Tidal volumes during delivery room stabilization of (near) term infants

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Abstract

Background: We sought to assess tidal volumes in (near) term infants during delivery room stabilization.

Methods: Secondary analysis of a prospective study comparing two facemasks used for positive pressure ventilation (PPV) in newborn infants ≥ 34 weeks gestation. PPV was provided with a T-piece device with a PIP of 30 cmH2O and positive end-expiratory airway pressure of 5 cmH2O. Expired tidal volumes (Vt) were measured with a respiratory function monitor. Target range for Vt was defined to be 4 – 8 ml/kg.

Results: Twenty-three infants with a median (IQR) gestational age of 38.1 (36.4 – 39.0) weeks received 1828 inflations with a median Vt of 4.6 (3.3 – 6.2) ml/kg. Median Vt was in the target range in 12 infants (52%), lower in 9 (39%) and higher in 2 (9%). Thirty-six (25—27) % of the inflations were in the target rage over the duration of PPV while 42 (25 – 65) % and 10 (3 – 33) % were above and below target range.

Conclusions: Variability of expiratory tidal volume delivered to term and late preterm infants was wide. Reliance on standard pressures and clinical signs may be insufficient to provide safe and effective ventilation in the delivery room.

Trial registration: This is a secondary analysis of a prospectively registered randomized controlled trial (ACTRN12616000768493).

Keywords: Term and late preterm infants, Delivery room stabilization, Positive pressure ventilation, Tidal volume

Background

Although most newborn infants initiate respiration spontaneously or after tactile stimulation within the first minutes after birth, approximately 5% require additional support [1]. Current guidelines recommend mask ventilation as the next step to achieve aeration of the lung [1, 2]. While volume-targeted ventilation has become standard of care in the neonatal intensive care unit due to its lung-protective effects [3], tidal volumes (Vt) are not routinely measured during non-invasive positive pressure ventilation (PPV) in the delivery room. Studies in preterm infants suggest an association between excessive Vt and intraventricular hemorrhage [4]. Others suggest that low Vt are associated with a higher intubation rate [5]. A clinical trial comparing the use of a RFM during PPV of preterm infants in the delivery room as a guidance for Vt delivery with no RFM showed that only 30% of inflations were within the target range [6]. In term and late preterm infants, less is known about the variability of measured Vt and changes of Vt over time. A recent single center study reported a median tidal volume at the lower end of the recommended range and substantial variation in tidal volumes measured in term infants [7].

In spontaneously breathing newborn term infants, expired Vt are known to be highly variable, ranging from 0.5 to more than 20 ml/kg [8, 9]. This may be due to changing breathing patterns during the transitional
During the provision of PPV, expired Vt may also vary chiefly due to interaction between spontaneous breaths and mask inflations.

Current European Resuscitation (ERC) guidelines recommend providing initial peak inflation pressures (PIP) of 30 cm H2O for term infants [1]. These recommendations are based on limited evidence [11]. The primary aim of this study was to assess Vt measured in term and late preterm infants during delivery room stabilization and changes in applied Vt over the duration of PPV.

Methods

Population and intervention

This is a secondary analysis of a previously published randomized controlled trial conducted at the Royal Women’s Hospital in Melbourne, Australia (ACTRN12616000768493) [12]. The original study and secondary analyses were approved by the local ethics committee. All parents provided written informed consent. The original trial compared the effect of two facemasks on mask leak in newborn infants ≥34 weeks gestation receiving PPV immediately after birth. PPV was started according to local neonatal resuscitation guidelines if the infant was gasping, not breathing or had a heart rate < 100 min [13]. The original study showed that the suction mask may have negative effects on mask ventilation [12, 14]. Therefore, the current secondary analysis only included infants resuscitated with the conventional mask (Laerdal Silicone mask, Laerdal, Stavanger, Norway).

Measurements and data collection

A Neopuff Infant Resuscitator (Fisher & Paykel Healthcare, Auckland, New Zealand) was used to provide PPV with initial peak inflation pressure (PIP) of 30 cm H2O and positive end-expiratory airway pressure (PEEP) of 5 cm H2O [1]. Changes to pressure settings were at the discretion of the treating clinician. Respiratory function parameters were recorded continuously during PPV using the NewLifeBox (Advanced Life Diagnostics UG, Weener, Germany). Breath-by-breath analysis was performed by manually placing inspiratory and expiratory markers using Pulmochart (Advanced Life Diagnostics UG). As previously published [6], all PPV inflations, including those coinciding with spontaneous breaths, were included. The clinical team was blinded to the RFM data. All resuscitations were video recorded.

Statistical analysis

Data from all available breaths were analysed. Consistent with previous studies, we defined the optimal range for expiratory Vt to be 4 – 8 ml/kg [15]. Leak was calculated as the difference between inspiratory Vt and expiratory Vt, and expressed as a percentage of inspiratory Vt [16]. Obstruction was defined as Vt < 2 ml/kg with leak < 30% [16]. Variability of Vt was assessed by calculating the coefficient of variation (standard deviation divided by mean). The higher the coefficient of variation, the greater the level of dispersion around the mean. Skewed data are presented as median and interquartile range (IQR). Friedman test was used to compare Vt between different time points throughout episodes of PPV and Mann–Whitney U-test was used to compare parameters between groups. P-values < 0.05 were considered statistically significant. Analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp).

Results

Population

Overall, 23 infants with a median (IQR) gestational age of 38.1 (36.4 to 39.0) weeks received 1828 PPV inflations (see Table 1). A median of 110 inflations (67 to 181) were recorded per infant.

Tidal volume

Median (IQR) Vt was 4.6 (3.3 – 6.2) ml/kg. Nine infants (39%) had a median Vt < 4 ml/kg, 12 infants (52%) had a median Vt between 4–8 and 2 infants (9%) a median Vt > 8 ml/kg. There was a high intra- and interindividual variability in measured Vt (Fig. 1). The median (IQR)

| Table 1 | Demographics and respiratory outcomes for n = 23 infants. Numbers are presented as median (IQR) or numbers (%) |
|---------|---------------------------------------------------------------------------------------------------------------|
| **Demographics** | | |
| Gestational age (weeks) | 38.1 (36.4 – 39.0) | |
| Birth weight (g) | 3210 (2810 – 3330) | |
| Male (%) | 13 (57%) | |
| Cesarean delivery (%) | 21 (91%) | |
| Maternal general anesthesia (%) | 7 (30%) | |
| Umbilical cord pH | 7.20 (7.11 – 7.24) | |
| Apgar 1 min | 3 (2 – 4) | |
| Apgar 5 min | 8 (6 – 9) | |
| Apgar 10 min | 9 (8 – 9) | |
| Meconium stained amniotic fluid | 5 (22%) | |
| Admission to NICU | 10 (43%) | |
| Intubation | 2 (9%) | |
| **Respiratory outcomes** | | |
| Vt (ml/kg) | 4.6 (3.3 – 6.2) | |
| PIP (mbar) | 30.5 (29.9 – 31.8) | |
| PEEP (mbar) | 5.2 (4.2 – 5.8) | |
| Respiratory rate (bpm) | 51 (44 – 56) | |
| Ti (s) | 0.58 (0.53 – 0.66) | |
| **Duration of PPV** | | |
| Episode duration (min) | 5 (3 – 8) | |
| Median number of inflations | 110 (67 – 181) | |
coefficient of variation was 52 (45 – 77) %. Per infant, a
median (IQR) of 36 (25–27) % of inflations were within
target range during the duration of PPV, while 42 (25
– 65) % and 10 (3 – 33) % were above and below target
range, respectively. Typical RFM waveforms for ventilations
within (appropriate ventilations), above (excessive ventilations)
and below (inadequate ventilations) the
target range are shown in Fig. 2. There were no impor-
tant changes in \( V_t \) over the duration of an episode of PPV
(Fig. 3; \( p = 0.673 \)).

**Leak and obstruction**

Median (IQR) leak was 30 (11 – 44) %. The median num-
ber of inflations with obstruction was 0 (0 – 13). At least
one obstructive episode was noted in 10/23 (43%) of the
infants. Infants with at least one episode of obstruction
had a median (IQR) of 9 (1 – 30) obstructed inflations.
The infant with the highest \( V_t \) [13.4 (11.7 – 15.5) ml/
kg] had a median leak of 3% and no obstruction (patient
11, Fig. 1). The video recording showed one resuscitator
applying the mask tightly with two hands while a second
operator applied the inflations to an apneic, floppy infant.

**Clinical outcomes**

Ten of 23 (43%) infants included in the study were admit-
ted to the neonatal intensive care unit (NICU) with the
following diagnosis on admission: sepsis (\( n = 5 \)), respira-
tory distress syndrome (\( n = 2 \)), transient tachypnea of
the newborn (\( n = 1 \)), hypoglycemia (\( n = 1 \)) and hydro-
cephalus (\( n = 1 \)). Four of them received non-invasive res-
piratory support after admission to NICU and two were
intubated. \( V_t \) and number of PPV inflations per infant
in those admitted versus those not admitted were simi-
lar [\( V_t \): 4.8 (2.9 – 7.1) ml/kg versus 4.2 (3.4 – 5.9) ml/kg,
\( p = 0.95 \); number of PPV inflations: 58 (31 – 166) versus
58 (32 – 100), \( p = 0.88 \)].

Two infants were intubated (patient 17 and 18). There
was a non-significant trend towards a lower \( V_t \) and a
higher number of PPV inflations in those infants who
were intubated compared to those who were not [\( V_t \): 2.6
(1.9 – 3.3) ml/kg versus 5.1 (3.4 – 6.4) ml/kg \( p = 0.07 \);
number of PPV inflations 142 (82 – 201) versus 49 (31
– 103), \( p = 0.24 \)]. The two infants that were intubated
had a higher proportion of inflations with obstruction
[19 (7 – 31) %] in comparison with the infants that were
not intubated [0 (0 – 1.5) %], albeit the difference did not reach statistical significance ($p = 0.095$).

One of the infants who were intubated had respiratory distress syndrome and the other transient tachypnea of the newborn.

**Discussion**

We found marked variability of $V_t$ measured in term and late preterm infants when using currently recommended pressure levels for PPV during delivery room stabilization. These findings are in line with recently published data in term infants [7]. Our data, however, highlight that not only was there substantial variability between infants, but $V_t$ was inconsistent within the same individual and leak and obstruction were common.

There are several potential causes of the high variability of $V_t$ observed in this study: (1) The presence of leak and obstruction may contribute. In this study median face-mask leak was 30% and obstruction occurred in 43% of infants. Leak was similar to that previously reported [7]. The incidence of obstruction in term infants has not been reported before. However, obstruction was reported in 25% of preterm infants [5]. (2) The presence of simultaneous spontaneous breaths either during inflation or during deflation may influence $V_t$ variability [17]. Spontaneous breaths during PPV can be triggered by tactile stimulation during mask ventilation [18].

Only half of the infants had a median $V_t$ within the currently recommended target range of 4–8 ml/kg and $V_t$ was in the target rage in only one third of the inflations over the duration of PPV. The optimal $V_t$ during mask ventilation at birth is unknown and the currently recommended $V_t$ target range of 4–8 mL/kg is largely based on data from endotracheal ventilation [3]. Recent studies suggested that $V_t$ in spontaneously breathing term infants during transition are between 2 – 6.5 ml/kg [8] and 2.5 – 8.5 ml/kg [9]. It is unclear whether the suggested reference range of 4–8 ml/kg is safe and effective for term newborns receiving PPV.

The recommended PIP for PPV in the delivery room is based on limited evidence [1] and it remains unclear whether it is sufficient to achieve adequate tidal volumes and lung aeration. Consistent with other reports, our data show that tidal volumes vary considerably despite a fixed PIP [7]. $V_t$ tended to be lower in infants who were subsequently intubated. We speculate that higher PIP levels may be necessary in selected critically ill infants, however more data are required. On the

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**Fig. 2** Shows flow and pressure wave forms as an example for inadequate ventilation (A), appropriate ventilation (B) and excessive ventilation (C). A1 shows inadequate ventilation due to obstruction: although pressure is applied, there is almost no airflow. A2 shows inadequate ventilation due to mask leak: there is very little airflow coming back during expiration. B is an example of appropriate ventilation: there is no leak and $V_t$ is in the target range. C shows excessive ventilation.
other hand, one case showed very high \( V_t \) under optimal conditions in the absence of leak and obstruction. Based on our data, an individualised approach whereby pressures are adjusted to maintain a safe and effective \( V_t \) may be beneficial. A RFM in the delivery room may assist in this regard.

Data from term infants who received 20 PPV inflations with a self-inflating bag without a PEEP valve indicate that higher than recommended PIP levels (36 cmH\(_2\)O) were necessary to achieve adequate \( V_t \) of 3–6 ml/kg [11]. Moreover, there seems to be a positive relationship between heart rate increase and measured \( V_t \) in depressed infants needing PPV [19].

Clinical assessment of \( V_t \) and identification of leak and obstructions is challenging, and the use of a RFM may improve the effectiveness of mask ventilation [20]. However, a multicenter randomized controlled trial showed that the use of a RFM compared to no RFM as guidance for \( V_t \), did not increase the percentage of inflations in a predefined target range [6]. It is unclear whether improvements in monitor design or education in the use of RFM might lead to a different result.

This study has some limitations. It is an exploratory analysis and outcomes were not prospectively defined. It is a single center study with a small sample size and results may not be generalizable to other units using different equipment. Different definitions for target range for \( V_t \) as well as leak and obstruction used in the literature make comparisons with other studies difficult. It would have been interesting to evaluate the effectiveness of the resuscitation in terms of heart rate and oxygen saturations between the groups according to tidal volume, but we were unable to measure these data consistently in our study population.

**Conclusion**

Tidal volumes delivered to term and late preterm infants in the delivery room vary widely both between and within infants, despite a consistent PIP. Airway obstruction and facemask leak are common, resulting in only one third of inflations having an expired \( V_t \) in the recommended range. Finding optimal pressure settings seems challenging and a respiratory function monitor may improve the safety and effectiveness of mask ventilation.
Abbreviations
V̇: Tidal volume; PPV: Positive pressure ventilation; IQR: Inter quartile range; 
RFM: Respiratory function monitor; PIP: Peak inspiratory pressure.

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Authors’ contributions
LS, CMR, VDG and EO contributed to data collection; JT and LS performed data 
extraction and data analysis and wrote the first draft of the manuscript; LS, 
CMR and PGD supervised the project. All authors made substantial contribu-
tions to revising the article critically for intellectual content, and approved the 
final version of the manuscript.

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Availability of data and materials
De-identified individual participant data, study protocol and statistical analysis 
data are available from three months to 10 years following article publication to 
researchers who provide a methodologically sound proposal, with approval by 
an independent review committee ("learned intermediary"). Proposals should 
be directed to janine.thomann@usz.ch to gain access. Data requestors will 
need to sign a data access or material transfer agreement approved by USZ.

Declarations

Ethics approval and consent to participate
This is a secondary analysis of a previously published randomized controlled 
trial conducted at the Royal Women’s Hospital in Melbourne, Australia. The 
original study and secondary analyses were approved by the local ethics 
committee (The Human Research Ethics Committee at The Royal Women’s 
Hospital, Melbourne). All parents provided written informed consent. All 
methods were performed in accordance with the NHMRC National Statement 
on Ethical Conduct in Human Research and other relevant federal and state 
legislation and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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References
1. Madar J, Roehr CC, Ainsworth S, Ersdal H, Morley C, Rudiger M, et al. Euro-
pean resuscitation council guidelines 2021: newborn resuscitation and 
support of transition of infants at birth. Resuscitation. 2021;161:291–326.
2. Perlman JM, Wyllie J, Kattwinkel J, Wyckoff MH, Aziz K, Guinsburg R, et al. 
Part 7: Neonatal resuscitation: 2015 international consensus on cardiopul-
monary resuscitation and emergency cardiovascular care science with 
treatment recommendations. Circulation. 2015;132(16 Suppl 1):S204–41.
3. Klingenberg C, Wheeler KL, McCallion N, Morley CJ, Davis PG. Volume-
targeted versus pressure-limited ventilation in neonates. Cochrane 
Database Syst Rev. 2017;10:CD003666.
4. Mian Q, Cheung PY, O’Reilly M, Barton SK, Polglase GR, Schmolzer GM. 
Impact of delivered tidal volume on the occurrence of intraventricular 
haemorrhage in preterm infants during positive pressure ventilation in 
the delivery room. Arch Dis Child Fetal Neonatal Ed. 2019;104(1):F57–62.
5. Schmolzer GM, Dawson JA, Kamlin CO, 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 Ed. 
2011;96(4):F254–7.
6. van Zanten HA, Kuypers K, van Zewet EW, van Vonderen JJ, Kamlin COF, 
Springer L, et al. A multi-centre randomised controlled trial of respiratory 
function monitoring during stabilisation of very preterm infants at birth. 
Resuscitation. 2021;167:317–25.
7. Bjorland PA, Ersdal HL, Haynes J, Ushakova A, Oymar K, Rettedal SI. Tidal 
volumes and pressures delivered by the NeoPuff T-piece resuscitator dur-
ing resuscitation of term newborns. Resuscitation. 2022;170:222–9.
8. Baixauli-Alacreu S, Padilla-Sanchez C, Hervas-Marin D, Lara-Canton I, 
Solaz-Garcia A, Alemany-Anchel MJ, et al. Expired tidal volume and 
respiratory rate during postnatal stabilization of newborns born at 
term via cesarean delivery. J Pediatr. 2021;16:100063.
9. Blank DA, Gaertner JD, Kamlin COF, Nyland K, Eckard NO, Dawson JA, 
et al. Respiratory changes in term infants immediately after birth. Resusi-
cation. 2018;130:105–10.
10. te Pas AB, Wong C, Kamlin CO, Dawson JA, Morley CJ, Davis PG. Breathing 
patterns in preterm and term infants immediately after birth. Pediatr Res. 
2009;65(3):352–6.
11. Ersdal HL, Ellestvønn J, Perlman J, Gomo O, Moshiro R, Mdoe P, et al. 
Establishment of functional residual capacity at birth: observational study of 
821 neonatal resuscitations. Resuscitation. 2020;153:71–8.
12. Lorenz L, Ruegger CM, O’Currain E, Dawson JA, Thiø M, Owen LS, et al. 
Suction mask vs conventional mask ventilation in term and near-term 
infants in the delivery room: a randomized controlled trial. J Pediatr. 
2018;198:181-6.e2.
13. Liley HG, Mildenhall L, Morley P, Australian New Zealand Committee on 
R. Australian and New Zealand committee on resuscitation neonatal 
resuscitation guidelines 2016. J Paediatr Child Health. 2017;53(7):621–7.
14. Ruegger CM, O’Currain E, Dawson JA, Davis PG, Kamlin COF, Lorenz L. 
Compromised pressure and flow during suction mask ventilation. Arch 
Dis Child Fetal Neonatal Ed. 2010;94(6):F662–3.
15. Yang KC, Te Pas AB, Weinberg DD, Foglia EE. Corrective steps to enhance 
ventilation in the delivery room. Arch Dis Child Fetal Neonatal Ed. 
2020;105(6):605–8.
16. Kamlin COF, Schmolzer GM, Dawson JA, McGrory L, O’Shea J, Donath SM, 
et al. A randomized trial of oropharyngeal airways to assist stabilization of 
preterm infants in the delivery room. Resuscitation. 2019;144:106–14.
17. Schillerman K, van der Pot CJ, Hooper SB, Lopriore E, Walthier FJ, te Pas AB. 
Evaluating manual inflations and breathing during mask ventilation in 
preterm infants at birth. J Pediatr. 2013;162(3):457–63.
18. Gaertner JD, Ruegger CM, Bassler D, O’Currain E, Kamlin COF, Hooper SB, 
et al. Effects of tactile stimulation on spontaneous breathing during face 
mask ventilation. Arch Dis Child Fetal Neonatal Ed. 2021;107(5):508–12.
19. Linde JE, Schulz J, Perlman JM, Oymar K, Blacy L, Kidanto H, et al. The rela-
tion between given volume and heart rate during newborn resuscitation. 
Resuscitation. 2017;117:80–6.
20. O’Currain E, Thiø M, Dawson JA, Donath SM, Davis PG. Respiratory moni-
tors to teach newborn facemask ventilation: a randomised trial. Arch Dis 
Child Fetal Neonatal Ed. 2019;104(6):F582–6.

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