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Investigation of Inspiratory Circuit Condensation due to Room Temperature in a Heated Humidifier during Mechanical Ventilation

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Abstract

Heating and humidification control during mechanical ventilation is important. Water condensation can occur due to insufficient humidification. Condensation in the breathing circuit can cause various adverse events. In this study, we investigated whether the occurrence of tubing condensation in the breathing circuit could be affected by room temperature using a simulated respiratory circuit with a humidifier. The room temperature was set at 23˚C, 25˚C, and 27˚C, and mechanical ventilation was performed for 8 h. The inspired gas was appropriately heated and humidified according to the manufacturer's instructions. The weight of the circuit was measured every 2 h at room temperature to estimate the amount of condensation. During the mechanical ventilation, condensation continued to increase at a room temperature of 23˚C, but only for the first 2 h at 25˚C, and did not occur at 27˚C. The room temperature of the indoor environment was one of the factors generating water condensation in the breathing circuit with a humidifier even when a heater wire in the breathing circuit was appropriately operated.

Keywords

Room Temperature, Heated Humidifier, Mechanical Ventilation

1. Introduction

To prevent ventilator-related lung injury, sufficient humidification using a heat and moisture exchanger or a heated humidifier is required during mechanical

ventilation. When using a heated humidifier, a large amount of condensation occurs depending on the living environment, such as room temperature, humidity, and use of room air conditioner, as well as breathing circuit configuration and ventilator setting. Condensation within the breathing circuit affects inspiratory resistance and triggers sensitivity [1], and in large amounts, it can cause condensation to drip into the lungs, resulting in ventilation-associated pneumonia [2] [3] [4]. At a temperature range of 23˚C to 25˚C in the hospital rooms, we have frequently observed condensation within the breathing circuit. However, we have empirically dealt with this phenomenon by warming the room temperature up to 27˚C to 28˚C. In this study, we investigated whether the occurrence of tubing condensation in the inspiratory breathing circuit could be affected by room temperature using a simulated respiratory circuit.

2. Materials and Methods

The experiment was performed in an operating room, where the humidity was maintained between 50% and 60%. A simulated respiratory circuit used in this study consisted of the following (**Figure 1**):

Ventilator: NELLCOR PURITAN BENNET 840 Ventilator (Japan Medtronic Co. Ltd., Tokyo, Japan);

Breathing Circuit: Paykel Evaqua2 RT380 (circuit for adults) (Fisher & Paykel HEALTHCARE Co. Ltd., Auckland, New Zealand);

Water Chamber: MR290 (Fisher & Paykel HEALTHCARE Co. Ltd.);

Heated Humidifier: MR850 (Fisher & Paykel HEALTHCARE Co. Ltd.);

Test Lung: Venti Plus, (GaleMed Corporation, Taipei).

The experimental ventilator was set to volume-controlled ventilation. The following settings were used: tidal volume was set at 500 ml with 5 cmH_2O of

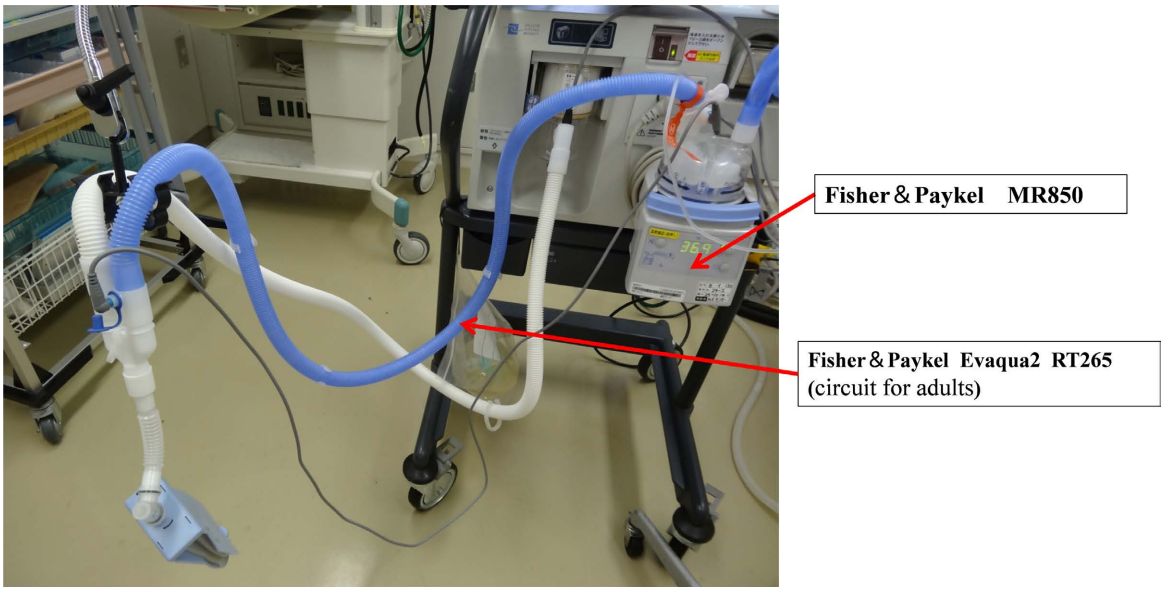

Figure 1. Mechanical ventilation circuit. Fisher & Paykel Evaqua2 RT265 (adult circuit) was used for the breathing circuit, and the weight of the inspiratory circuit was measured. Fisher & Paykel MR850 was used as a heated humidifier.

PEEP, ventilation rate was 10 times/min with 1.5 s of inspiratory time, and oxygen concentration was set at 21%. For the humidifier, the invasive mode, which is used for intubated patients, was selected. The simulated circuit was ventilated for 8 h at 23˚C, 25˚C, and 27˚C room temperatures. During the experiment, we confirmed that the humidifier chamber outlet temperature and temperature at the Y-piece were displayed at approximately 37˚C and 40˚C, respectively. The amount of condensation was measured by weighing the breathing circuit every 2 h and temporarily discontinuing ventilation. A digital infant scale (NS-608N Digital Infant Scale, Atom Medical Corp. Tokyo, Japan） was used to weight (**Figure 2**). The amount of condensation generated for 2 h was used to calculate the difference before and after ventilating the circuit. Each measurement was repeated thrice, and the average was recorded. The 8-h measurement of tubing condensation was performed at 23˚C, 25˚C, and 27˚C room temperatures. Ventilation was initiated at each temperature after at least 1 h had passed since the temperature reached the determined temperature. The experiment was repeated five times under each temperature environment.

Statistical Analysis

Comparisons between the groups were analyzed by one-way analysis of variance (ANOVA) followed by Bonferroni's test. All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University), which is based on R (The R Foundation for Statistical Computing) and R commander [5], and P values of <0.05 were considered statistically significant. Sample size calculation was not done because this study was an observational exploratory research study.

Figure 2. A digital infant scale (NS-608N Digital Infant Scale, Atom Medical Corp. Tokyo, Japan) was used to weight condensation. The difference before and after ventilating the circuit was determined as the amount of condensation generated.

3. Results

Table 1 shows individual accumulated values of tubing condensation every 2 hour and at each temperature. At 23˚C, about 2.5 g of condensation was observed every 2 hours. At 25˚C, an increase of about 1.6 g was observed in the first 2 hours, but little sustained increase was observed. No condensation was observed at 27˚C. Figure 3 shows the averaged accumulated values of tubing condensation at 23˚C, 25˚C, and 27˚C, compared to at 27˚C, condensation at 23˚C significantly increased in the first 2 hours. In addition, condensation at 23˚C significantly increased 6 hours after the commencement of ventilation even compared to at 25˚C. In case of accumulated condensation at 25˚C, condensation was not statistically different compared to at 27˚C until 4 hours had elapsed.

Table 1. Individual condensation in the breathing circuit at each measurement. We conducted 8-h observation five times at 23˚C, 25˚C, and 27˚C.

At room temperature 23˚C

Elapsed time (hour)	I (g)	II (g)	III (g)	IV (g)	V (g)	Mean (SD) (g)
0	0	0	0	0	0	0
2	2	2	4	2	2	2.4 (0.8)
4	5	4	9	4	4	5.2 (1.9)
6	8	7	11	4	6	7.2 (2.3)
8	10	10	12	6	8	9.2 (2)

At room temperature 25˚C

Elapsed time (hour)	I (g)	II (g)	III (g)	IV (g)	V (g)	Mean (SD) (g)
0	0	0	0	0	0	0
2	2	0	0	2	2	1.2 (1.0)
4	2	0	0	2	4	1.6 (1.5)
6	2	0	0	2	4	1.6 (1.5)
8	2	0	0	2	4	1.6 (1.5)

At room temperature 27˚C

Elapsed time (hour)	I (g)	II (g)	III (g)	IV (g)	V (g)	Mean (SD) (g)
0	0	0	0	0	0	0
2	0	0	0	0	0	0
4	0	0	0	0	0	0
6	0	0	0	0	0	0
8	0	0	0	0	0	0

The value is the accumulated value of condensation. SD: standard deviation.

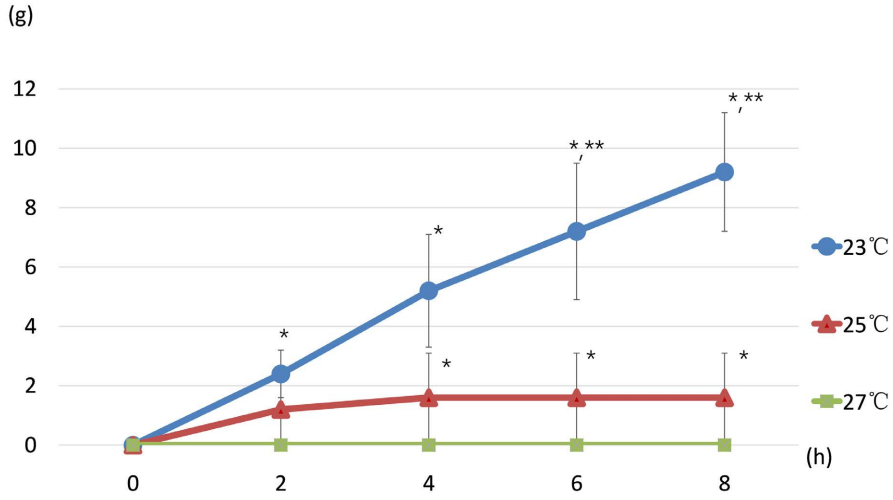

Figure 3. Condensation in the breathing circuit at each temperature. Single asterisk indicates significant differences compared to at 27˚C. Double asterisks indicate significant differences compared to at 25˚C.

4. Discussions

In general, temperature settings for heated humidifiers are 37˚C for the outlet chamber and 40˚C at gas temperatures being delivered to the patient, as measured at the Y-piece. To avoid condensation in the tubing, the inspired gas is warmed up at 39˚C - 40˚C using a heater wire in the breathing circuit during delivery. These settings cause the inspired gas to reach 100% humidity at 37˚C although the inspired gas bypasses the upper respiratory tract [3] [6] [7] [8] [9] [10]. However, after excessive cooling in the breathing circuit, a large amount of condensation occurs, which may drop into the airway. In addition, due to the condensation, the inspired gas loses its humidity. Airway mucosal damage may occur due to exposure to the inspired gas with lower humidity. These unfavorable events have also been reported to cause micro-atelectasis, airway obstruction, and poor compliance due to drooling [3] [4] [6].

The equipment for mechanical ventilation and the indoor environment in which mechanical ventilation is used are both factors that can affect heating and humidification in the breathing circuit. Device-dependent factors include ventilators, humidifiers, and type of circuitry. The operation of a ventilator differs depending on the model. Different ventilators have different steady-state flows and different ventilator modes and operations. The humidification of a heating humidifier is affected by the differences in operation due to the differences in humidifier type and the set temperature. There are several differences in the circuit configuration between a heat and moisture exchanger circuit and a heating humidifier circuit. The type of circuit, heating, and humidification, as well as the shape and arrangement of the heater wire in the breathing circuit, are determined by the circuit manufacturers (located in the center of the tubing or arranged in a spiral shape along the circumference of the tubing). Room temperature and airflow from the air conditioning are features of the indoor environ-

ment related to heating and humidification in the breathing circuit. Room temperature has a considerable impact on heating and humidification. When the room temperature is sufficiently low, the breathing circuit is sufficiently cooled to cause water condensation in the circuit although the circuit is well heated. When the airflow in the room blows against the breathing circuit, the circuit is sufficiently cooled and water condensation is likely.

We only tested the room temperature to determine how changes in its daily range could affect condensation. According to the current findings, water condensation in the breathing circuit can be decreased by maintaining the room temperature at 25˚C or higher, and water condensation is unlikely if the room temperature is set at 27˚C. However, a standard temperature range of 21˚C - 24˚C can be used in most healthcare zones [11]. Therefore, simply increasing the room temperature may result in heat stress for healthcare providers [12]. This heating system may have room for improvement. Aluminum-coated foils have been used for heat insulation for a long time [13]. Covering breathing circuits with aluminum-coated foils could be effective for heat insulation. It may be difficult to apply the present results to other conditions because of the limitations of this study. In current clinical practice, various humidifiers, heater wires, breathing circuits, and ventilators are available. However, all heating and humidification devices are manufactured according to a set of standards [10]. Therefore, it is reasonable to consider that the different conditions would obtain similar results.

5. Conclusion

The room temperature of the indoor environment is a factor causing water condensation in the breathing circuit with a humidifier. When using ventilators in various environments, such as hospitals and homes, we should keep in mind that condensation can occur in the breathing circuit at low room temperatures even when the heater wire in the breathing circuit is appropriately operated.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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