Assist control volume guarantee ventilation during surfactant administration

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ABSTRACT

Objective: To measure changes in ventilator parameters in preterm infants receiving surfactant during assist control volume guarantee (AC/VG) ventilation.

Methods: 22 preterm infants (up to 32 weeks' gestation) receiving surfactant for respiratory distress syndrome were enrolled in a prospective study of ventilator parameters during AC/VG ventilation at a tertiary neonatal intensive care unit. Ventilator pressures, flow and tidal volume waveforms were recorded from the Dräger Babylog 8000 plus in real time, and compared to pre-surfactant measurements.

Results: Following surfactant administration, 21 of 22 babies experienced completely obstructed endotracheal gas flow. Peak inflation pressure (PIP) increased by a median (IQR) of 8 (4–10) cm H_2O, and took 30–60 min to return to baseline. Inspired oxygen concentration was reduced from a median (IQR) of 39% (26%–44%) to 26% (21%–30%) in the first 5 min. The set maximum PIP (P_{max}) limited the delivered PIP such that most babies received tidal volumes less than the target value ($V_{Ttarget}$) immediately following surfactant delivery. Four infants, in a subgroup of 11 infants where P_{max} was set to less than 10 cm H_2O above baseline PIP, were still receiving $<$90% of $V_{Ttarget}$ 20 min post surfactant.

Conclusions: When giving surfactant during AC/VG ventilation, complete obstruction is common. PIPs increased and remain elevated for 30–60 min. The P_{max} setting may restrict tidal volume delivery.

During volume targeted ventilation, the ventilator adjusts peak inflation pressure (PIP) within set limits to achieve a target tidal volume ($V_{Ttarget}$). Volume targeting aims to stabilise the minute volume and reduce volutrauma[1] and atelectotrauma.[2] The Dräger Babylog 8000 plus ventilator targets expired tidal volume (V_{Te}) and therefore takes leak around the endotracheal tube (ETT) into consideration when selecting the PIP for the next inflation.[3 4]

During positive pressure ventilation, factors which affect V_{Te} and therefore the PIP include spontaneous respiratory effort, complete or partial airway occlusion, altered airway resistance, changes in lung or chest wall compliance, ETT leak, changes in respiratory disease and surfactant administration.[5 6]

We studied changes in volume guarantee ventilator parameters following endotracheal surfactant administration.

What is already known on this topic

- In respiratory distress syndrome, oxygen requirements quickly improve following natural surfactant administration.
- Following surfactant therapy, resistance and compliance may initially worsen.

What this study adds

Following surfactant administration during assist control volume guarantee ventilation:

- Complete obstruction to endotracheal tube gas flow is common and may last over 30 s.
- The peak inflation pressure (PIP) increases for up to an hour.
- Delivered tidal volumes may be reduced if set maximum PIP is set close to pre-surfactant PIP.

METHODS

Setting

All infants were studied in the Neonatal Intensive Care Unit (NICU) of The Royal Women's Hospital, Melbourne, Australia. This is a tertiary level unit with over 6000 deliveries annually.[7]

Patients

Preterm infants were studied during either their first or second dose of surfactant while being ventilated with a Dräger Babylog 8000 plus ventilator in assist control volume guarantee (AC/VG) mode. A convenience sample of 22 preterm infants (born at up to 32 completed weeks' gestation) receiving surfactant for respiratory distress syndrome (RDS) were studied when the researcher was available. Patients were not studied if they had another concurrent cause for respiratory distress (eg, pneumothorax) or life threatening congenial abnormalities.

The NICU policy was to give surfactant (Curosurf 100 mg/kg) as a single bolus using a closed technique (Trach Care MAC, Kimberley-Clark/Ballard Medical Products, Roswell, GA) during AC/VG ventilation. Oxygen saturation was targeted in the range 88%–92%.[8] Typical volume guarantee settings were back-up rate 50/min, set maximum PIP (P_{max}) 25 cm H_2O, inspiratory time 0.3 s. P_{max} was progressively increased to 30 or 35 cm H_2O if target tidal volumes were not attained.

Observations

Changes in the ventilator parameters (flow, pressure, volume and FiO_2) were recorded and measured. Digitised data were collected from the Dräger Babylog using Spectra software (Grove Medical, London, UK). Pressure and flow waveforms were recorded at 125 Hz. ETT flow was integrated to derive tidal volume and ETT leak. Ventilator settings (including FiO_2) were recorded every 2 s.

Recordings of ventilator parameters commenced with a baseline period of 10 min prior to surfactant administration and for a period of at least 30 min afterwards.

Main outcome measures

The outcome measures of interest were ETT flow, ventilator pressures and FiO_2. Tidal volume and leak were derived from the flow waveform.

Data were collected and analysed using Access and Excel (v 2003; Microsoft, Redmond, WA) and Stata (v 10, StataCorp, College Station, TX). The Mann–Whitney U test (Wilcoxon rank sum test) was used to assess the null hypothesis for non-normally distributed variables.

RESULTS

The characteristics of the patient cohort and their ventilation settings are shown in table 1.

Obstruction

Immediately following surfactant administration, complete cessation of flow down the ETT (obstruction) was seen in 21 of 22 (95%) infants. The median (IQR) duration of this obstruction was 16 (10–30) s. The longest episode of complete obstruction lasted 52 s. The median (IQR) duration of obstruction for infants receiving their second dose was 22 (14–34) s compared with 12 (10–23) s for infants receiving their first dose. This difference was not statistically significant ($p = 0.4$).

Oxygen

Inspired oxygen concentration was reduced in the first 5 min after surfactant administration from a median (IQR) of 39% (26%–44%) to 26% (21%–30%).

Inflation pressure

Pre-surfactant PIP was a median (IQR) of 19 (16–22) cm H_2O. Following surfactant administration, PIP increased in all patients up to 27 (23–30) cm H_2O ($p<0.001$) and then took 30–60 min to return to baseline (fig 1).

Tidal volume

Frequently, the set P_{max} limited the increase in PIP and the measured tidal volume was restricted. In the first 20 min following surfactant administration, 14 of 22 infants had a period of at least 1 min during which delivered tidal volume was less than 90% of $V_{Ttarget}$. In five infants, this persisted for 20 min after surfactant was given (even if the P_{max} setting was increased by the clinical team). Post hoc analysis suggested that this was more common in infants who had P_{max} set at less than 10 cm H_2O above pre-surfactant PIP. In this subgroup of 11 infants, four were still receiving less than 90% of $V_{Ttarget}$ 20 min post surfactant (fig 2). Review of the respiratory waveforms did not suggest that increasing the inspiratory time would adjust volumes to maintain $V_{Ttarget}$.

No patients in our sample subsequently developed a pneumothorax.

Table 1 Characteristics of the patient cohort and their ventilation settings (n = 22)

Infants	
Gestational age, weeks	28 (26–29)
Birth weight, kg	0.9 (0.7–1.4)
Intubated in delivery room, n (%)	17 (77%)
Female, n (%)	6 (27%)
Any antenatal steroid treatment, n (%)	16 (72%)
Outborn, n (%)	3 (14%)
Age at surfactant administration	
First dose (n = 14), h	1 (¾–4½)
Second dose (n = 8), h	13 (11–14½)
Duration of first period of ventilation, h	48 (20–98)
Ventilation	
Positive end expiratory pressure, cm H_2O	5 (5–6)
Set target tidal volume ($V_{Ttarget}$), ml/kg	4.0 (3.9–4.5)
Baseline peak inflation pressure (PIP), cm H_2O	18 (16–23)
Set maximum PIP limit (P_{max}), cm H_2O	30 (25–35)
Baseline inspired oxygen concentration, %	39 (32–44)
Ventilator back-up rate, per minute	50 (40–60)
Endotracheal tube leak, %	4 (0–10)

Continuous variables are expressed as median (inter-quartile range), discrete variables as number (%).

DISCUSSION

Obstruction

Immediately after surfactant administration, completely obstructed flow was seen in all except one infant. A quarter of the infants studied had complete obstruction persisting longer than 30 s. We note that infants received 1.25 ml/kg surfactant, a relatively small volume (100 mg/kg Curosurf).

This is not just a phenomenon related to volume guarantee ventilation. Obstruction was common during early studies of surfactant during non-volume guarantee ventilation. In a study comparing synthetic surfactant (Exosurf) with bovine surfactant (Infasurf), obstruction was reported to occur in 20%–50% of surfactant administrations.[9] The authors reported that obstruction was observed more commonly in infants receiving bovine surfactant, particularly during their second or third doses.

Hentschel *et al* measured resistance and compliance at 3 min intervals during a study of bolus versus slow infusions of (mainly bovine) surfactant.[10] A marked increase in resistance to three times baseline was observed immediately after surfactant administration, described as "acute massive obstruction of airways".

Our finding is important because clinicians may need to intervene if obstruction is prolonged. During complete obstruction, the Dräger Babylog suspends volume guarantee operation and uses a fixed PIP set midway between positive end expiratory pressure (PEEP) and PIP.[11] This reduced PIP may be insufficient to overcome the opposition to flow following surfactant administration and may prolong the duration of the obstruction. Clinicians prefer to avoid suctioning following surfactant administration. In order to overcome obstruction manual inflations, increasing the P_{max} setting and increasing ventilator cycle times may be tried. These strategies should be tested in future clinical trials.

Pressure

We observed an increase in inflation pressures following surfactant treatment which took 30–60 min to return to baseline. Hentschel *et al* also reported initially decreased compliance.[10] Immediately following bolus surfactant administration, compliance decreased before returning to baseline at 45 min after administration. A requirement for increased ventilator pressures in volume guarantee mode is consistent with increased resistance and decreased compliance. In their study, infants were followed to 102 min. During this time period, a statistically significant improvement in compliance was not observed in the bolus surfactant group, but they did report improved compliance at 90 min after administration in the group who received infused surfactant.

Tidal volume

In five of 22 infants, the P_{max} setting limited the delivered PIP to the extent that at 20 min after surfactant administration, infants were still not achieving 90% of $V_{Ttarget}$. Tidal volume

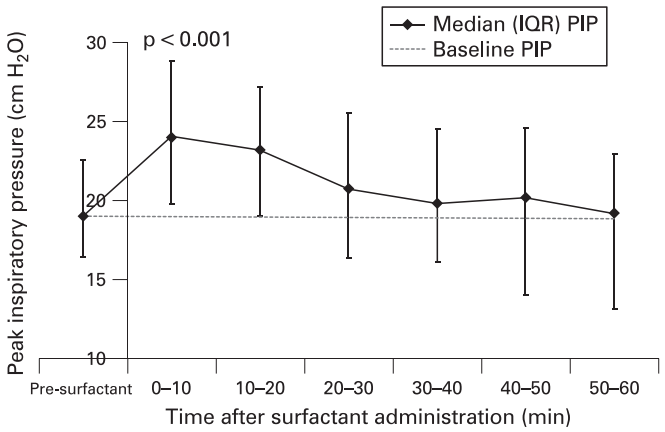

Figure 1 Graph showing peak inspiratory pressure (PIP) before and after surfactant administration. The mean PIP for each infant is calculated in 10 min epochs. Data are plotted as medians and inter-quartile ranges (IQR). The baseline pre-surfactant PIP is shown for comparison.

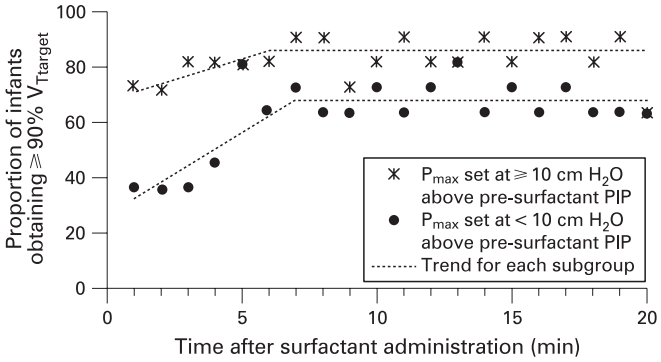

Figure 2 Graph showing the proportion of infants achieving at least 90% of the target tidal volume ($V_{Ttarget}$) during the 20 min after surfactant administration. Two subgroups are shown: those with P_{max} set at less than 10 cm H_2O above baseline PIP, and those with P_{max} set at least 10 cm H_2O above baseline PIP. The trend for each subgroup is shown for comparison. PIP, peak inflation pressure; P_{max}, set maximum PIP.

restriction was observed more commonly when P_{max} was set closer to baseline PIP.

This observation contrasts markedly with that of oxygen requirements which fell within 5 min of surfactant administration. We speculate that improved oxygenation is due to better ventilation–perfusion matching. However, infants will not receive the intended tidal volumes unless the ventilator maximum pressure settings are appropriate. During surfactant administration without volume targeting, tidal volumes and inflating pressures are often not monitored. Some clinicians advocate hand ventilating the infant for a period following surfactant administration. It may be this intervention uses high inflation pressures and longer inflation times, assisting with surfactant distribution and/or post-surfactant lung recruitment. Although first doses of surfactant are often given in delivery rooms, an increasing number of second doses will be given to infants receiving volume targeted ventilation. Surfactant given in delivery rooms is not usually administered during volume targeted ventilation. More research is needed to evaluate whether these findings are replicated in the delivery room. Changes in resistance and compliance may have implications for the practice of early extubation after surfactant administration.

Similarly, if these findings are due to peri-surfactant changes in resistance, then there may be implications for clinicians using pressure limited ventilation as well as other volume targeted ventilators. All patients in this study were ventilated using the volume guarantee mode on the Dräger Babylog 8000 plus ventilator, and it is not known whether our results are applicable to other ventilators which use different algorithms to achieve volume targeting.

Regardless of the ventilator used, settings should be selected with an awareness of changes in respiratory pathophysiology due to characteristics of the infant, their illness and therapy. This includes a potential need to increase PIP or inspiratory time in order to deliver appropriate tidal volumes.

Further research is needed to determine whether similar results are found when other volume targeted ventilators are used. In addition, optimal ventilator settings during volume guarantee ventilation including P_{max} and inspiratory time settings should be investigated. In clinical practice, infants with high pre-surfactant PIPs are a particular challenge as clinicians may be wary about using significantly higher P_{max} settings.

CONCLUSIONS

Following surfactant administration during AC/VG ventilation, completely obstructed flow was common and lasted over 30 s in 25% of infants. Oxygen requirements reduced, which allowed Fio_2 to be weaned within a few minutes. Median (IQR) PIP increased by 8 (4–10) cm H_2O, and took 30–60 min to return to baseline. The P_{max} setting limited the potential increase in PIP. In a subgroup of 11 infants where P_{max} was set at less than 10 cm H_2O above baseline PIP, four were still achieving less than 90% of $V_{Ttarget}$ 20 min after surfactant administration. It is speculated this may be due to changes in resistance.

More research is needed to evaluate optimal strategies for managing obstruction and the selection of ventilator settings during surfactant administration and to investigate whether these findings are seen in patients ventilated using different neonatal ventilators and with other modes of ventilation.

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