

File ID 205351
Filename Chapter 4: Endotracheal temperature and humidity in patients in a warm and dry environment and the effect of a heat and moisture exchanger

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type Dissertation
Title The influence of heat and moisture exchangers on tracheal climate in laryngectomized individuals: toward optimal pulmonary rehabilitation
Author R.J. Scheenstra
Faculty Faculty of Medicine
Year 2011
Pages 159

FULL BIBLIOGRAPHIC DETAILS:

<http://dare.uva.nl/record/367370>

Copyright

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use.

CHAPTER 4

Endotracheal temperature and humidity in laryngectomized patients in a warm and dry environment and the effect of a heat and moisture exchanger



Renske J. Scheenstra
Sara H. Muller
Frans J.M. Hilgers

Head Neck Oct 27 [Epub ahead of print].

Abstract

Objective

Assessment of endotracheal climate in laryngectomized patients in a warm and dry environment and the effects of a Heat and Moisture Exchanger (HME).

Methods

Endotracheal temperature and humidity were measured in 11 laryngectomized patients with a regularly used HME (Provox® Normal HME; R-HME), an HME with antimicrobial filter (Provox® Micron HME; F-HME), and without HME (open stoma). Measurements were performed at 32, 34 and 38 °C (< 25% relative humidity).

Results

Both R-HME and F-HME increase end-inspiratory humidity (AH_{insp}) equally (range 3.4 to 5.6 mgH₂O/L). The R-HME has a cooling effect on end-inspiratory temperature (T_{insp}), which is similar for all tested environmental conditions (-3.8 °C); F-HME decreases T_{insp} less (range -1.3 to -0.6 °C).

Conclusions

In a warm and dry environment, both R-HME and F-HME cool and humidify inspired air significantly. Therefore, consistent use of an HME also under these climate conditions probably is clinically beneficial.

Introduction

Total laryngectomy results in permanent disconnection of the upper and lower airways. Lack of climate conditioning of inspired air in these patients leads to an increase of an array of chronic pulmonary complaints, such as recurrent uncontrolled coughing, excessive mucus secretion, and repeated forced expectoration in order to clear the airways from phlegm [15]. Respiratory problems often worsen during wintertime and under cold climate conditions [15;83]. Already in the early eighties, Natvig et al [37] observed that a (temporary) stay in a warm and humid climate significantly improved respiratory function and reduced pulmonary complaints in Norwegian laryngectomees. At present, the use of passive heat and moisture exchangers (HMEs), improving humidification of inspired air, is an undisputed part of the pulmonary rehabilitation in laryngectomized patients. Application of HMEs has been proven to reduce pulmonary problems, and to improve quality of life [25-27]. The positive HME effects on endotracheal climate in both moderate and cold climate environmental conditions have been substantiated in several clinical studies [33;36;40;79;84].

It is not known however whether an HME is effective and useful under warm climate conditions. Moreover, temperature and humidity inside the trachea in laryngectomized patients are not known in such conditions. For healthy individuals, only one study was found in the available literature to report on temperature values at different locations in the respiratory tract in an extremely warm environment (50 °C), but no humidity measurements were performed under these environmental conditions [85]. It seems unlikely that an HME will contribute anything in a warm and humid climate as the environmental conditions are then almost equal to the climate in the trachea. In dry and warm conditions, however, the mucosa in the trachea in laryngectomized patients will be at risk of drying out, but it is not certain whether an HME will be able to improve this. During expiration water condenses in the HME if the temperature of the HME core is sufficiently low. At temperatures at and above body temperature, therefore, condensation would seem unlikely. However, because the material in an HME is impregnated with hygroscopic salt (such as calcium chloride), condensation may still occur even if the temperature is at or above body temperature.

The purpose of this study is to measure endotracheal temperature and humidity under warm and dry climate conditions in laryngectomized patients as well as the effects of an HME, if any, under these climate conditions.

Patients and Methods

Subjects

Eleven laryngectomized patients, 10 male and 1 female (median age 67 yrs; range 47–81 yrs, SD 11.3 yrs) were recruited from the outpatient clinic. All patients were regular HME users. In addition to their surgery, all patients also received radiotherapy, had quit smoking postoperatively, and were in long-term follow-up, on average 8.2 years postoperative (median 7.0 yrs, range 1–19 yrs, SD 5.8). The study was approved by the Protocol Review Board of the Netherlands Cancer Institute and written informed consent was obtained from all patients.

HME devices

The HMEs used in this study were the regularly used Provox® Normal HME (further referred to as R-HME) and the Provox® Micron HME with an additional virus and bacterial filter layer (further referred to as F-HME). The R-HME is a passive hygroscopic HME device, with an *in vitro* moisture loss of 23.7 mgH₂O/L and a pressure drop at 30 l/min of 89 Pa, according to ISO9360-2;2001. Previous *in vivo* studies in laryngectomized patients (in room climate conditions) showed end-inspiratory humidity to increase (3–6 mgH₂O/L) and end-inspiratory temperature to decrease (-1.5 °C) (Chapter 3) [33;84]. In the F-HME the air first passes through an electrostatic virus and bacterial filter before passing through the hygroscopic core providing heat and moisture exchange. The *in vitro* moisture loss is 26.0 mgH₂O/L and a pressure drop at 30 l/min of 78 Pa, according to ISO9360-2;2001. Previous *in vivo* studies in laryngectomized patients (in room climate conditions) showed both end-inspiratory humidity and temperature to increase (4.7 mgH₂O/L and 1.1 °C respectively) (Chapter 5).

Environmental temperature and humidity

All measurements were performed in a purposed-built room, partitioned off from a larger room in the hospital. The wooden wall was covered with plastic and extra isolation material. The room was heated with a portable heater with inbuilt thermostat (Andrews 20 CT 2.8 kW; Andrews Sykes Group PLC,

Amsterdam). The maximum environmental temperature that could be reached in this condition was 34 °C. In order to heat the room to temperatures above body temperature (> 37 °C), the remaining three walls of the room also had to be covered with extra insulation material. It took about four hours to warm up the room in either temperature condition. The room was kept dry by use of an adsorption dryer (Andrews Sykes Group PLC, Amsterdam). Environmental conditions were monitored with a calibrated temperature and humidity sensor (Testo BV, Almere, The Netherlands).

Measurements were performed at nominal temperatures of 32 °C and 38 °C for 10 patients each. Additionally 6 patients were measured at nominal 34 °C. Four patients could be measured at all temperatures (32, 34 and 38 °C), 4 patients were measured both at 32 and at 38 °C and 2 patients both at 32 and 34 °C. One patient was measured only at 38 °C.

In Table 4.1, the actually reached temperature and humidity values (and standard deviations) are shown. Sweating of the subject and the investigator are the cause of the increase of the humidity with increasing environmental temperature.

Table 4.1 Median values and standard deviations (between brackets) of temperature, absolute humidity and relative humidity for the different room environmental conditions during the measurements.

	Temperature (°C)	Absolute Humidity (mgH₂O/L)	Relative Humidity (%)
32 °C	32.0 (1.0)	6.4 (0.9)	19.2 (2.7)
34 °C	33.7 (0.8)	8.9 (1.7)	24.9 (4.9)
38 °C	38.2 (0.7)	11.4 (1.4)	24.6 (2.9)

Measurement protocol

The measurement protocol was identical to that used in our previous studies (see Chapter 3, 4, 5 and 6). All patients were measured during rest breathing seated in a chair. A small hole was punched in a peristomal HME adhesive (Provox®, Atos Medical, Hörby, Sweden), through which the distal tip of the sample catheter of the Airway Climate Explorer (ACE; described below) was

inserted. The catheter tip was positioned approximately 1 cm behind the stoma opening in the trachea. Each measurement session included at least three 10-minutes breathing periods (observations), in a randomized sequence: one observation with open stoma breathing (without HME), one observation with the R-HME and one with the F-HME. Measurements in different environmental climate conditions for the same patients were performed on different days.

Airway Climate Explorer (ACE)

Endotracheal temperature and humidity were measured with the Airway Climate Explorer (ACE). Its development and validations have been extensively described and published elsewhere [33]. In summary, a small diameter (5 mm) sample catheter (30 cm) is proximally connected to a sensor house in which a fast humidity sensor is built. Both the sample catheter and the sensor house are internally heated to 40 °C in order to prevent condensation of water vapour within the sample catheter and/or sensor house, and externally insulated to prevent artificial heating of the tracheal air. For the assessment of temperature a thermocouple (MLT1402 T-type Ultra Fast Thermocouple Probe (IT-23), response time 5 ms, accuracy ± 0.1 °C; ADInstruments Ltd, Oxfordshire, UK) is placed just inside the distal tip of the central, air-sampling canal of the sample catheter. The airflow during respiration is sampled with a constant rate of 0.6 L/min. The breathing frequency was monitored with respiratory inductive plethysmography (Respirtrace QDC, Viasys Healthcare, Houten, The Netherlands) attached to the thorax and abdomen. Due to excessive sweating of the subjects, the Respirtrace wires could not record the breathing cycles correctly for most patients at 38 °C.

Data collection and analysis

All data have been checked for sufficient quality prior to analysis since measurement errors can occur particularly in the humidity measurements (Chapter 3) [33;84]. Good-quality measurements for both temperature and humidity were available in all patients, except one measurement at 34 °C. During this measurement, irregular breathing curves occurred during open stoma breathing, probably due to variations in insertion depth of the probe, so that the results of open stoma breathing could not be analysed properly.

Therefore all data at 34 °C of this patient was excluded from further analysis. Data at 32 °C and 38 °C of this patient are included.

The last two minutes of each observation were selected for analysis. In this 2-minute period, one representative breath with a clinically relevant (i.e. type specific) inhalation breath length (IBL) was selected for analysis. The end-inspiratory and end-expiratory values of temperature (T_{insp} and T_{exp}) and absolute humidity (AH_{insp} and AH_{exp}) and the corresponding IBL of this breath were registered in a database (Microsoft Office Excel v2003). This method of analysis (i.e. raw data analysis) has been validated with statistical modeling previously (Chapter 3). The difference of the raw data analysis compared to mixed effect models was found to be < 0.15 °C and < 0.25 mgH₂O/L. In the present study, the raw data analysis was chosen instead of the mixed effects models, since the temperature traces showed somewhat different breathing patterns when compared to the previous studies. As a consequence, the breaths could not be identified using the peak detection algorithm ('peaks' – Splus) which was used in other studies (Chapter 3, 4, 5 and 6).

The IBL of the representative breath was chosen as close as possible to the median IBLs found in the previous investigations (1.1 and 1.35 s for breathing respectively with and without HME, see Chapter 3) in order to facilitate comparison of the results with studies at room temperature and at low temperatures (Chapter 3, 5 and 6) [36;84]. The average IBL of the representative breaths was 1.0 for open stoma breathing and 1.2 for breathing with HME. Since the IBL for both with and without HME is about 0.1 s shorter than intended, this could have led to an overestimation of the AH_{insp} of less than 0.5 mgH₂O/L, based on the formula published previously (for more details see Chapter 3). The influence of this difference in IBL on the difference between with and without HME (HME effect) is negligible. As in previous studies, the temperature curves were used to calculate the IBL, because of the fast response time of the thermocouple (5 ms). However, the temperature patterns of the measurements at 38 °C appeared to be difficult to interpret (see results), and could not be used to determine a reliable IBL. Therefore at 38 °C the humidity curves were used to calculate the IBL with a correction for the longer response time of the humidity sensor. This approach was validated at 32 °C and for several measurements where the RespiTrace signal was available. The results are reported as mean and median values. To compare the present data with those of previous studies, all data mentioned in the text are means.

Due to the small sample size, non-parametric statistical analysis using the Wilcoxon rank test (related samples) was performed where applicable.

Results

Inspiratory and expiratory temperature patterns

Figure 3.3 shows an example of a typical temperature and humidity pattern as observed both during open stoma breathing and during breathing with an HME at room climate conditions (Chapter 3). In this pattern, the end-inspiratory temperature (T_{insp}) and absolute humidity (AH_{insp}) correspond with the minimum temperature and humidity respectively, and the end-expiratory temperature (T_{exp}) and humidity (AH_{exp}) correspond with the maximum temperature and humidity.

Figure 4.1 shows the patterns for one patient (patient A) at 32, 34 and 38 °C. At these elevated temperatures the humidity pattern is still quite similar to the pattern observed at lower temperatures, both with and without HME. Clearly humidity decreases during inhalation and increases during exhalation. However, the temperature patterns behave differently, in particular without HME. During open stoma inhalation at 32 and 34 °C the temperature rapidly decreases at the beginning of the inspiration and then slowly increases during the remainder of the inspiration (Figure 4.1a and d; open arrows). During open stoma breathing in a 38 °C environment this is even more pronounced, with a much shorter and smaller decrease in temperature and a larger increase in temperature during inspiration (Figure 4.1g; open arrow). During the following expiration the temperature rises very shortly and then slowly decreases (Figure 4.1g; bold arrow). As a result the temperature pattern at 38 °C is more or less “inverted” when compared to open breathing in moderate climate conditions. At 34 °C (and 32 °C) exhalation starts with a much larger rapid temperature increase, followed by a slow decrease (Figure 4.1d; bold arrow). As a result the overall pattern at 34 °C and 32 °C is not inverted. With the R-HME and F-HME temperature patterns are more similar to the room temperature pattern, but the decrease in temperature during exhalation is observed as well (Figures 4.1f, h and i; bold arrows). At 38 °C, a short temperature peak is observed immediately after the start of inhalation (Figure 4.1h and i, arrows) which is in particular observed during breathing with the F-HME, but also and less pronounced with the R-HME.

The pattern as described in Figure 4.1 was typical for most of the measurements. Figure 4.2 shows the patterns at 38 °C for 2 different patients (patients B and C). Also in these patients both the “inversion” of the temperature pattern

without HME and the decrease in temperature during exhalation are visible (open and bold arrows). The short temperature peak at the start of inhalation with HME is only present with the F-HME patient C (Figure 4.2f, arrow).

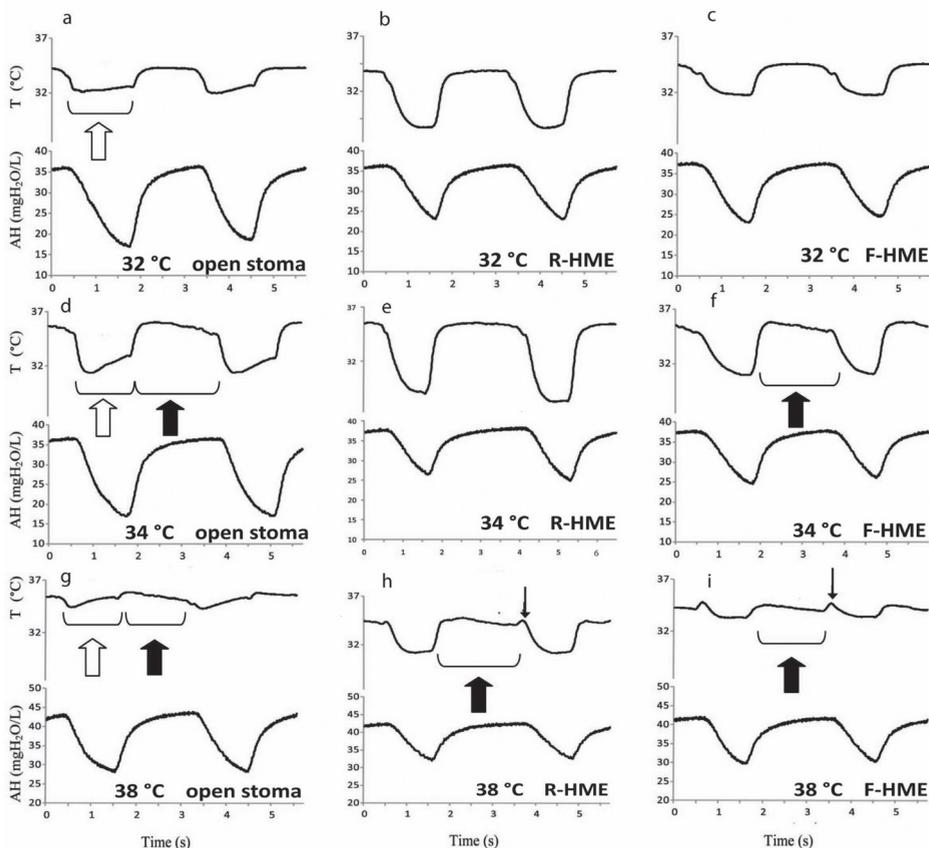


Figure 4.1 Temperature and humidity pattern of a pair of breaths of patient A is shown for all environmental temperatures (32 °C: a-c; 34 °C: d-f; 38 °C: g-i) and for all three conditions (open stoma breathing: a, d, g; with R-HME b, e, h; with F-HME: c, f, i). Bold arrow: decreasing temperature during exhalation; open arrow: increasing temperature during inhalation; arrow: short temperature peak. Arrows are further explained in the results and discussion.

Note that the end-inspiratory temperature (T_{insp}) is higher than the minimum temperature (T_{min}) and the end-expiratory temperature (T_{exp}) is lower than the maximum temperature (T_{max}).

Absolute Humidity

Table 4.2 gives an overview of the results for the mean and median end-inspiratory and end-expiratory humidity (AH_{insp} and AH_{exp}). Environmental humidity increased with increasing environmental temperature (from 6.4 mgH₂O/L at 32 °C to 11.4 mgH₂O/L at 38 °C, see Table 4.1). During open stoma breathing both AH_{insp} and AH_{exp} increased as well (Table 4.2: AH_{insp} increases from 18.6 to 25.2 mgH₂O/L, respectively, and AH_{exp} from 35.5 to 40.0 mgH₂O/L, respectively). At all environmental temperatures both R-HME and F-HME increased AH_{insp} significantly over the value open stoma breathing (3.4–5.6 mgH₂O/L). The change in AH_{exp} with an HME was limited (+0.8 to 1.0 mgH₂O/L).

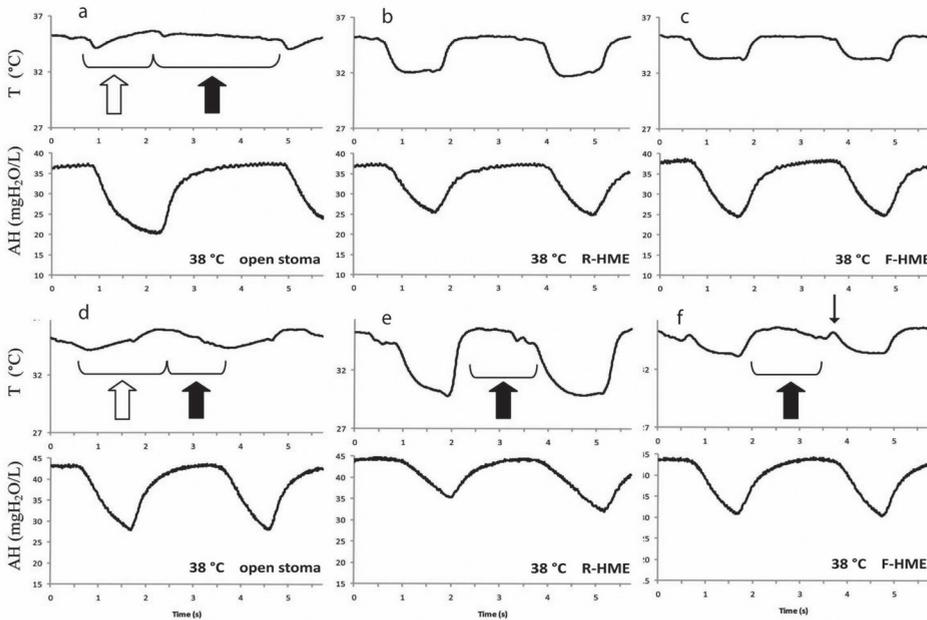


Figure 4.2 Temperature and humidity patterns at 38 °C for patients B (a-c: open stoma, R-HME, F-HME), and patient C (d-f ditto). Bold arrow: decreasing temperature during exhalation; open arrow: increasing temperature during inhalation; arrow: short temperature peak. Arrows are further explained in the results and discussion.

Temperature

Table 4.2 gives an overview of the results for the mean and median end-inspiratory and end-expiratory temperature (T_{insp} and T_{exp}). Both HMEs

Table 4.2 The mean, standard deviation, median, and range of the end-inspiratory and end-expiratory temperature (T_{insp} and T_{exp}) and humidity (AH_{insp} and AH_{exp}) values and the differences between the means during breathing through the open stoma and through the R-HME and F-HME in the three different climate conditions studied. Values between brackets indicate standard deviations, respectively ranges.

	n	Open Stoma		R-HME		F-HME		Diff. R-HME – open stoma	Diff. F-HME – open stoma	Diff. R-HME – F-HME
		Mean (SD)	Median (range)	Mean (SD)	Median (range)	Mean (SD)	Median (range)			
T _{insp}	10	31.9 (0.5)	32.0 (31.2 – 32.7)	28.2 (1.5)	28.3 (26.1 – 30.5)	31.3 (0.7)	31.5 (30.4 – 32.3)	-3.7*	-0.6*	-3.1*
	5	32.7 (0.6)	32.7 (31.8 – 33.5)	29.2 (1.0)	29.0 (28.3 – 31.0)	31.4 (0.4)	31.3 (31.0 – 32.1)	-3.5*	-1.3*	-2.2*
	10	35.4 (0.5)	35.3 (34.9 – 36.5)	31.7 (0.8)	31.7 (29.8 – 32.7)	34.1(0.8)	33.9 (33.3 – 36.0)	-3.7*	-1.3*	-2.4*
T _{exp}	10	33.9 (0.7)	33.7 (33.0 – 35.3)	33.6 (0.8)	33.5 (32.5 – 35.6)	34.6 (0.5)	34.6 (33.7 – 35.4)	-0.3	0.7*	-1.0*
	5	34.7 (0.8)	34.5 (33.8 – 35.9)	33.9 (0.7)	34.1 (32.8 – 34.7)	35.0 (0.6)	34.8 (34.4 – 35.8)	-0.8*	0.3	-1.1*
	10	34.6 (0.4)	34.7 (33.9 – 35.2)	34.3 (0.3)	34.4 (33.7/34.6)	35.1 (0.5)	35.1 (34.6 – 35.9)	-0.3	0.5*	-0.8*
AH _{insp}	10	18.6 (2.7)	18.8(14.9 – 23.5)	24.2 (2.5)	23.4 (21.5 – 29.0)	23.6 (2.7)	22.8 (20.6 – 27.8)	5.6*	5.0*	0.6
	5	21.8 (2.7)	23.0 (17.1 – 25.2)	27.2 (2.7)	27.2 (23.8 – 30.5)	26.8 (2.0)	26.4 (24.0 – 29.3)	5.4*	5.0*	0.4
	10	25.2 (3.2)	26.5 (20.7 – 29.4)	29.2 (5.3)	28.1 (20.3 – 37.2)	28.6 (4.1)	28.8 (20.7 – 33.9)	4.0*	3.4*	0.6
AH _{exp}	10	35.5 (1.4)	35.8 (32.6 – 37.5)	36.4 (1.7)	36.3 (33.8 – 39.2)	36.5 (1.8)	36.5 (33.6 – 39.9)	0.9*	1.0	-0.1
	5	36.8 (1.2)	36.1 (35.9 – 38.4)	37.6 (0.9)	37.4 (36.4 – 38.9)	37.8 (0.8)	37.6 (36.8 – 38.8)	0.8	1.0*	-0.2
	10	40.0 (4.1)	41.4 (32.1 – 45.5)	40.8 (3.6)	41.2 (34.2 – 46.7)	40.9 (3.2)	41.0 (34.7 – 45.2)	0.8	0.9	-0.1

*significant ($p < 0.05$)

cool the inspired air significantly compared to open stoma breathing and the cooling effect of the R-HME is significantly larger than that of the F-HME at all temperatures (range -3.1 to -2.2 °C; $p < .05$). The HME effect is similar for all environmental temperatures.

The minimum temperature (T_{min}) during open stoma breathing at environmental temperatures of 32, 34 and 38 °C is respectively 31.5 °C, 31.7 °C and 34.3 °C so that T_{min} is on average 0.9 °C lower than end-inspiratory temperature (T_{insp}) for open stoma breathing due to the deviating temperature patterns. With the HMEs T_{min} is about equal to T_{insp} (difference < 0.2 °C).

The end-expiratory temperature values remain quite constant, even at higher environmental temperature (38 °C), both with and without HME. At 32 and 34 °C, T_{exp} equals the maximum temperature (T_{max}). Due to the different temperature pattern at 38 °C, T_{max} is on average 0.9 °C higher than T_{exp} (T_{max} : open stoma 35.8 °C; R-HME 35.3 °C; F-HME 35.6 °C).

Discussion

Breathing pattern

This is the first study, which reports endotracheal temperature and humidity in laryngectomized patients in a warm (up to 38 °C), and dry (less than 25% relative humidity) environmental conditions. One of the intriguing findings is that the breathing-related temperature patterns are different from those previously found in room climate conditions. This is most obvious in the 38 °C environment. Whereas in room climate conditions the minimum and maximum temperatures (T_{min} and T_{max}) correspond to end-inspiratory and end-expiratory temperatures (T_{insp} and T_{exp}), this is no longer the case during open stoma breathing at 38 °C environment, where T_{min} and T_{max} are almost "inverted". In other words, warm air is inspired and cooler air is expired. This can be explained by the phenomenon of evaporative cooling. The examples in Figure 4.1a,d, and g (open arrows) show that at the beginning of the inspiration, the temperature rapidly (shortly) decreases, immediately followed by a slow increase in temperature. The water on the trachea surface, 'deposited' there during expiration, will evaporate in the warmer air. This heat-consuming process leads to cooling of the trachea. However, the amount of water in the trachea probably is rapidly depleted (as is also suggested by the rapidly decreasing humidity curve), so that the cooling effect of the trachea is

limited and the temperature will increase again. This phenomenon disappears with the presence of an HME, which probably (together with the trachea) stays wet enough to achieve sufficient cooling, as is shown by the continuously decreasing temperature curves during breathing with R-HME and F-HME.

At the beginning of the expiration (i.e. the “fast” phase of the expiration) another difference in comparison to the earlier observed phenomena under room temperature conditions can be noted: in particular at 38 °C the temperature first, as usual, rapidly increases, now however followed by a slow decrease in temperature (Figure 4.1d, f-i; bold arrows). At first sight this cooling suggests that the patient slowly inhales, but the RespiTrace signals (available at 32 and 34 °C) and the increasing humidity make this very unlikely. Probably this cooling also is due to the evaporation of water of the mucosal layer of the tracheostoma. Normally, breathing air cools along the respiratory tract during expiration, and the lowering temperature of the trachea induce condensation of water vapor on the tracheal wall. At very high environmental temperatures, the tracheostoma is warmer than the lungs, so that water from the mucosal respiratory layer evaporates instead. Hence absolute humidity was observed to increase continuously during expiration.

Subsequently at the onset of inspiration the temperature rapidly increases shortly, which is in particular observed during breathing with the F-HME, but also and less pronounced with the R-HME (Figure 4.1h, i, and 4.2f; arrows). We propose that this temperature peak occurs since warm air from the environment initially negates the additional cooling achieved by moisture from the trachea wall. Very quickly however the HME evaporatively cools the air and the temperature drops. The F-HME is built with an isolation layer in which heat will be stored (Chapter 5). Indeed, a larger increase in temperature at the beginning of the inspiration was observed with this device. In the 32 and 34 °C environment, similar features can be identified in the temperature patterns, although less extreme.

Heat and moisture exchange; open stoma breathing

This study shows once more that the trachea, just like the nose and pharynx, acts as an HME itself [33;36;79]. The proximal trachea mucosa rapidly humidifies inspired air from 6.4 to 18.6 mgH₂O/L at 32 °C, from 8.9 to 21.8 mgH₂O/L at 34 °C, and from 11.4 to 25.2 mgH₂O/L at 38 °C. Thus, the increase in end-inspiratory humidity over the environmental humidity is 12.2, 12.9 and 13.9

mgH₂O/L, respectively. Additionally, at these high environmental temperatures, the trachea cools the inspired air: the decrease in end-inspiratory temperature compared to the environmental temperature (nominal 32, 34 and 38 °C) is -0.1, -0.9 and -2.8 °C respectively.

Heat and moisture exchange; HME effect

Both R-HME and F-HME increase AH_{insp} significantly at high environmental temperatures (with a relatively low humidity). Both HMEs keep their humidifying capacity even in the 38 °C room environment (i.e. above body temperature). Heat and moisture exchange capacity is primarily based on condensation of (warm) expired air on the (colder) HME device. This condensation leads to storage of water, which evaporates subsequently into the inspired air. Theoretically, if the HME is even warmer than the expired air, water vapor would not be able to condense on the HME. However, both R-HME and F-HME do lead to a significant increase in humidity compared to open stoma breathing (+4.0 and +3.4 mgH₂O/L, respectively), even at a temperature above body temperature. This performance must be due to the hygroscopic salt (calcium chloride) with which the foam of both HMEs is impregnated. Since the HME is also able to exchange water in warm climate conditions (even at 38 °C environment), the evaporation also leads to cooling of the inspired air. The R-HME is even a better cooler than the F-HME (about -3.7 compared to -1.1 °C respectively). First, the R-HME is constructed with more foam and is therefore a better water exchanger, leading to more evaporative cooling. Secondly, the F-HME is constructed with an additional antimicrobial filter, covered over its core material (i.e. the hygroscopic foam). In room climate conditions, the F-HME acts as a heater of inspired air, in contrast to the R-HME, which cools already at room climate conditions (Chapter 5). Although a cooling effect might be desirable at higher temperatures, the F-HME also has an electrostatic filter capacity, so that this HME might be a good choice if the environment is dusty as is often the case in a warm and dry environment.

Comparison with cold and room climate conditions

This study shows that an HME works as a humidifying and cooling device in a warm environment. In cold conditions (4 °C) it still humidifies, but then warms the air [36]. In Table 4.3 the results of all measurements of open stoma breathing and breathing with R-HME from our research group in different environmental conditions are collected, and graphically shown in Figure 4.3.

Figure 4.3a shows the end-inspiratory temperature at 1 cm in the trachea for both open stoma breathing and for the R-HME as a function of the environmental temperature. In addition, the environmental temperature itself is shown. It is obvious that already the first centimeter(s) of the trachea itself act as a heat exchanger and reduce the temperature differences in the trachea considerably. The effect of the trachea is almost linear with a very strong heating at near freezing, limited heating at room temperature and cooling at temperatures near body temperature. Both at low and at high environmental temperatures the R-HME enhances the effect of the trachea itself. At room temperature the R-HME still heats the air, but less than open stoma breathing. In Figure 4.3b the end-inspiratory humidity of both open stoma breathing and breathing through the R-HME is shown as a function of the temperature of the environment. In addition the environmental absolute humidity is shown. At all conditions both the trachea and the R-HME have an almost constant humidifying effect compared to the environmental humidity and the R-HME adds an also near constant additional 5 mgH₂O/L to the end-inspiratory humidity. Both the curve for open stoma breathing and the curve of the R-HME closely follow the environmental humidity. This is in agreement with our finding at room temperature that environmental humidity is an independent predictor for AH_{insp} (Chapter 3).

In conclusion, the studied HME improve tracheal climate in all situations with a low environmental absolute humidity, in winter, indoor, and in desert climates (Phoenix Arizona).

Limitations of the study

Although in previous studies the end-inspiratory and end-expiratory values correspond to the minimum and maximum values respectively, in the present study they do not, in particular at 38 °C. However, using T_{min} or T_{max} (as reported in the results) does not change the conclusions.

The number of patients included is not very large. The measurements at high temperatures were a great burden on the patients so that only a few patients were willing to and able to participate at all three temperature conditions. Because the inter-patient variability is limited (Chapter 3), it is unlikely that including more patients would modify our results.

Table 4.3 The mean inspiratory and expiratory temperatures (T_{insp} and T_{exp}) and humidity's (AH $_{insp}$ and AH $_{exp}$) during breathing through open stoma or through the R-HME and F- HME in different climate conditions. For the cold room condition only data for the R-HME are available [36].

		Cold climate (Zuur et al) [36]	Room climate (Chapter 3)	Warm climate (present study)		
		4.7 °C; 4.5 mgH ₂ O/L	23.8 °C; 6.4 mgH ₂ O/L	32 °C; 6.4 mgH ₂ O/L	34 °C; 8.8 mgH ₂ O/L	38 °C; 11.3 mgH ₂ O/L
T_{insp}	Open stoma	19.7	28.3	31.9	32.7	35.4
	R-HME	23.6	26.7	28.2	28.8	31.7
	F-HME	-	29.4	31.3	31.4	34.1
T_{exp}	Open stoma	31.0	34.8	33.9	34.7	34.6
	R-HME	32.2	34.8	33.6	33.7	34.3
	F-HME	-	35.4	34.6	34.9	35.1
AH $_{insp}$	Open stoma	20.9	17.8	18.6	21.8	25.3
	R-HME	25.1	22.6	24.2	26.3	29.2
	F-HME	-	22.5	23.6	26.2	28.5
AH $_{exp}$	Open stoma	29.6	32.9	35.5	36.8	40.0
	R-HME	32.1	33.7	36.4	36.9	40.8
	F-HME	-	34.9	36.5	37.5	40.9

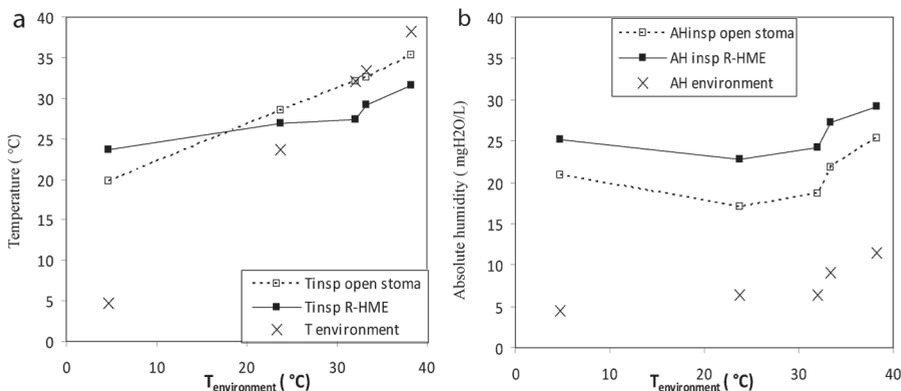


Figure 4.3 In Figure 4.3a the end-irspiratory inspired temperature (T_{insp}) for both open stoma breathing and breathing through the R-HME and the environmental temperature (T_{env}) are shown as a function of environmental temperature. In 4.3b the end-inspiratory humidity (AH $_{insp}$) for both open stoma breathing and R-HME and the environmental humidity (AH $_{env}$) are shown as a function of environmental temperature.

Conclusions

Endotracheal temperature patterns in warm and dry climate conditions in laryngectomized patients, particularly at 38 °C, are quite different from those in moderate climate conditions. During inspiration there is a short period of decreasing temperature, followed by a longer increase in temperature in the remaining part of the inspiration. During expiration a short increase is followed by a long, slow decrease. As a result, the overall temperature pattern is “inverted”. Humidity patterns are similar to those at room temperature.

In warm and dry climate conditions, the tracheostoma itself acts as a climate conditioner in laryngectomized patients: it cools and humidifies the inspired air. Use of the R-HME or the F-HME increases this cooling and humidifying effect significantly. The R-HME cools more than the F-HME, but the F-HME might add important filtering in dusty conditions. Both HMEs might therefore have a beneficial clinical effect (reducing pulmonary complaints) not only at room temperature and in cold conditions but also in warm and dry environmental conditions.