Temperature loss by ventilation in a calorimetric bench model

Holger Herff[1,*], Daniel C. Schroeder[1], Kevin Bowden[2], Peter Paal[3], Thomas Mitterlechner[4], Volker Wenzel[5]
1 Department of Anaesthesiology and Intensive Care Medicine, University Hospital of Cologne, Cologne, Germany
2 O-Two Medical Technologies Inc., Brampton, Canada
3 Department of Anaesthesiology and Intensive Care Medicine, Hospitallers Brothers Hospital, Paracelsus Medical University, Salzburg, Austria
4 Department of Anesthesiology, Privatklinik Hochrum, Sanatorium der Kreuzschwestern, Rum, Austria
5 Department of Anaesthesiology, Intensive Care Medicine, Emergency Medicine and Pain Therapy, Klinikum Friedrichshafen, Friedrichshafen, Germany

*Correspondence to: Holger Herff, MD, holger.herff@uk-koeln.de.
orcid: 0000-0002-7380-4013 (Holger Herff)

Abstract

In intensive care medicine heat moisture exchangers are standard tools to warm and humidify ventilation gases in order to prevent temperature loss of patients or airway epithelia damage. Despite being at risk of hypothermia especially after trauma, intubated emergency medicine patients are often ventilated with dry and in winter probably cold ventilation gases. We tried to assess the amount of temperature-loss due to ventilation with cold, dry medical oxygen in comparison to ventilation with warm and humidified oxygen. We ventilated a 50-kg water-dummy representing the calorimetric capacity of a 60-kg patient over a period of 2 hours (tidal volume 6.6 mL/kg = 400 mL; respiratory rate 13/min). Our formal null-hypothesis was that there would be no differences in temperature loss in a 50 kg water-dummy between ventilation with dry oxygen at 10°C *vs*. ventilation with humidified oxygen at 43°C. After 2 hours the temperature in the water-dummy using cold and dry oxygen was 29.7 ± 0.1°C compared to 30.4 ± 0.1°C using warm and humidified oxygen. This difference in cooling rates between both ventilation attempts of 0.7 ± 0.1°C after 2 hours represents an increased cooling rate of ~0.35°C per hour. Ventilation with cool, dry oxygen using an automated transport ventilator resulted in a 0.35°C faster cooling rate per hour than ventilation with warm humidified oxygen in a bench model simulating calorimetric features of a 60-kg human body.

Key words: calorimetric model; emergency medicine; heat moisture exchangers; hypothermia; mechanical ventilation; multiple trauma; simulation; temperature; ventilation gases; water dummy

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Introduction

In intensive care medicine or aesthesia, active or passive heat moisture exchangers are standard tools to warm and humidify ventilation gases in order to prevent the temperature loss of patients, or to avoid drying and damaging airway epithelia.[1,2] In contrast, emergency medicine patients are usually ventilated with dry and cold ventilation gases. These gases are commonly not humidified, and expired gas is diverted directly into ambient air by the one-way valves of single-use bag-valve-devices or transport ventilators without preserving their stored intrinsic energy. In this study, we tried to assess in a water-dummy designed to represent a patient with 60 kg body mass the amount of temperature-loss due to ventilation with cold and dried oxygen in comparison toventilation with actively warmed and humidified oxygen.

Our formal null-hypothesis was that there would be no difference in temperature loss in a 50-kg water-dummy between ventilation with dry oxygen at 10°C *vs*. ventilation with humidified oxygen at 43°C.

Materials and Methods

The study was performed in a laboratory setting. Since this was a completely technical simulation with no participants apart from the authors, no ethical approval was required.

In a first step, we insulated a plastic tank which we filled with 50 kg of water (heat capacity of water 4.182 J/kg•K) equilibrated before each experiment to a temperature of 37.0°C. The water-dummy tank simulating the calorimetric characteristics of a 60-kg person (heat capacity of a human body 3.469 J/kg•K, ~83% of the water heat capacity).[3] The water tank was ventilated with an automated transport ventilator (CAREvent® ALS, O-Two Medical Technologies, Mississauga, Canada). Oxygen supply to the ventilator was provided with cooled oxygen at a temperature of 10°C (refrigerator) in both groups. In the attempt with cool and dry oxygen, the connection tube of the ventilator was put directly in the water tank. In the attempt with warm and humidified ventilation gas, the oxygen provided from the transport ventilator additionally passed a container filled with 300 mL distilled water prior to a second connection tube leading the oxygen from this container into the 50 kg water-dummy tank. The container filled with 300 mL of distilled water representing our active heat moisture exchanger was immersed in a another tank filled with 10 L tap water, that was kept at a constant temperature of 43–43.5°C; in result the distilled water in the container was actively warmed to 43°C as well and subsequently warmed and humidified the oxygen that was streaming through the connection tubes (experimental setting in **Figure 1**).

All connection tubes and the transport ventilator itself were insulated in this experiment to avoid confounding by ambient

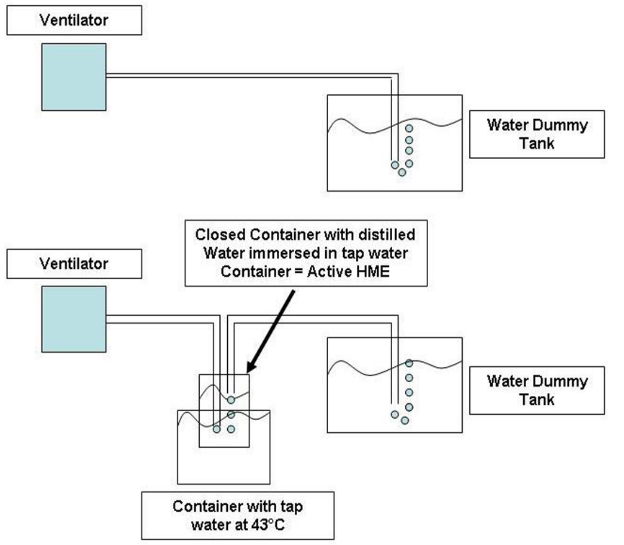

Figure 1: Experimental setting with the ventilator being connected to the water tank.
Note: (A) Direct connection without warming. (B) Connection via active heat moisture exchanger. HME: Heat moisture exchanger.

air temperature. Temperature of the 50 kg water-dummy and the temperature of the heat moisture exchanger-heating tank were determined with standard electronic thermometers (GTH 175/PT, Greisinger, Regenstauf, Germany) with an exactness of 0.1°C. Room temperature was kept constant between 21.5 and 22°C, since the water dummy was losing warmth to ambient air. Humidity in room air was constantly 37–40%, ambient air pressure was approximately 100 kPa.

We either ventilated in random order with cool dry pure oxygen or with humidified pure oxygen at 43°C. The transport ventilator was adjusted to a tidal volume of 400 mL (6.6 mL/kg) at a frequency of 13/min (minute volume: 5.2 L). The "inspired" oxygen-volumes streamed through the water in the tank before bubbling to the surface and discharging into the ambient air. This results in an equilibration in temperature and specific humidity between water of the dummy and "inspired" oxygen comparable to the situation in patients' respiratory tracts (mainly the lungs).

Each setting was done seven times for minimizing random confounding elements. Temperature was determined at baseline and every 15 minutes; experimental runtime was 2 hours. Different settings were performed in random order. SPSS Statistics 25.0 was used for statistical analysis (SPSS IBM, Armonk, NY, USA); data were compared using Student's *t*-test. Results are given as the mean ± standard deviation.

Results

The difference of cooling rate between both ventilation attempts was 0.7 ± 0.1°C after 2 hours, with an increased cooling rate of 0.35°C per hour. Exact data are given in **Table 1**.

Discussion

In this experiment the cooling rate was 0.35°C/h faster when ventilating with cold dry oxygen compared to ventilating with warmed and humidified oxygen in a bench model, which is substantially more than the 0.2°C per hour reported in perioperative patients.[4] The lower cooling rate in these patients may be explained by warmer ventilation gases in the operating theatre than in our experiment and by the healthy organisms' ability to maintain body temperature actively in contrast to our water dummy.[5] However, temperature regulation is often overcome in trauma patients.[6,7] In cold surroundings as in the northern hemisphere especially in winter, trauma patients are often substantial hypothermic upon hospital admission.[7] Therefore, emergency ventilation that additionally cools the patients may only be tolerated if it is performed for a short period of time. Even in advanced emergency medical systems time before multiple trauma patients arrive at a trauma center had been up to 3 hours several years ago.[8] And even today transport times can be extended due to necessary secondary transports from a local trauma center to a level one trauma center.[9] In these cases, prolonged ventilation with cool, dry air may unnecessarily lower the body temperature of multiple trauma patients in addition to the loss of temperature by convection. A recent study showed loss of temperature of 0.36°C during long distance flights of an average of 71 minutes. In this study hypothermia was strongly associated with death, as well.[10] In these cases ventilation with actively warmed gases could make up a clinical difference. Accidental hypothermia is still underdiagnosed worldwide and diagnosis may increase due to higher awareness, training and equipment.[11,12]

Table 1: Temperature of water in the dummy during the experiment

Time (min)	Cool oxygen (°C)	Warm oxygen (°C)	Mean difference (°C)	*P* value
0	37.0±0.0	37.0±0.0	0	1
15	35.9±0.1	36.0±0.2	0.1	0.38
30	34.8±0.1	35.0±0.2	0.2	0.073
45	33.8±0.2	34.0±0.1	0.2	0.026
60	32.8±0.2	33.2±0.2	0.4	0.002
75	31.9±0.2	32.4±0.2	0.5	0.001
90	31.0±0.2	31.5±0.2	0.5	0.004
105	30.3±0.2	30.9±0.2	0.6	0.001
120	29.7±0.3	30.4±0.2	0.7	0.001

Hypothermia has been proved to be one of the major factors predicting fatal outcome in multiple trauma patients.[13,14] Due to its impact on blood coagulation and acid base balance morbidity and mortality may be enhanced.[15-18] Further, ventilation even for a few hours with cooled gases damages airway epithelia which may increase the risk of pneumonia.[1] Although ventilation with warm and humidified gases will most probably not be sufficient to maintain a stable body temperature alone,[19] based on our data we propose to stop providing prolonged emergency ventilation without humidifying and warming ventilation gases especially in trauma patients. Prehospitally, it is difficult to rewarm a hypothermic patient, but at least further cooling should be limited.[20,21]

Passive heat moisture exchangers, that work perfectly well in intensive care units at 25–27°C ambient temperature, may cool in the cold surroundings of out-of-hospital emergency situations and may then be ineffective.[22] Thus, special and active emergency-heat moisture exchangers may be necessary to provide active warming; humidification will then be delivered by the patient's exhaled air and by added saline solution. However, we are not able to present a technical solution for active heat moisture exchangers suitable to emergency settings. Previous experiments using large amounts of soda lime to produce heat in an exothermic chemical reaction, may heat up ventilation gases uncontrollably up to 103°C which is uncomfortable for the patient if not dangerous.[23] In the last years battery driven devices for fluid warming had been developed.[24] Potentially on this basis it may be possible to develop active heat moisture exchangers for preclinical settings. However, more research on technical solutions to this problem is necessary.

Limitations

We have not been able to measure the effective temperatures of the "inspired" oxygen at the end of the connection tubes, which is technically difficult due to the short contact time with any thermometer during the inspiration phase. Thus, since gases cool down during expansion from any pressure tank, the temperature in the cool oxygen group may have been even lower than the 10°C, the oxygen in the pressure tank had. *Vice versa*, we are not able to prove that the warmed oxygen was completely equilibrated to the 43°C in our heat moisture exchangers. Further, we are not able to prove complete equilibration between "inspired" oxygen and the water in the tank in both groups as it occurs in human lungs. However, if equilibration was incomplete, we may even have underestimated the impact on temperature loss of cool dry oxygen compared to warm humidified oxygen in this study. Lastly, the main limitation of any bench model is that it represents only a small spectrum of a real life situation and thus its results cannot be directly extrapolated to real emergency settings. However, this model may be a good tool to assess the calorimetric impact of different ventilation modes on body temperature.

Conclusion

Ventilation with cool and dry oxygen using an automated transport ventilator resulted in a 0.35°C faster cooling rate per hour than ventilation with warm humidified oxygen in a bench model simulating the calorimetric features of a 60 kg human body.

Author contributions
Resources: HH, KB, VW; methodology: HH, KB, PP, VW; conceptualization: HH, KB, PP; investigation: HH, DCS, KB, TM; formal analysis: HH, DCS, PP, TM; visualization and writing – original draft preparation: HH, TM; data curation: KB; supervision: VW; writing – review & editing: DCS, KB, PP, VW. All authors approved the final version of manuscript for publication.
Conflicts of interest
Mr. Bowden is Clinical Director of O-Two Medical Technologies Inc. which produces bag-valve-devices or automated transport ventilators as the one used in this experiment (but no heat moisture exchanger techniques). Apart from the actual study a previous study of us was sponsored by O-Two Medical Technologies Inc. several years ago. There are no further competing interests in regard of this study.
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Data sharing statement
Datasets analyzed during the current study are available from the corresponding author on reasonable request.
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