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CHAPTER 9

Summary and Conclusions



The studies, as presented in this thesis, contribute to the insights and knowledge about heat and moisture exchangers (HMEs) used by laryngectomized individuals. Based on these data, recommendations for further HME development can be provided. Developing an HME with heat and moistening effects equal to those of normal upper airways should be aimed at. It is hypothesized that, by further improving endotracheal climate, the remaining postoperative pulmonary problems (coughing, crusting, mucous production, etc) will be reduced even more.

The question is how realistic it is to aim at the known subglottic values, so far only obtained in young and healthy individuals. As laryngectomized individuals are mostly elderly, (ex-) smokers, treated with radiotherapy, these values are probably not representative for this patient group. For this reason, a study was performed in a more comparable patient group, consisting of head and neck cancer patients with temporary tracheotomy (**Chapter 2**). In these patients, endotracheal temperature and humidity were measured through the tracheotomy, just prior to the planned decannulation. The end-inspiratory temperature and humidity values during nose breathing appeared to be 31.1 °C and 29.3 mgH₂O/L, respectively, which are considerably lower than the values of young and healthy patients (32.2 °C and 35.0 mgH₂O/L, respectively). Ideally, if laryngectomized patients breathe through an HME, these values should be reached. It must be noted however that the patient group in this study consisted of mostly postoperative and post-radiotherapy patients, of whom some had oropharyngeal mucosa defects (with or without reconstruction of that defect). Patients with such mucosal defects were found to have a quite obvious, although non-significant, decrease in end-inspiratory humidity values than patients without such defects. Although the difference was not statistical significant in these small patient series, a clear trend was visible. Therefore, we suggest that slightly higher target values should be aimed at.

For the development of new HMEs it is important to measure endotracheal temperature and humidity of these HMEs. For this reason, previously a purpose-built measurement system has been developed and validated (the Airway Climate Explorer, abbreviated as ACE). In order to improve our insight in the accuracy and reproducibility, the inter- and intra-patient variability and the influence of environmental factors were determined and described in **Chapter 3**. Repeated measurements have been performed in 16 patients on the same day, and on different days spread over the year. The environmental

humidity appeared to have influenced end-inspiratory humidity: the higher the environmental humidity, the higher the end-inspiratory humidity. Additionally, the inter-patient variability (variations between different patients) appeared to be smaller than the intra-patient variability (variations between different measurements in one patient). An important consequence of this relatively high intra-patient variability is that multiple measurements in more patients are just as useful as repeated measurements in one patient.

Most studies investigating endotracheal temperature and humidity are performed in room climate conditions. Some of them are also performed in cold (4.5 °C) climate conditions. Before publication of this thesis, no data were available in hot climate conditions. Especially in a hot and dry climate, the trachea is at risk of drying out. The question is whether or not an HME is of any therapeutic value in these climate conditions. Basically, at environmental temperatures above body temperature, expired water vapor will not condense any longer on the surface of the HME material, unless the hygroscopic salt (with which the foam of the HME is impregnated) is able to absorb some water. To find answers to these questions, a study was conducted where endotracheal temperature and humidity at higher environmental temperatures (32, 34 and 38 °C) were measured (**Chapter 4**). From the results described in this chapter we have learned that the trachea itself is the main contributor to the cooling and humidification of the inspired air, but that an HME enhances this effect of the trachea considerably. Based on these results, we can suggest that an HME certainly is useful in these climate conditions, even at temperatures above 37 °C, underlining the added value of the hygroscopic salt.

Apart from conditioning inspired air, the upper airways also provide breathing resistance. Physiologically, this breathing resistance decreases if physical activity rises. The question is whether or not an HME also should provide breathing resistance equal to that of the upper airways. An important disadvantage of the (fixed) breathing resistance of an HME is that it is generally experienced as uncomfortable, particularly during increased physical activity. Uncomfortable breathing would lead to a reduced patient compliance. For patient's comfort, previously an HME with reduced breathing resistance has been developed (HiFlow HME, in this thesis abbreviated as L-HME) with a breathing resistance of 0.13 kPa.s/L. Illustratively, the regular HME (Normal HME; in this thesis abbreviated as R-HME) has a breathing resistance of 0.18 kPa.s/L. To achieve this low breathing resistance, the foam material of this HME is more porous,

which means that there is less basic material within the same HME volume, which reduces the moisture capacity. In **Chapter 5** it was tested whether the humidification capacity of the L-HME is still sufficient. As anticipated, the L-HME appeared to be a slightly less good humidifier than the R-HME, but still achieved a significant improvement of the end-inspiratory values. Based on these results, the L-HME may be used as an effective therapeutical device in laryngectomized patients appreciating a lower breathing resistance, or needing that during physical activities. From the results from this study we also learned that an HME has a beneficial effect on breathing with a slight but significant increase of the tidal volume (about 15% for the R-HME and slightly less for the L-HME).

Laryngectomized patients are thought to be extra susceptible for airborne infections, during flu epidemics for instance, as they are lacking the filtration system of the upper airways. For this reason, an HME with additional antimicrobial filtering has been developed (Micron HME, in this thesis abbreviated as F-HME). As this antimicrobial filtration layer provides some extra breathing resistance, the amount of basic HME material had to be reduced in comparison to the R-HME in order to achieve still comfortable breathing. To investigate the conditioning capacities of this Micron HME a study was conducted in order to measure endotracheal temperature and humidity of this HME compared to those of the R-HME (**Chapter 6**). Apart from the (anticipated) finding that the effect of the F-HME on end-inspiratory humidity was lower than that of the R-HME, also an unexpected effect on temperature was found; the F-HME appeared heat inspired air, (+1.1 °C) in contrast to the lowering effect of the R-HME (-1.6 °C). The most likely explanation for this heating effect is that the additional filtration layer covering the HME material functions as isolation material and preheats inspired air. Additionally, a clinical study was also performed in 17 laryngectomized individuals to investigate the practical issues addressed to the F-HME. Interestingly, half of the patients remarked a considerable reduction of the sputum production. We assume this clinical improvement to be due to the heating effect of the HME, but the antimicrobial effect must not be excluded.

Based on the above-mentioned results, a new generation of HME devices has been developed. The new version of the Normal HME (R-HME) was called the XtraMoist HME (in this thesis abbreviated as Rplus-HME), the new version of the L-HME the XtraFlow HME (in this thesis abbreviated as Lplus-HME). The endotracheal temperature and humidity of this new generation HMEs was

measured, and compared to the R-HME (**Chapter 7**). The Rplus-HME appeared to have an almost twice as large moistening capacity than the R-HME (+6.8 mgH₂O/L vs. +3.7 mgH₂O/L). The moistening capacity of the Lplus-HME was comparable to that of the R-HME (+4.3 mgH₂O/L). Both new HMEs had no influence on temperature, at least no *decreasing* effect like the R-HME (-1.5 °C) and L-HME (-1.0 °C) are known to cause. In addition, the practical implications of these new devices were investigated in 13 laryngectomized individuals. About half of the patients experience a decrease in sputum production, which is thought to be due to the improved heat and moistening effect of the new HMEs. A technical disadvantage of the new devices was a “plopping” sound during speech. For this reason, the new devices will be redesigned such that this disturbing sound will disappear.

Based on the above-discussed studies on endotracheal temperature and humidity in laryngectomized individuals, we can give the following recommendations for the further development of next generations of HMEs:

1. Although the new generation HMEs has proven to form a step forward, the target values (based on the subglottic values in head and neck cancer patients) are still not reached. Therefore, further improvement of HMEs is still warranted.
2. The limiting factor for the humidifying capacity of an HME device is the heating capacity. The primary focus should be improving heat capacity. Warmer air can hold more water vapor, and will indirectly lead to improved humidification performance of an HME. Increasing the thermal capacity of an HME can be achieved either by using more (hygroscopic) foam, or to use a pre-heating layer. The challenge is not to simultaneously increase the breathing resistance.
3. A breathing resistance of an HME of 0.18 kPa.s/L seems to be sufficient. Based on the present results, a higher breathing resistance is not necessary and may only reduce patient compliance.
4. The parameters mentioned above include only technical aspects. In these considerations, we go beyond the fact that these HME devices must be comfortable and cosmetically acceptable for daily use in laryngectomized individuals. Generally, this implicates that the HME must be limited in size, weight, easy airtight closure (needed for voice prosthesis speech), easy changeable, disposable and affordable.