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CHAPTER 5

Influence of the hand squeeze and mask distensibility on tidal volume measurements during neonatal mask ventilation

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Abstract

**Background:** During mask ventilation the mask volume can vary as it is pressurized or when it is squeezed. The change in volume of the mask may affect tidal volumes delivered and difference in inspired (Vti) and expired tidal volumes (Vte).

**Objectives:** To investigate whether hand squeeze and distensibility of the mask during ventilation influences tidal volume measurements.

**Methods:** For both experiments we ventilated a leak free mask ventilation model using pressures of 25/5 cmH$_2$O through a t-piece. Vti and Vte were measured. A) 2 consultants performed mask ventilation with 1) consistent hand squeeze, 2) release during inflation and squeeze during expiration, 3) squeeze during inflation, release during expiration, and 4) gentle squeeze. B) 30 caregivers performed mask ventilation.

**Results:** Experiment A) Vti was different during consistent hold 1) 8.1 (0.4) and loose grip 4) 8.2 (0.3)mL compared to squeezing during inflation 2) 18.9 (1.9), or expiration 3) 6.4 (3.5)mL. Variance in difference between Vti and Vte occurred only when mask was squeezed during inflation (-47.4 (101.5)%). Experiment B) volumes measured were consistent (intra-individual coefficient of variance (CV) 3-5%, inter-individual CV 9-10%). When comparing gas flow rate of 6 to 10 L/min, volumes increased approximately 8%, differences in Vti and Vte were small with both flow settings (-0.9 (-3.9-1.4)% and -0.6 (-3.3-1.8)% (ns)).

**Conclusion:** Variation in mask hold during mask ventilation can influence volume measurement, but this hardly occurs when testing caregivers.
Introduction

Adequate non-invasive ventilation using a mask as interface plays an important role in neonatal resuscitation (1-4). It has been suggested that a respiratory function monitor as a feedback device during neonatal resuscitation will be helpful and can inform the clinician about the tidal volumes delivered and whether mask leak occurs (5). Recently we observed that during mask ventilation caregivers exerted variable forces on the head, which might imply that the mask is squeezed on the face in a variable way (6). The hand squeeze and release could affect the volume of the masks of the mask. In addition, during inflation the mask is pressurized fast which could lead to some distention. Depending on how much flow is used (4), this could happen faster and cause more distention. When the inspiratory pressure is decreased the mask will possibly deflate.

We hypothesized that the interaction between 1) the pressurization and pressure release of the mask and 2) squeezing and release of the mask could result in a variable dead space of the mask affecting the tidal volumes administered during resuscitation and measured by a respiratory function monitor. This interaction could also lead to differences in inspired (Vti) and expired tidal volumes (Vte). This difference is used to calculate mask leak (6) and therefore under- or overestimation of mask leak could occur.

The aim of this study was to investigate whether during mask ventilation, using two different gas flow rates, there is a variation in dead space influencing tidal volumes measurement and the difference in Vti and Vte.

Methods

The study was performed in the Leiden University Medical Center (LUMC), Leiden, the Netherlands. This is a tertiary level perinatal center with an average of 400 neonatal intensive care admissions per year. Thirty registrars, fellows and nurses of the Neonatology department of the LUMC were asked to mask-ventilate a modified leak free manikin (Laerdal Resusci Baby, Laerdal, Stavanger, Norway). The manikin, representing a term newborn, had a modified leak free 50 mL test lung (Dräger, Lübeck, Germany) that was positioned so that chest excursions were visible. Non-distensible tubing connected the lung and mouth.

Our aim is to measure the effect of ‘hand-squeeze’ and release during mask hold, and pressurization or pressure release of the mask, which can decrease and increase dead space of the mask. To eliminate all other variables that could influence our measure-
ments, the mask (Laerdal size 0/1 round mask, Stavanger, Norway) was glued onto the face of the manikin, making the system leak free. Before each participant entered the room we confirmed that there was no leak in the system or between the mask and face. The mask was glued in such a way that volume changes of the mask were still possible. Positive pressure ventilation was applied using a T-piece infant resuscitator (Neopuff, Fisher & Paykel Healthcare, Auckland, New Zealand). The Neopuff was set to a peak inspiratory pressure (PIP) of 25 cmH$_2$O and a positive end expiratory pressure (PEEP) of 5 cmH$_2$O at both gas flow rates; gas flow rate was alternately set to 6 and 10 L/min and 21% oxygen was used.

Gas flow was measured using a Florian respiratory function monitor (Acutronic Medical Systems AG, Hirzel, Switzerland) which uses a hot-wire anemometer as a flow sensor with a dead space of ±1 mL. The hot-wire anemometer measures gas flow across the sensor by measuring differences in conductance. These measurements are then automatically integrated over time of the inflation or expiration to provide Vti and Vte. The manufacturer of the anemometer (Acutronic Medical Systems AG, Switzerland) indicates an accuracy of ±8% (manufacturer’s data) (7). When measuring mask ventilation in the delivery room, the amount of mask leak would be expressed as the percentual difference in Vti and Vte ((Vti-Vte)/Vti*100%) which we address as difference in Vti and Vte as the system is leak free (8). The flow sensor was placed distally from the Neopuff, between the T-piece and the facemask. The output signals were digitized and recorded at 200 Hz using a customized data acquisition program (Spectra, Grove Medical Limited, Hampton, UK) (9). For experiment A) we tested if hand squeeze and release could cause a variation in tidal volume and difference in Vti and Vte we asked 2 consultants to ventilate the manikin at 8 L/min and 1) apply a consistent hand squeeze using the two point top hold (2), 2) deliberately let the mask expand during inflation and applying a hand squeeze during expiration, 3) deliberately apply a hand squeeze during inflation and let the mask extend during expiration and 4) apply only a gentle hand squeeze (a loose grip). During all episodes we recorded 30 s of ventilation. Both the selected consultants have more than 10 years of experience in mask ventilation. Furthermore, we empirically tested the maximum volume change by filling the glued mask with water up to the tubing attached to the mouth, which was blocked, and varying mask squeeze from maximal to minimal using a Laerdal 0/1 facemask.

For experiment B) 30 participants were asked to ventilate the manikin. These participants were all experienced in mask ventilation and are trained four times a year in mask ventilation using the two-point top hold. They were randomly selected from the medical staff at work on the days of recording. The mask was held in position by one of the inves-
tigators when participants entered the room. The participants were not fully informed about the aim of this study. All participants were told that solely the effect of mask hold was investigated, not mask position and that mask leak could still occur. The screen of the respiratory function monitor and the laptop were not visible for the participants. All participants were asked to ventilate the manikin for 30 seconds on two occasions: using a gas flow rate of 6 L/min and 10 L/min. Since both experiment A and B were conducted using a manikin no ethical approval was required.

**Statistical analysis**

Data were analyzed using SPSS for Windows version 17.0.0. The results are presented as mean (SD) or median (range). Mean percentage of difference in Vti and Vte were compared using a paired t-test. To quantify the intra- and inter-individual differences an ANOVA was used. To express variability in measurements between caregivers (inter-individual) and between inflations per caregiver (intra-individual) we used the coefficient of variation (CV), which was calculated as (SD/mean)*100%. A CV <5% was regarded to reflect good agreement and a CV <10% to reflect acceptable agreement. A p-value <0.05 was considered statistically significant. Reported p-values are two-sided.

**Results**

**Experiment A**

Measured Vti were significantly different from consistent hold (1) 8.1 (0.4), 4) 8.2 (0.3) mL when squeezed during inflation or expiration ((2) 18.9 (1.9), 3) 6.4 (3.5) mL; p<0.0001). Variance in difference between Vti and Vte occurred only when mask was squeezed during inflation and released during expiration with -47.4 (101.5)% (table 1). Maximal volume change measured by filling the mask with water was 21 mL (out of a total dead space of 40 mL). Figure 1a illustrates a measurement during a consistent hold and figure 1b during mask squeeze during inflation and release during expiration.

**Table 1.** Ventilation of the manikin by 2 consultants applying different mask holds. A) consistent hold, B) allowing mask distention during inflation and squeeze during expiration, C) squeeze during inflation and distention during expiration and D) loose grip. * = P <0.01

<table>
<thead>
<tr>
<th></th>
<th>Consistent hold</th>
<th>Squeeze expiration</th>
<th>Squeeze inflation</th>
<th>Loose grip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vti (mL)</td>
<td>8.1 (0.4)</td>
<td>18.9 (1.9)</td>
<td>6.4 (3.5)*</td>
<td>8.2 (0.3)</td>
</tr>
<tr>
<td>Vte (mL)</td>
<td>8.3 (0.5)</td>
<td>19.0 (1.5)</td>
<td>6.3 (1.9)*</td>
<td>8.4 (0.2)</td>
</tr>
<tr>
<td>Leak (%)</td>
<td>-2.7 (7.4)</td>
<td>-1.1 (8.4)</td>
<td>-47.4 (101.5)</td>
<td>-1.6 (3.2)</td>
</tr>
</tbody>
</table>
Experiment B

Participants

In total 1177 inflations were analysed. These were 551 inflations (±37 inflations per minute) at a gas flow rate of 6 L/min and 626 inflations (±42 breaths per minute) at a gas flow rate of 10 L/min. We obtained recordings from 30 participants (10 consultants, 5 registrars and 15 neonatal intensive care unit nurses). All participants were trained and experienced in mask ventilation.

Tidal volume

Increasing gas flow rate from 6 to 10 L/min led to a small but significant increase in Vti from 8.1 (0.8)mL to 8.8 (0.8)mL (p<0.01) and Vte from 8.2 (0.8) mL to 8.9 (0.8)mL (p<0.01) (figure 2).

The intra-individual CV was 4 (1-7)% for Vti and 5 (1-12)% for Vte at a gas flow rate of 6 L/min. At a gas flow rate of 10 L/min the CV was 3 (1-6)% for Vti and 4 (1-10)% for Vte (figure 3). At both gas flow rates the intra-individual CV showed good agreement.

The inter-individual CV was 9%, which reflects acceptable agreement for both Vti and Vte at a gas flow rate of 6 L/min. At a gas flow rate of 10 L/min inter-individual CV for Vti was 9% and for Vte 10%, which in all cases indicates acceptable agreement (figure 4).
**Difference in Vti and Vte**

Median difference in Vti and Vte during mask ventilation using a flow of 6 L/min and 10 L/min was respectively -0.9 (-3.9-1.4)% and -0.6 (-3.3-1.8)% (ns).

**Figure 2.** Changes in tidal volumes during positive pressure ventilation at a flow of 6 L/min (grey bars) and at a flow of 10 L/min (hatched bars). The box plots show median values (solid black bar), inter quartile range (margins of box), and range of data.

**Figure 3.** Changes in inspiratory tidal volumes during inflations at a gas flow rate of 6 L/min per participant. The box plots show median values (solid black bar), inter quartile range (margins of box), and range of data.
Discussion

In this study we have evaluated the effect of different applications of squeeze and release by two practitioners on tidal volumes and the difference in Vti and Vte. Also, we have tested the occurrence of variations in tidal volumes and difference in Vte-Vti during ventilation by 30 participants at two different gas flow rates. The maximal volume change between a collapsed and a distended mask is 21 mL.

We observed a difference in measured tidal volumes when hand squeeze and release occurs during ventilation when compared to a consistent hold. Also, when hand squeeze occurred during inflation and was released during expiration we observed a large variation in Vti-Vte difference. If this occurs during mask ventilation, tidal volume to the lung and the amount of mask leak could be over or underestimated. However, when testing caregivers, the measured tidal volumes were quite consistent. Also, the differences between Vti and Vte were minimal. There was some increase in tidal volumes when flow was increased, but the clinical significance of this is questionable. Apparently when caregivers, unaware of the purpose of this study, ventilate the manikin as they normally would, there was little variation in tidal volumes and difference in tidal volumes which might implicate that there was minimal variation in mask squeeze and gaseous distention of the mask.

When, in experiment A, hand squeeze occurred during expiration and was released during inflation the increased dead space of the mask explains the larger tidal volumes
as this is now added to the total measured volume. However, when hand squeeze occurred during inflation and release during expiration, smaller tidal volumes were measured. The squeeze and release caused a flow into the opposite direction and did not only change the flow rate but also interrupted inflation and expiration, which led to measurement of two inflation-expiration cycles instead of one (figure 1b). This also led to unequal in-and expiratory flow waves leading to large Vti-Vte differences. In addition, it is possible that the change in gas flow rate put the flow measurement into different regions of the measurement sensitivity curve, thereby giving different measurements. We speculate that spontaneous breathing interfering with mask ventilation can have similar effects on flow measurements. Indeed, McCallion et al. described that during expiratory breaking of infants (causing changes in gas flow) tidal volumes measurements became inaccurate (7;10).

In experiment B the effect of gaseous distention and hand squeeze of the face mask during the administration of PPV caused small variation in tidal volumes delivered providing a CV with good agreement. The observed variations are within the measurement error of the respiratory function monitor and are probably clinically not relevant.

te Pas et al. reported that leak decreased using a lower gas flow rate (5 L/min) during PPV when compared to a higher gas flow rate (10 L/min) (11). It was speculated that the higher pressurization, leading to larger gas distension of the mask and thus more bouncing, would explain higher incidence of leak by breaking the seal (11). However, our current findings do not support this relationship. We observed a small increase in measured tidal volumes and the Vti-Vte difference remained very small (within the 8% accuracy level of the hot wire flow meter). When we tested participants in experiment B, we did find a significant difference in Vti and Vte, between participants or inflations given by the same participant. This difference is however not clinically important. Also, comparing a low versus a higher gas flow rate, potentially causing more distention and bouncing of the mask, did not significantly influence the difference in Vti and Vte and tidal volumes significantly. Apparently there is little variation in tidal volumes and the observed difference is within the 8% accuracy level of the respiratory function monitor. It is possible that the consistent “hand squeeze” reduces the effect of pressurization and release.

O’Donnell et al. tested the accuracy of the hot wire anemometer during mask ventilation and observed that during inflations with small leak (<51%) a larger change in tidal volume at the face mask was observed compared to the tidal volume that entered the test lung (8). It was concluded that a part of the administered volume distended the mask and therefore did not enter the lungs. The difference in tidal volumes measured at
the mask and in the test lung however decreased as leak increased. However, we could not confirm this in our study. We eliminated leak in our study and we observed that intra- and inter individual variance of the tidal volumes was small reflecting good and acceptable agreement. Therefore, it is likely that in the study of O’Donnell et al. (8) the volume differences were caused by the occurrence of leak in both in- and expiration and not by distention.

To test our hypothesis, we needed to eliminate other factors influencing measurements and are therefore bound to a manikin model. The manikin has its limitations (3) and there is no guarantee that we will find the same results in a clinical setting. Mask hold of caregivers, during a stressful resuscitation in the delivery room, could be different than when they ventilate a manikin. Also, although participants were told that leak was possible, less effort could have been provided to reduce mask leak given that the mask was fixated on position due to the visibility of the pressure gauge on the Neopuff. However, participants were taught that a decrease in pressure occur only when there is a large mask leak, as a recent study has shown performed in our unit (10).

Conclusion

We demonstrated in a leak free mask ventilation model that variation in hand squeeze and mask distensibility could influence volume measurements and difference between Vti and Vte. However, when testing caregivers very little variation occurs and not relevant to take into account when measuring tidal volume during mask ventilation.

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References
