Improving neonatal resuscitation at birth : technique and devices

Schilleman, K.

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Changing gas flow during neonatal resuscitation: a manikin study

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Abstract

Introduction

When using a T-piece device, resuscitators may try to improve airway pressures by increasing gas flow instead of correcting face mask position.

Aim

To measure the effects of changing gas flow during positive pressure ventilation (PPV) on peak inflating pressure (PIP), positive end expiratory pressure (PEEP), expired tidal volume (V_{Te}) and mask leak.

Methods

Using a Neopuff T-piece device, 20 neonatal staff members delivered PPV to a modified, leak-free manikin. Resuscitation parameters were recorded. Study A: PPV for four minutes at PIP 30 cm H_2O and PEEP 5 cm H_2O. Each minute gas flow was increased (5, 8, 10, and 15 L/min). PIP and PEEP settings were unchanged. Study B: same pressure settings; PPV for one minute with 5, 8, 10, and 15 L/min in a random order, at a rate of ~60/min. The pressures were adjusted to maintain the same PIP and PEEP after each flow change.

Results

Study A: as gas flow increased (5, 8, 10 and 15 L/min) the median PEEP increased from 4.7 to 26.4 cm H_2O ($p < 0.002$). Median V_{Te} decreased from 10.0 to 0.8 mL ($p < 0.001$). PIP increased slightly from 30 cm H_2O to 36 cm H_2O at 15 L/min ($p < 0.005$). Mask leak increased from 14% to 98% ($p < 0.001$) because mask pressure increased. Study B: when PIP and PEEP were maintained there were no significant differences in V_{Te} ($p = 0.42$) or mask leak ($p = 0.51$) with changing gas flow.

Conclusion

During PPV increasing gas flow dramatically increased PEEP and mask leak and in consequence reduced V_{Te}. Gas flow should rarely be changed during T-piece resuscitation.

Introduction

The Neopuff Infant Resuscitator (Fisher & Paykel Healthcare, Auckland, New Zealand) is a T-piece device that is commonly used to provide positive pressure ventilation (PPV) for newborn infants in the delivery room.[1-3] The object of PPV is to establish a functional residual capacity and deliver an appropriate tidal volume to achieve effective gas exchange.[4] Failure to achieve a set airway pressure with a T-piece resuscitation device may be due to a large mask leak. This is a common, usually unrecognised problem and can lead to inadequate ventilation.[5-10] Resuscitators may try to increase the airway pressure by increasing gas flow instead of correcting face mask position. The Neopuff T-piece resuscitation device uses a flow resistor expiratory pressure valve system to generate a positive end expiratory pressure (PEEP) or continuous positive airway pressure (CPAP). It does so by imposing an adjustable orifice resistance to exhaled flow rate. When the flow rate is constant, the expiratory positive pressure varies inversely with the orifice size. The pressure generated is directly related to the resistance to the gas flow.[11] A recent study by Hawkes et al. demonstrated that the peak inflating pressure (PIP) and PEEP valves of a Neopuff T-piece device can be overridden when the gas flow is increased. In that study the mean PEEP increased from 5 to 20 cm H_2O and the mean PIP increased from 20 to 28 cm H_2O when gas flow was increased from 5 to 15 L/min.[12] Another study found that if the gas flow is increased to 15 L/min the PEEP rises to about 24 cm H_2O, and PIP is similar to, or just above, the set PIP even when max PIP is set very high.[13]

No study has reported the effects of increasing gas flow on tidal volume and mask leak. Using a modified, leak-free, manikin we investigated the effects of gas flow changes on delivered expired tidal volume (V_{Te}), ventilating pressures and face mask leak during PPV.

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Methods

Participants

Neonatal consultants, fellows (SpR grade), registrars (SHO grade) and nurses of The Royal Women's Hospital, Melbourne, Australia participated in this study. All had received training in neonatal resuscitation and mask handling technique. It is a tertiary perinatal care centre with about 6000 deliveries and admits more than 100 extremely low birth weight infants a year. Participants were acquainted with resuscitation research and may have participated in studies before.

Manual ventilation device and face mask

The Neopuff Infant Resuscitator (Fisher & Paykel Healthcare, Auckland, New Zealand) is a T-piece continuous flow, pressure limited device with a manometer and a PEEP valve. All participants were experienced in its use. A size 0/1 Laerdal round face mask (Laerdal, Stavanger, Norway) was used.

Modified manikin

A Laerdal Resusci Baby manikin (Laerdal, Stavanger, Norway) was modified by replacing the original lung with a 50 mL test lung (Dräger, Lübeck, Germany) positioned so inflation caused visible chest rise. The test lung was connected by non-distensible tubing to the mouth with an airtight seal which bypassed the bar in the neck that can cause obstruction when the neck is over flexed or extended.[8] A pressure monitoring line was connected to the airway. The system compliance when pressurised to 30 cm H_2O was 0.5 mL/cm H_2O, with a maximal lung volume of 65 mL.

Respiratory function monitor and recording system

A Florian Respiratory Function Monitor (Acutronic Medical Systems AG, Zug, Switzerland) was used to measure airway pressures and gas flow. A hot wire anemometer flow sensor was placed between the T-piece and face mask. Gas flow, airway pressures and tidal volume were recorded at 200 Hz using Spectra physiological recording software (Grove Medical, London, UK). Airway pressure was calibrated against a column of water and tidal volume was calibrated using a 10 mL syringe. Tidal volume (V_T) was calculated by the program integrating the gas flow. Mask leak was calculated by using the following formula: ((inspired V_T – expired V_T) / inspired V_T) x 100 and expressed as a percentage of the inspired V_T.[8,14,15] During the study neither the Florian monitor nor the computer screen were visible to the participants.

Study protocol

The participating staff were asked to give PPV to the modified manikin using the following technique: place the manikin's head in a neutral position and gently roll the mask upwards onto the face from the tip of the chin. Hold the mask with the two-point-top hold where the thumb and index finger apply balanced pressure to the top flat portion of the mask where the silicone is thickest. The stem is not held and the fingers should not encroach onto the skirt of the mask. The thumb and index finger apply an even pressure on top of the mask. The third, fourth and fifth finger perform a chin lift using the same pressure upwards as applied by the thumb and index finger downwards.[16] The technique was explained, demonstrated and practice time was given to each participant before the studies. There was a five minute rest period between each study. Each participant did two studies and randomly started with either one.

Study A

With a gas flow of 5 L/min the PIP and PEEP were set to 30 cm H_2O and 5 cm H_2O. Each participant was asked to deliver PPV continuously for four minutes with a rate of ~60/min. Each minute the gas flow was increased to 8, 10, and 15 L/min. Neither the PIP nor the PEEP were adjusted after each gas flow increment.

Study B

The PIP and PEEP were set to 30 cm H_2O and 5 cm H_2O. Participants were asked to deliver PPV for one minute with gas flows of 5, 8, 10, and 15 L/min in a random order, at a rate of ~60/min. After each gas flow change, both the PIP and PEEP were adjusted to maintain 30 cm H_2O and 5 cm H_2O.

Participants were aware that gas flow was being studied but were masked to the gas flows used during both studies. The order of the studies, as well as the order of changes in gas flow in study B, was randomised. The manometer showing the pressures being delivered to the manikin was visible.

Questionnaire

The participants' professional category, level of neonatal experience and their level of experience with mask ventilation (either with a T-piece device or bag and mask) were recorded. In addition, participants were asked which of the four gas flows were the most and least comfortable during study B.

Data collection and analysis

Data were recorded for each gas flow change. The first five inflations of each recording were excluded from the analysis. Each inflation was analysed separately using the Spectra software and the waves of pressure, flow and tidal volume were used to determine the delivered expired tidal volume, PIP, PEEP, and mask leak for each inflation. Because of the difference in ventilation rate for each participant and thereby the number of inflations given in 60 seconds the median expired tidal volumes and percentage leak were calculated for each participant with each recording.

Data was analysed and entered into an SPSS database (SPSS for windows, version 16.0, 2008, Chicago, IL). Results are presented as mean (SD) for normally distributed continuous variables and median (IQR) for variables with a skewed distribution. ANOVA for repeated measurements were compared for each of the different gas flow rates. A p-value of < 0.05 was considered statistically significant. Reported p values are two-sided.

Results

Participants

Five neonatal consultants, five fellows, five registrars and five nurses participated in the study. The mean (SD) years of experience with mask ventilation were: consultants 15.0 (5.1) years, fellows 7.8 (3.1) years, registrars 0.7 (0.4) years and nurses 4.0 (2.4) years. A total of 9644 inflations were analysed; 3493 for study A and 3451 for study B. The mean (SD) number of inflations per participant used for analysis were 175 (41) in study A and 173 (43) in study B.

Airway pressures

Study A

The median (IQR) PEEP increased with increasing gas flow. At 5 L/min it was 4.7 (4.2–5.2) cm H_2O, with 8 L/min 11.4 (10.5– 12.4) cm H_2O, with 10 L/min 16.8 (14.4–18.2) cm H_2O and with 15 L/min 26.4 (24.5–27.4) cm H_2O ($p < 0.002$ for each gas flow rate compared) (figure 1).
The median (IQR) PIP increased with increasing gas flow. With a gas flow of 5 L/min participants delivered 29.8 (29.3–30.3) cm H_2O, with 8 L/min 31.2 (29.8–31.7) cm H_2O, with 10 L/min 32.2 (30.8–33.2) cm H_2O and with 15 L/min 35.6 (33.7–37.0) cm H_2O ($p < 0.005$ for each gas flow rate compared) (figure 1).

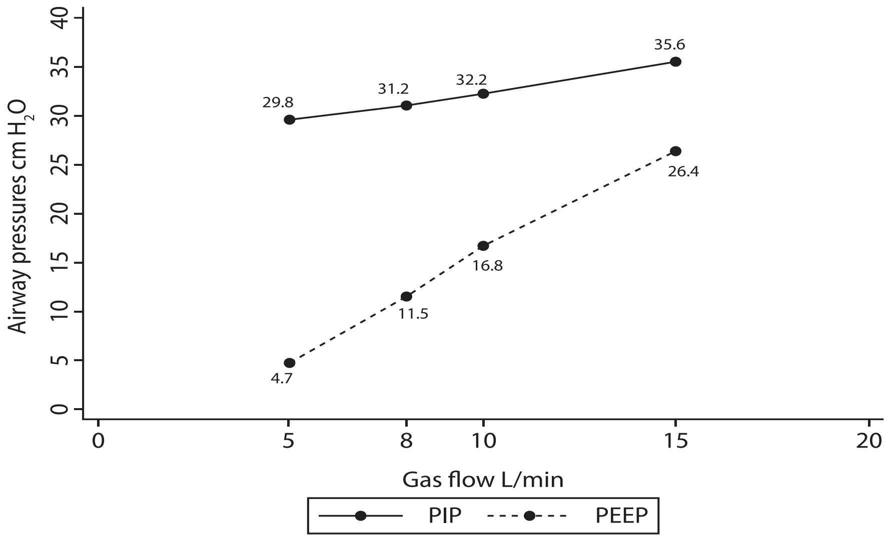

Figure 1. Adjustments in gas flow in study A and the effect on PIP and PEEP. These lines show the effect of altering the gas flow on ventilatory pressures. The continuous line shows the effect on PIP. The dotted line shows the effect on PEEP.

Study B

The PIP and PEEP were maintained as planned to 30 cm H_2O and 5 cm H_2O.

Expired tidal volume

Study A

The median (IQR) V_{Te} decreased significantly with increasing gas flow from 10.0 (8.5–11.4) mL at 5 L/min to 6.3 (3.9–7.4) mL at 8 L/min, 3.5 (0.7–5.4) mL at 10 L/min and 0.8 (0–1.7) mL at 15 L/min gas flow ($p < 0.001$ for each gas flow rate compared) (figure 2).

Study B

There was no significant change in V_{Te} with different gas flow rates ($p = 0.42$). The median (IQR) V_{Te} was 10.5 (8.7–10.9) mL with a gas flow of 5 L/min, 10.5 (8.8–11.6) mL with 8 L/min, 11.0 (9.2–12.4) mL with 10 L/min and 11.3 (9.3–12.2) mL with 15 L/min (figure 2).

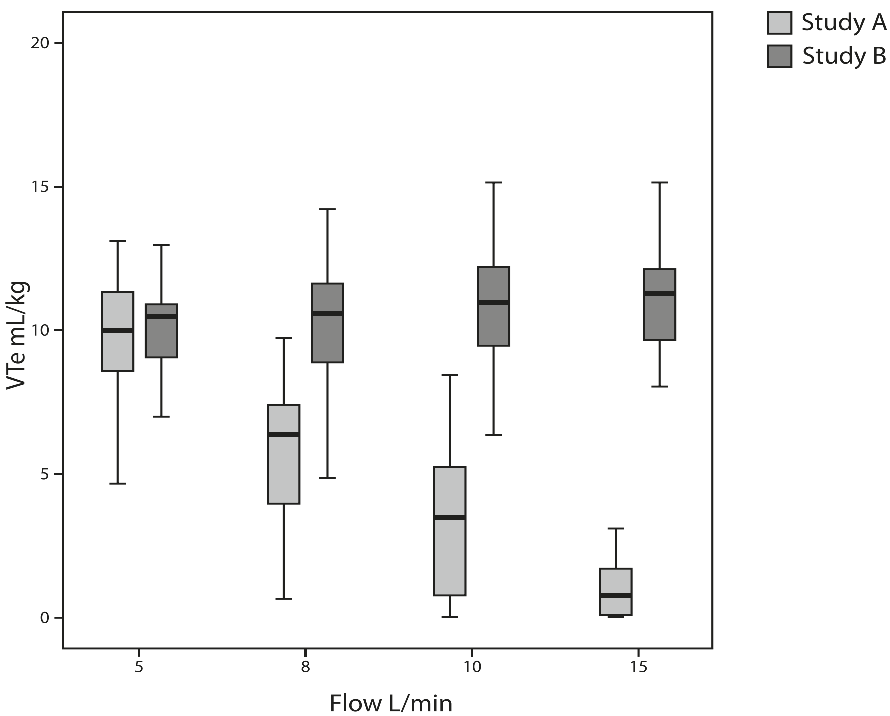

Figure 2. Changes in tidal volume during both studies. The hatched bars show the results of study A. The plain grey bars show the results of study B. The box plots show median values (solid black bar), inter quartile range (margins of box), and range of data.

Relationship between PEEP and V_{Te}

Study A

With increasing gas flow the median (IQR) PEEP showed a significant increase and V_{Te} showed a significant decrease. PIP increased less then PEEP with changes in gas flow and the pressure difference between PIP and PEEP was therefore reduced as the flow increased. This caused a reduction in V_{Te}. The relationship between the change in PEEP and V_{Te} is shown in figure 3.

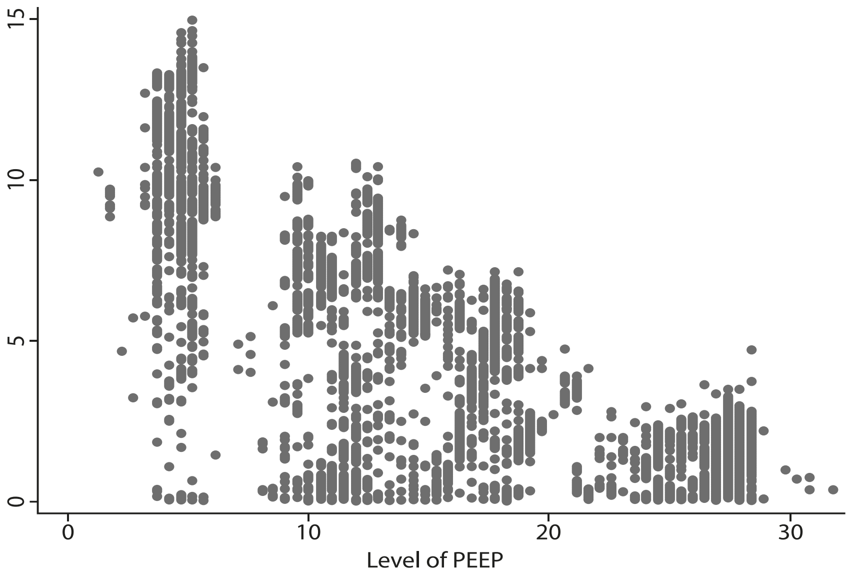

Figure 3. Study A: Scatter plot of measured expired tidal volume (V_{Te}) on the y-axis and PEEP on the x-axis. With increasing gas flow the PEEP is increased and V_{Te} is decreased.

Study B

In Study B there was no change in the pressure difference between PIP and PEEP and even with higher gas flows there were no significant changes in the relationship between PEEP and V_{Te} (figure 4).

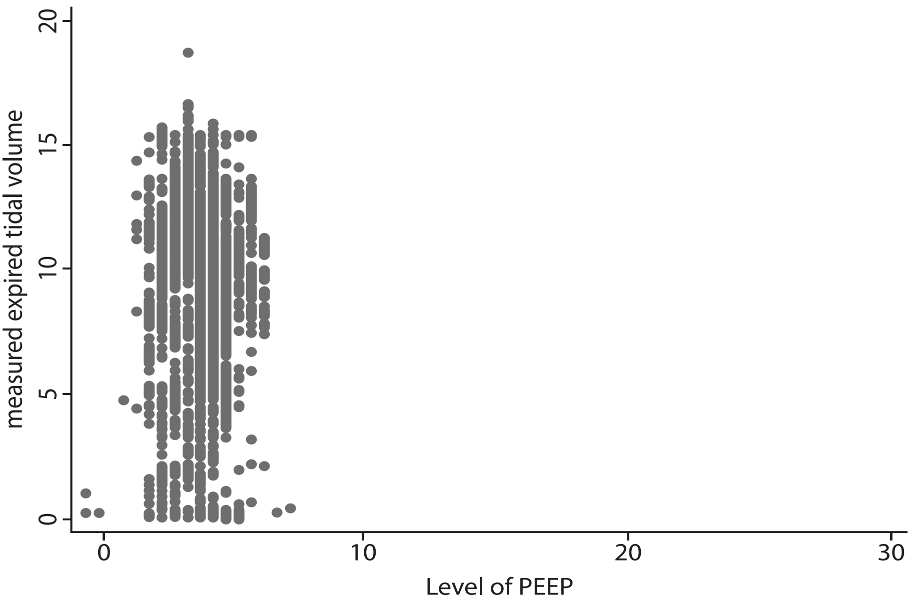

Figure 4. Study B: Scatter plot of measured expired tidal volume (V_{Te}) on the y-axis and positive end expiratory pressure on the x-axis showing no difference in delivered V_{Te} with changing gas flow.

Face mask leak

Study A

The median (IQR) mask leak at a gas flow of 5 L/min was 14 (5–47) %, for 8 L/min 46 (20–79) %, for 10 L/min 79 (39–98) % and 98 (91–100) % for 15 L/min. Mask leak significantly increased with increasing gas flow ($p < 0.001$ for each gas flow rate compared) (figure 5). This is related to the increasing pressure in the mask during expiration with the increasing PEEP.

Study B

Mask leak did not change with changing gas flow ($p = 0.51$). The median (IQR) mask leak for a gas flow of 5 L/min was 23 (0–61) %, for 8 L/min 35 (3–65) %, for 10 L/min 35 (12–62) % and for 15 L/min 22 (4–62) % (figure 5).

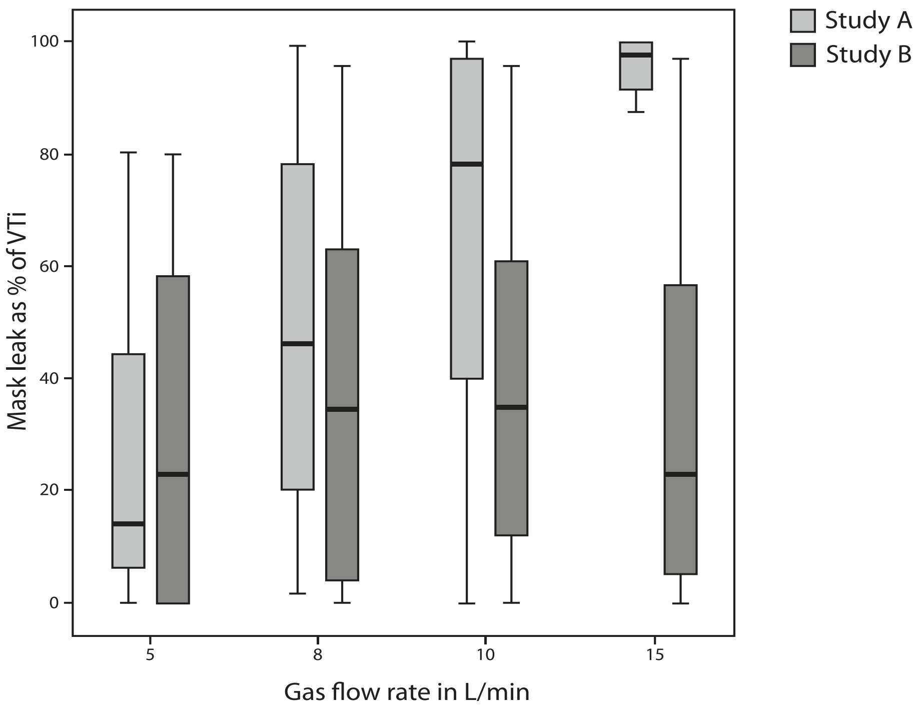

Figure 5. Changes in percentage of mask leak during both studies. The hatched bars show the results of study A. The plain grey bars show the results of study B. The box plots show median values (solid black bar), inter quartile range (margins of box), and range of data.

Discussion

The objective of PPV is to deliver an adequate tidal volume. Failure to achieve a set airway pressure with a T-piece resuscitation device can be due various factors.[16-18] Resuscitators may try to improve the airway pressure by increasing gas flow. With a Neopuff T-piece device, the pressure generated is directly related to the resistance that the flow resistor valve imposes on the gas flow through that valve. This rule only applies when the flow rate is constant.[11] When the valve resistance is constant, it can be predicted that the PEEP will rise upon increasing the flow rate. In this study we evaluated the effect of adjusting gas flow on the pressures delivered, the expired tidal volume and the face mask leak.

A study by Hawkes et al., using a Neopuff T-piece device, demonstrated that high airway pressures can be delivered when the gas flow is very high. In particular, PEEP increased significantly when gas flow was increased from 5 L/min to 15 L/min.[12] In Study A we recorded a similar increase in PEEP with increasing gas flow, from 4.5 cm H_2O at 5 L/min to

26.4 cm H_2O at 15 L/min. The increase in PEEP, but little change in PIP caused a significant decrease in expired tidal volume from 10.0 mL at 5 L/min to 0.8 mL at 15 L/min gas flow (figure 4). Face mask leak significantly increased from 14% at 5 L/min to 98% at 15 L/min as the PEEP inside the mask increased during expiration.

When the PIP and PEEP were maintained the V_{Te} and the face mask leak did not change significantly despite the different flow rates (figure 5). The increase in mask leak and resulting decrease in tidal volume delivery is therefore directly caused by the significant increase in PEEP (figure 4). When flow is increased PEEP rises more than PIP. The decrease in tidal volume is explained by the decrease in pressure difference between PIP and PEEP.

The major limitation of our study was the use of manikins rather than newborns in the delivery room. Face mask leak and decrease in V_{Te} as observed in this manikin study also occur in the delivery room.[15] Replication of the findings of our study during neonatal resuscitation would be ideal but cannot be done in an experimental manner.

Participants of this study were trained in neonatal resuscitation and mask handling technique. They were also aware that different gas flow settings were going to be tested. This might have influenced the results. Participants might have payed more attention to the differences between gas flow settings. The different gas flow settings are fairly distinguishable in sound. It was therefore impossible to entirely blind participants for the used gas flow.

Our concern about increasing gas flow during PPV is that airway pressures are not always adjusted at the same time. This could adversely affect tidal volume delivery, lead to insufficient gas exchange, failure of resuscitation, and subject the baby to worryingly high PEEP levels. The only way to adjust the PIP and PEEP when flow is changed is to take the mask off the baby and recalibrate it. This is obviously unsatisfactory during a difficult resuscitation.

Conclusion

When using a T-piece device for resuscitation clinicians should be aware of the effect of changing gas flow on airway pressures. We advise to choose a gas flow (about 8 L/min), then set the PIP and PEEP and to not change the gas flow during the resuscitation as set pressures will then change as well. If the airway pressures are not achieved this is likely to be due to poor mask technique which should be adjusted and not the gas flow. Increasing gas flow results in increased PEEP and decreased tidal volume with subsequent inadequate ventilation.

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