Reilly M, LaBossiere J, Lee T-F, Cowan S, Qin S, et al. Cardiopulmonary resuscitation with chest compressions during sustained inflations: a new technique of neonatal resuscitation that improves recovery and survival in a neonatal porcine model. *Circulation* 2013;128:2495–503.

- [17] Blank D, Rich W, Leone TA, Garey D, Finer N. Pedi-cap color change precedes a significant increase in heart rate during neonatal resuscitation. *Resuscitation* 2014;85:1568–72.
- [18] Hooper SB, Fouras A, Siew M, Wallace MJ, Kitchen M, te Pas A, et al. Expired CO<sub>2</sub> levels indicate degree of lung aeration at birth. *PLoS One* 2013;8:e70895.
- [19] Kang LJ, Cheung P-Y, Pichler G, O'Reilly M, Aziz K, Schmölzer GM. Monitoring lung aeration during respiratory support in preterm infants at birth. *PLoS One* 2014;9:e102729.
- [20] Kong JY, Rich W, Finer N, Leone TA. Quantitative end-tidal carbon dioxide monitoring in the delivery room: a randomized controlled trial. *J Pediatr* 2013;163:104–8.e1.
- [21] Chalak LF, Barber CA, Hynan L, Garcia D, Christie L, Wyckoff MH. End-tidal CO<sub>2</sub> detection of an audible heart rate during neonatal cardiopulmonary resuscitation after asystole in asphyxiated piglets. *Pediatr Res* 2011;69:401–5.
- [22] Li ES-S, Cheung P-Y, O'Reilly M, LaBossiere J, Lee T-F, Cowan S, et al. Exhaled CO<sub>2</sub> parameters as a tool to assess ventilation-perfusion mismatching during neonatal resuscitation in a swine model of neonatal asphyxia. *PLoS One* 2016;11:e0146524–11.
- [23] Palme-Kilander C, Tunell R, Chiwei Y. Pulmonary gas exchange immediately after birth in spontaneously breathing infants. *Arch Dis Child* 1993;68:6–10.