INFLUENCE OF PASSIVE HUMIDIFICATION ON RESPIRATORY HEAT LOSS IN TRACHEOTOMIZED PATIENTS

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Abstract: Background. The aim of this study was to evaluate changes in total respiratory heat loss during use of a heat and moisture exchanger (HME) in tracheotomized patients.

Methods. Tracheal humidity and temperature were measured before the application and during use of the HME (plastic foam impregnated with CaCl₂), and total respiratory heat loss was calculated.

Results. No significant difference was found between the convective heat exchange before and after use of the HME for a 10-minute period. When the HME was placed on the tracheal opening, the evaporative heat exchange and the total respiratory heat loss decreased significantly.

Conclusions. The results indicate that passive airway humidification is effective in tracheotomized patients even after a 10-minute period. However, the positive effect on the energy balance of the tracheal mucosa after prolonged use of the HME remains to be proven.

Keywords: airway physiology; respiratory pathophysiology; tracheostomy care; respiratory heat loss; heat and moisture exchanger

In patients after tracheotomy, the upper airway system and the normal heat and moisture exchanging process of inhaled air is bypassed. A continuous loss of heat and moisture occurs and can lead to serious damage of the tracheobronchial mucosa. Heyden1 studied patients after tracheostomy and found that mucus glands and goblet cells became hyperactive, and excessive mucus production was frequently observed when the normal upper airway was bypassed. Mercke and Tormalm2 evaluated the effects of inspired temperatures and humidities on mucociliary activity and demonstrated that both temperature and relative humidity are important in the pathogenesis of ciliary damage caused by inspired gases.

It has long been considered desirable to provide warm and humid inspired air to patients with an artificial airway (tracheostomy tube or endotracheal tube), and various methods to achieve this have been proposed. Complications after tracheotomy may be prevented by the use of different vaporizers, nebulizers, or a heat and moisture exchanger (HME). HMEs have a good moisture-conserving performance. During expiration, partial condensation of water vapor in the HME occurs that can be evaporated and retransferred to the inhaled air. Thus, up to 70% of expired heat and humidity may be recovered.3

Whereas numerous studies on heat and moisture exchange and thermoregulation in the lower...
airways during anesthesia have been performed, only scanty data on clinical parameters of humidification in patients with tracheotomies is currently available.

This study was, therefore, done to examine the influence of HME on the convective heat exchange ($W_C$), the evaporative heat exchange ($W_E$), and the total respiratory heat loss ($W_T$) of the lower airways in patients after tracheotomy. For this purpose, we prospectively studied a cohort of patients with tracheotomies to determine whether changes in $W_C$, $W_E$, or $W_T$ could be evaluated from changes in tracheal temperature and humidity before and during use of a HME.

**MATERIALS AND METHODS**

The Ethics Committee of the University of Ulm, Germany, approved this study, and informed consent was obtained from all patients. We studied 20 patients (median age, 58 years) with tracheal opening because of laryngeal obstructive diseases. Patients with signs or symptoms of pulmonary or cardiovascular disease were excluded from the study.

Tracheal temperature ($T$) and relative humidity (RH) before and after application of the HME were detected similar to measurements of nasal and tracheal conditioning as described previously. A thermocouple and a suction probe that was connected to a relative humidity sensor outside the body were placed into the upper part of the trachea. The thermocouple measured the temperature within the tracheal lumen close to the tip of the suction probe. RH was detected at the end of the suction probe in the air that was sampled in the trachea. To minimize errors caused by any slight condensation within the suction system and the sensor box, a heat map was wrapped around the sensor box, and warming of the suction system was achieved.

The design of the study was as follows. Each patient was brought to the laboratory (ambient temperature, 24 ± 1°C; RH, 35% ± 4%) and seated in a chair. After removal of the tracheostomy tube, each patient was instructed to breathe calmly through the tracheal stoma for 15 minutes. First the detection device was inserted into the upper part of the trachea. The lower end of the detection cannula reached 3 cm distal to the tracheal stoma. Baseline values of $T$ and humidity (temperature during inspiration, baseline [TinspB], and RH during inspiration, baseline [RHinspB]; temperature during expiration, baseline [TexB], and RH during expiration, baseline [RHexpB]) in the tracheal air stream were obtained during respiration at quiet breathing for 5 minutes. An HME (Prim-Air system [filter made of plastic foam impregnated with CaCl$_2$, Heimomed, Kerpen, Germany) was then placed onto the tracheal opening. Ten minutes after application of the MEH, measurement of tracheal $T$ and RH was repeated through a little hole on the HME (TinspHME and RHinspHME, TexHME and RHexpHME).

Data of RH and $T$ were used for calculation of the inspiratory and expiratory absolute humidity and total respiratory heat exchange. Values of temperature and humidity before and after application of the HME were not different from values presented elsewhere and, therefore, are not shown here.

Total respiratory heat exchange (or loss) ($W_T$) within the tracheal airways was computed by summing the algebraic values of the convective or sensible heat exchange ($W_C$) and the evaporative, latent, or insensible heat exchange ($W_E$):

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W_T = W_C + W_E
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W_C = V \times \rho \times c_p \times (T_{in} - T_{out})
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W_E = V \times \lambda \times (C_{e,H_2O} - C_{in,h_2o})
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$V$ represents the minute ventilation; $\rho$ is the volumetric mass of the ventilatory gas ($\rho$ of N$_2$ [79%], 1.25 g/L; $\rho$ of O$_2$ [21%], 1.43 g/L); $c_p$ is the specific heat of the gases ($c_p$ of N$_2$, 1.0412 J/g per °C; $c_p$ of O$_2$, 0.9202 J/g per °C); $T_{in}$ and $T_{out}$ represent the temperatures of the inhaled and exhaled gases; $\lambda$ is the latent heat of water evaporation (2449 J/g H$_2$O); $C_{e,H_2O}$ and $C_{in,h_2o}$ represent the water concentrations of inhaled and exhaled gases. In this study, values of absolute humidity at the end of inspiration and expiration were used ($AH_{in} - AH_{out}$).

The tidal volume ($V_T$) in the spontaneously breathing patients with tracheotomies was approximately 500 mL, and the respiratory frequency (f) was 15 breaths per minute, as measured in prior spirometry. The phase of inspiration and expiration and respiratory frequency was continuously detected using a stress-sensitive belt around the thorax of each patient. Thus, constancy of the tidal volume was assumed. Minor changes of the tidal volume were shown not to be of relevant impact on temperature and humidity results. Because of higher expiratory temperatures and humidities than inspiratory ones, in the origi-
nal equations ($W_C = V \times \rho \times c_p \times [T_{insp} - T_{ex}]$, $W_E = V \times \lambda \times [C_{inspH_2O} - C_{exH_2O}]$) negative values for $W_T$, $W_C$, and $W_E$ were obtained, indicating a heat energy loss.\(^{13}\) Therefore, the term “loss” is used instead of “exchange” to describe respiratory heat changes. In this study, however, only positive values for $W_T$, $W_C$, and $W_E$ ($W_C = V \times \rho \times c_p \times [T_{ex} - T_{insp}]$, $W_E = V \times \lambda \times [C_{exH_2O} - C_{inspH_2O}]$) are calculated and demonstrated for practical reasons.

The nonparametric Wilcoxon signed rank test was used to compare $W_T$, $W_C$, and $W_E$ obtained at two detection times.\(^{15}\) Significance was accepted at the 95% confidence level ($p \leq 0.05$). Statistical analysis was performed using the statistical software WinSTAT (Kalmia Inc., Cambridge, MA).

RESULTS

The insertion of the detection device into the trachea was well tolerated by all patients. The use of the HME did not subjectively increase the work of breathing of the patients.

The median $W_C$ before use of the HME was 63 J/min (interquartile ranges, 52–74 J/min), the median $W_C$ after wearing the HME was 58 J/min (interquartile ranges, 50–66 J/min). The median $W_E$ before use of the HME was 330 J/min (interquartile ranges, 237–351 J/min), the median $W_E$ after wearing the HME was 245 J/min (interquartile ranges, 205–293 J/min).

The decrease of the convective heat exchange after application of the HME was not significant (Figure 1). When the HME was placed on the tracheal opening, the evaporative heat exchange decreased significantly compared with the baseline values before application of the HME (Figure 2).

The median $W_T$ before use of the HME was 391 J/min (interquartile ranges, 307–407 J/min); the median $W_T$ after wearing the HME was 300 J/min (interquartile ranges, 245–361 J/min; $p = 0.001$; Figure 3).

$W_T$ decreased significantly after use of the HME for a 10-minute period.

DISCUSSION

During normal breathing, the nose and upper respiratory tract act as a natural heat and moisture exchanger. When a patient is tracheotomized, this mechanism is bypassed. Respiratory problems such as excessive sputum production, coughing, crusting, and recurrent tracheobronchitis after
tracheostomy are frequently observed. Because of these conditions, an artificial way of reducing heat and moisture loss is needed. However, objective clinical parameters in the evaluation of HME after tracheotomy are still missing.

Therefore, the aim of this study was to evaluate an HME in patients after tracheotomy by measuring conditioning parameters within the tracheal lumen before and during use of an HME and to calculate total respiratory heat loss.

When the HME was placed on the tracheal opening, the evaporative heat exchange decreased significantly, whereas the convective heat exchange showed only a trend toward decreased values after use of the HME. The total respiratory heat loss after application of the HME was significantly reduced.

In this study, a 10-minute period of use of the HME between the two measurements was investigated. This short period plus the time of adaptation before the measurements was chosen, because a longer period without the tracheostomy tube and a potential shrinkage of the tracheal opening had to be avoided. Furthermore, an HME reliably functions in front of the airways without clinically relevant delay time.

The calculated total respiratory heat loss was based on tracheal humidity and temperature values obtained by miniaturized fast-response sensors. Several studies showed that the sensors used are suitable for in vivo measurements in the respiratory tract throughout the respiratory cycle. However, in vivo measurements are complicated, and attention has to be given to minimizing condensation within the suction system.

The importance of calculations of enthalpy changes of the breathed air was already demonstrated in investigations on respiratory heat exchange in mechanically ventilated patients. In a few investigations, mainly changes of airway humidity during and after use of HME have been reported, whereas significant changes of temperature have not been found or have not been reported. In this study, the significant decrease in $W_E$ also reflects a significant change in tracheal humidity during short-time use of an HME. A significant increase in temperature 10 minutes after application of the HME was shown in laryngotomized patients. However, only an insignificant decrease in $W_C$ in the small patient group in this study was shown. This finding may indicate that temperature changes after application of an HME may not be the main effects of HME after a short-term use.

The observation that humidity rather than temperature of the lower airways was increased after use of an HME underlines the special relation of heat and moisture exchange on the mucosal surface of the lower respiratory tract. The total energy content of the tracheal air consists of sensible heat content (ie, the temperature of air) and latent or insensible heat content (ie, the absolute humidity). The transfer of humidity from the tracheal mucosal surface to the inspired air needs much more energy, provided by the epithelial and subepithelial structures of the mucosal surface, than heating of the air.

In this study, the evaporative or insensible heat exchange was approximately five times higher than the convective or sensible heat exchange before use of the HME. During short-term use of the HME, the evaporative heat exchange significantly decreased, and the relation of $W_C$ to $W_E$ changed from $\sim 1.5$ to $\sim 1.4$, indicating a significantly reduced amount of energy that is necessary to warm and humidify tracheal air.

The results of this study support the fact that HME sufficiently assists in conservation of humidity within the tracheobronchial airways. We, therefore, believe that passive humidification is effective in patients with tracheotomies even after a short period of use. However, the potential impact of HME on the energy balance of the tracheal mucosa after prolonged application remains to be proven and will be investigated by our working group with the equipment presented in this study.

REFERENCES