Inspired Gas Temperature in Ventilated Neonates

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Summary. The warming and humidification of inspired gases for ventilated neonates are routine. There are no data on the temperature of the gas at the airway opening in ventilated neonates. Is the inspired gas temperature at the airway opening, as expected and set on the humidifier, around 37°C? We aimed to measure temperature at the airway opening and compare this with the circuit temperature. This was an observational study in a neonatal intensive care unit. Twenty-five mechanically ventilated infants were studied. All had humidifiers with chamber temperature set at 36°C and the circuit temperature set at 37°C. Two temperature probes were inserted and rested at the circuit-exit and at the airway opening, and temperatures were measured for 2 min in each infant. At this time, the circuit temperature was also noted. The mean (SD) temperature at the airway opening in infants nursed in incubators was 34.9 (1.2)°C, compared with radiant warmers where the mean (SD) was 33.1 (0.5)°C. The mean (SD) difference in temperature from the circuit temperature probe to the airway opening was greater under radiant warmers, with a mean (SD) drop of 3.9 (0.6)°C compared with a mean (SD) drop of 2.0 (1.3)°C in the incubators. In conclusion, the temperature at the circuit temperature probe does not reflect the temperature at the airway opening. Inspired gas temperatures are lower than the expected 37°C with the normal circuits and usual humidifier settings. Pediatr Pulmonol. 2004; 38:50–54. © 2004 Wiley-Liss, Inc.

Key words: infant; newborn; inspired gas temperature; mechanical ventilation.

INTRODUCTION

The warming and humidification of inspired gases delivered to ventilated neonates is a routine practice in neonatal intensive care units.1–3 A humidifier warms and humidifies the gases delivered to the infant during mechanical ventilation via the inspiratory line of the ventilator circuit. While the warming of ventilator gases primarily allows adequate levels of humidification to be achieved, the actual inspired gas temperature is also important. Low temperatures may not only be associated with inadequate humidification and drying of the airway mucosa, but may also lead to poor temperature control in the infant and discomfort. High temperatures may also disturb the infant’s temperature control and cause discomfort, and in the extreme case may cause burns to the respiratory epithelium. Adequate inspired gas temperatures are associated with a lower incidence of pneumothorax and a decreased severity of chronic lung disease in ventilated very low birth weight infants.3 These temperature measurements, however, were measured at the circuit temperature probe, which is at least 8 cm from the airway opening.

There are no data on the temperature of the gas at the airway opening (i.e., the proximal end of the endotracheal tube; ETT) in ventilated neonates. As such, the clinician assumes that the humidifier circuit temperature equals inspired gas temperature. We asked, is the inspired gas temperature at the airway opening, as expected and set on the humidifier, around 37°C? Our hypothesis was that the temperature of the gas will decrease the further it travels from the circuit temperature probe site and towards the patient. We also hypothesised that this temperature drop may be different between infants nursed in radiant warmers or incubators. The aims of this study were to measure temperature at the airway opening in ventilated neonates, and to compare this with the circuit temperature; and to compare temperature at the airway opening between infants nursed in incubators and radiant warmers.

MATERIALS AND METHODS

Our setting was the Intensive Care Nursery at the Royal Women’s Hospital, Brisbane. A convenience sample of...
infants receiving intermittent mandatory ventilation was studied.

**Procedure**

Each patient had temperatures measured on one occasion only. Two temperature probes (from Mon-a-therm General Purpose Probes, Mallinckrodt, Inc., St. Louis, MO) were inserted through the suction port of the ETT-circuit manifold. The probes rested at the circuit exit (T1) and at the airway opening (T2), which are separated by 2 cm. The probes sat in the gas stream and did not touch any part of the circuit. See the Figure 1 for details of temperature probe placement. The same two probes were used in all infants. Temperatures (T1 and T2) were measured every 5 sec for 2 min, and the mean was calculated. In each case, at least 1 min was allowed between placing the probes into the manifold and starting data collection. The circuit temperature probe was part of the humidification system, and was in situ at time of data collection. At the time of these temperature measurements, the circuit temperature probe reading was noted from the humidifier. The room temperature and presence of condensation in the circuit were noted. The time constants for the two types of temperature probe used were determined in dry air, using an instantaneous change from room temperature to 37°C. The time constants of the Mon-a-therm and Fisher & Paykel (Auckland, New Zealand) temperature probes were 12 and 23 sec, respectively. Both of these probe types are medical grade, with an interchangeability of ±0.1°C. Both measurement systems calculate temperature from probe resistance, using the Steinhart and Hart equation.

**Equipment**

The ventilator circuit is configured as shown in Figure 1. Humidifiers used were the MR500, MR600, MR700, and MR730 models, and all used the 900MR560 temperature probe (Fisher & Paykel). Two “parallel” corrugated circuit arms, rather than a coaxial circuit, were used from the ventilator and humidifier to the ETT: an inspiratory line and an expiratory line. Two lengths of corrugated inspiratory tubing were used: 1) short, 4 cm from circuit temperature probe to ETT-circuit manifold, if the infant was nursed in an radiant warmer; and 2) long, 63 cm from circuit temperature probe to ETT-circuit manifold, if the infant was nursed in an incubator (in this case, the heated inspiratory limb and the circuit temperature probe were located outside the incubator). The circuit temperature was maintained by the use of a heater wire in the inspiratory limb of the ventilator circuit, from the humidifier to the circuit temperature probe. The 4-cm and 63-cm extensions were not heated. The expiratory circuit was not heated, and a water trap was needed to collect condensate. Temperature was measured at the outlet of the humidifier chamber (the chamber temperature) and at the patient end of the inspiratory circuit (the circuit temperature), with the final temperature of the gases at the patient end of the inspiratory circuit being controlled to the value set on the humidifier. With the chamber temperature set lower than the temperature at the patient end of the inspiratory circuit, the heater wire heated the gases passing through the circuit. This slightly decreased the relative humidity, thereby minimizing the possibility of condensation. In the intensive care nursery, the humidifiers had the chamber temperature set at 36°C and the circuit temperature set at 37°C.

**Statistics**

Means were compared with repeated-measures ANOVA (with Bonferroni’s post test) and Student’s t-test. Linear least squares regression was used to determine the relationship between continuous variables. Sample size was determined using data from a simple lung model: the Star Neonatal/Paediatric Test Lung, with a volume of 1 l and a compliance of 1 ml/cmH2O (Infrasonics, San Diego, CA). This was placed in an incubator at 37°C and ventilated at pressures of 20/5 at a rate of 60 breaths per minute, giving a mean (SD) T2 of 36.7 (0.12)°C. Therefore, a sample size of at least 5 in each group was required to give a power of 80% to detect a difference of at least 0.25°C, with a two-tailed alpha of 0.05.

**RESULTS**

Twenty-five infants each had a 2-min recording, 20 in incubators and 5 in radiant warmers. The studied infants were typical of those ventilated in our Intensive Care Nursery (as compared with data from the Royal Women’s Hospital Brisbane, Annual Reports, Neonatology, 1999–2002) by cot type. Seventeen of 25 (68%) had hyaline membrane disease, 2/25 (8%) had chronic lung disease,
and 6/25 (24%) had no lung disease. Significant spontaneous respirations were noted in only two infants. No significant condensation was seen in the ventilator circuits of any infant studied. The results of temperature readings are presented in Table 1 and the mean temperatures from circuit temperature to T1 to T2 are summarized in Figure 2. For both incubators and radiant warmers, the means are significantly different \((P < 0.0001, \text{repeated-measures ANOVA})\), and Bonferroni’s post test gives statistically significant differences between circuit temperature and T1 \((P < 0.001)\) and circuit temperature and T2 \((P < 0.001)\); however, the difference between T1 and T2 was not significant \((P > 0.05)\).

The mean (SD) T2 in incubators \((N = 20)\) was 34.9 (1.2) °C compared with radiant warmers \((N = 5)\), where the mean (SD) T2 was 33.1 (0.5) °C \((P = 0.0001, \text{Student’s t-test})\). The circuit temperature-T2 gradient was greater in the radiant warmers, with a mean (SD) temperature drop of 3.9 (0.6) °C compared with a mean drop of 2.0 (1.3) °C in the incubators \((P = 0.0042, \text{Student’s t-test})\).

For infants in incubators, the inspired gas temperature \((T_2)\) correlated with:

- Incubator temperature \((\text{IncTemp})\)
  \[ T_2 = 0.4162 \times \text{IncTemp} + 20.544, \quad r^2 = 0.73, \quad P < 0.001, \text{ and} \]
- Weight \((Wt)\)
  \[ T_2 = -0.0008495 \times \text{Wt} + 36.30, \quad r^2 = 0.31, \quad P = 0.016. \]

There was no correlation of T2 and room temperature, skin temperature, or flow. In all infants, fresh gas flow rates were 5–8 L/min⁻¹.

**DISCUSSION**

Humidification and warming of inspired gas during mechanical ventilation are essential in the neonate. Inadequate humidification of the inspired gas stream can

![Fig. 2. Mean (± SEM) temperatures at circuit temperature probe site (Circuit), ETT-circuit manifold (T1), and ETT adapter (T2).](image)
Inhibit mucociliary clearance, make secretions viscid, and lead to endotracheal plugging and, in extreme cases, to death due to lung injury. Even very short periods of exposure to inadequate humidification can lead to changes of lung function in the neonate. Pneumothorax and chronic lung disease were more frequent in very low birth weight infants with inadequate humidification. Similar results were shown in animal studies. Excessive temperature and/or humidification of the inspired gas stream can be equally as injurious to the lungs.

Humidity is not measured during neonatal ventilation. It is technically difficult, given the small tidal volumes and the need to not increase dead space. Indirect measurement via calculation from water consumption, gas flow, and temperature would provide, at best, a crude long-term average measure of humidity. Airway temperature, as measured by a probe placed in the inspiratory limb of the ventilator circuit, is used as a surrogate measure of humidity. Previous studies and clinicians assumed that this temperature is a true measure of the gas temperature actually delivered to the lungs. In some cases, the use of nonheated extensions on the inspiratory limb of the ventilator circuit means that this temperature probe can be more than 50 cm from the top of the endotracheal tube. This extension then passes through the heated environment of the incubator, changing both the temperature and humidity of the inspired gas. Placing the heated inspiratory limb in the incubator, and exposing it to a raised ambient temperature, can also lead to inadequate humidification.

This study measured the temperature of the gas stream closer to the patient, at the level of connection of the inspiratory and expiratory limbs to the patient manifold and at the airway opening in the endotracheal tube adapter (Fig. 1). Infants nursed in both incubators and under radiant warmers were studied. In all infants, the humidifier was set to a circuit temperature of 37°C. As expected, the humidifier maintained the circuit temperature at a mean (SD) of 37.0 (0.17)°C, or more correctly, maintained the circuit temperature probe at 37°C. In the case of radiant warmers, direct heating of the probe may have occurred. However, the circuit temperature did not represent the temperature of the gas at the top of the ETT (Table 1, Fig. 2). The temperature measured at the top of the ETT would be a more accurate reflection of the true inspired gas temperature.

In all the ventilators studied, gas flow past all the probes would have occurred during both inspiration and expiration. With the small tidal volumes used in neonatal ventilation, fresh and expired gases are deliberately mixed in the patient manifold. As such, the minute contribution of expired gases would not have lowered the measured temperature, given the flow of fresh gas at 5–8 L min⁻¹. This high volume of fresh gas, along with the long time constants of the temperature probes, would make temperature changes occurring during the respiratory cycle insignificant. No cyclical changes or trends in temperature due to humidifier or incubator temperature control were seen during the recording period in any infant. No effect of fresh gas flow rate or temperature was seen over the range studied, though an effect may occur outside this narrow range.

The normal physiological temperature of the neonatal airway is unknown, as are the optimal temperature and humidity of the inspired gas. While this study provided temperature measurements at the airway opening, the temperature and humidity at the tip of the endotracheal tube remain unknown. We do know that adequate inspired gas temperatures are associated with a lower incidence of pneumothorax and a decreased severity of chronic lung disease in ventilated very low birth weight infants. It would seem prudent to keep the temperature of inspired gases at the presumed physiological range until more data are available (i.e., 36.6–37.6°C). We demonstrated, however, that this temperature does not equal the circuit temperature, as there is a drop of around 2–4°C between the circuit temperature probe and the airway opening.

The total amount of water in the inspired gas is fixed once the gas leaves the humidifier, and changes in temperature will cause changes in relative humidity and may result in inadequate humidification or promote condensation in the circuit and the possible delivery of injurious particulate water to the lungs. In neonates, it was shown that over 30–60% of the time humidity at the patient manifold is below British standards. This study showed that airway temperature, as measured by a probe placed in the inspiratory limb of the ventilator circuit, is not an accurate measure of inspired gas temperature, and therefore cannot be used as a surrogate measure of humidity. Clearly, for optimal respiratory management, there is a need to measure both temperature and humidity as close as possible to the patient.

The differences found in incubators and radiant warmers are similar to those found by others and reflect both the use of differing lengths of nonheated extension tubing after the airway temperature probe and whether the extension and temperature probe are heated by the incubator or radiant warmer. In this study, a larger temperature drop was found with the shorter extension used under radiant warmers. The nonheated extension in the incubator may have lost little heat due to the high ambient temperature in the incubator. Any condensation in this extension will release thermal energy and reduce temperature loss. A significantly large temperature drop occurred under the radiant warmer, despite the very short extension. This was probably due to the airway temperature probe being heated directly by the radiant warmer. The probe would indicate 37°C, but this would not be a true indication of gas temperature. The humidifier would reduce the power to the heater wire,
resulting in the low inspired gas temperatures seen. It is common practice in many units to place reflective covers over these probes to prevent direct heating from the radiant warmer.

The correlation seen between temperature and weight in infants nursed in incubators is due to a strong correlation ($r^2 = 0.56$, $P < 0.001$) between weight and incubator temperature, with heavier infants having lower incubator temperatures.

It would seem prudent, therefore, to measure temperature closer to the patient than current practice allows. Such measurements would circumvent the drop in inspired temperature and the differences seen between incubators or radiant warmers.

In summary, the temperature at the circuit temperature probe does not reflect the temperature at the airway opening, and inspired gas temperatures are lower than the expected 37°C with the normal circuits and usual humidifier settings. We speculate that unless temperature is measured closer to the patient, it may well be worth setting the circuit temperature higher to compensate for the drop in temperature from the circuit temperature probe site to the airway opening.

REFERENCES