AIRFLOW RESISTANCE OF HEAT AND MOISTURE EXCHANGE FILTERS WITH AND WITHOUT A TRACHEOSTOMA VALVE

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Rehabilitation of laryngectomees has been furthered by the introduction of heat and moisture exchange (HME) filters, placed over a tracheostoma or on a tracheostoma valve (TSV). The airflow resistance of HME filters is an important factor with regard to the comfort of the patient. The goal of this study was to determine the airflow resistance (defined as the pressure drop over the device divided by the squared airflow through the device) of 4 commercially available HME filters with and without a TSV. The pressure drop over and the airflow through the devices were measured in vitro. Distinct differences among the devices were found. The mean airflow resistance of the HME filters ranged from 135 to 346 Pa • s²/L², that of TSVs was between 66 and 297 Pa • s²/L², and that of the combination was between 263 and 454 Pa • s²/L². The Stom-Vent 2 HME filter and the Adeva Window TSV with an Adeva filter had the lowest airflow resistance of the devices measured in this study.

KEY WORDS — airflow resistance, heat and moisture exchange filter, laryngectomy, pressure drop, tracheostoma valve.

INTRODUCTION

One method of restoring speech after laryngectomy is with the aid of a tracheoesophageal shunt equipped with a shunt valve1,2 such as the Blom-Singer valve,3 the Provox valve,4 or the Groningen button.5 These are used regularly, in spite of their limited lifetimes.6

When the skin around the tracheostoma is sufficiently flat, mucus production is low, and endotracheal phonation pressure is limited, a tracheostoma valve (TSV) can be applied.7-11 The patient can produce a spurt of air that closes the TSV, thus obtaining the capacity for hands-free speech.

To restore the nasal functions of laryngectomized patients, heat and moisture exchange (HME) filters have been introduced.12,13 These HME filters were derived from comparable devices that are used in patients who are mechanically ventilated.14-16 During expiration, an HME filter accumulates heat and moisture. During inhalation, the air is moisturized and warmed by the filter, thus preventing the tracheal tissue from drying out. This tracheal conditioning reduces both excessive mucus production and the occurrence of tracheal crusts. The filter can be attached to a TSV or applied directly by gluing it onto the skin like a TSV. A further advantage of an HME filter is that it offers an easy and efficient way to close the stoma manually.

Apart from the heat- and moisture-retaining capabilities, studied by Grolman et al.17 and Thomaschot et al.18 airflow resistance is another factor determining the quality of HME filters.17 Filters with a high airflow resistance require a high pressure to produce a certain airflow; thus, the patient must expend considerable energy in inhaling and exhaling. When these high pressures cannot be produced, a limited airflow will result that might cause problems in breathing.

The airflow resistance of HME filters has not been studied extensively. Only Grolman et al.17 have reported on airflow resistance. However, that article concentrates more on the economic aspects of HME filters than on airflow resistance. Pressure loss is determined only for 3 different airflow values and only during inhalation (Fig 117); thus, the study is not accurate enough to determine airflow resistance behavior during inhalation and exhalation. Moreover, variations between different specimens of a device and the influence of time have not been studied.

The aim of this study was to give more insight into the airflow behavior of HME filters and of the combination of an HME filter and a TSV.

MATERIALS AND METHODS

Four commercially available HME filters, 2 commercially available TSVs, and 2 combinations of HME filters and TSVs were examined. The HME filters (Fig 2) were the Blom-Singer HumidiFilter (Inhealth Technologies, Carpinteria, California) in a

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Blom-Singer HumidiFilter holder; the Provox Stoma Filter (Atos Medical AB, Hörby, Sweden) in a Provox Filter cassette; the Free Vent (Pharma Systems AB, Knivsta, Sweden); and the Stom-Vent 2 (Louis Gi-beck AB, Upplands Väsby, Sweden). The TSVs (Fig 2) were the Blom-Singer ATV (adjustable tracheostoma valve, Inhealth Technologies) and the Adeva Window (Adeva Medical, Lübeck, Germany). The combinations were the Blom-Singer ATV with the HumidiFilter and the Adeva Window with the Adeva Filter.

Figure 3 shows schematically the test setup used to measure airflow resistance. Pressure drop was measured by HP pressure transducers (model 267BC, Hewlett Packard, Waltham, Massachusetts), and airflow was measured by a Lilly flowhead (Mercury Electronics, Glasgow, Scotland). Air was applied by mouth blowing. More details are given by Geertsema et al. All 4 HME filters, the 2 TSVs (the Blom-Singer ATV is adjusted in the 2 extreme positions, marked 90 and 0), and the 2 combinations of HME filter and TSV were measured. Measurements were made in triplicate on 3 specimens of each of the devices. The breathing time per measurement was 10 seconds. The influence of breathing time was determined for 2 devices (Blom-Singer HumidiFilter and Provox Stoma Filter) by breathing through them for 1 hour, and then pressure drop and airflow measurements were made. The results are presented in graphs with the pressure drop plotted against the squared airflow.

RESULTS

In Fig 4, the pressure drop over a Stom-Vent 2 HME filter is plotted against the squared airflow. A linear relationship appears between pressure drop and squared airflow. All other HME filters and TSVs show a similar linear relationship. Table 1 depicts the mean airflow resistance, defined as the slope of the trend-line, of all the measured devices. Among the HME filters, the HumidiFilter shows the highest airflow resistance, and the Stom-Vent 2 the lowest. Among the TSVs, both with and without an HME filter, the Blom-Singer ATV-90 has the highest airflow resistance, followed by the Adeva Window and the Blom-Singer ATV-0. The airflow resistance of a combined HME filter and TSV is slightly higher than that of an HME filter alone.

Table 1 also depicts the range of measured results. This range is rather large for most devices, because a distinct difference among the 3 specimens was found. The maximum difference in airflow resistance
between 2 specimens appeared to be 28%.

The airflow resistance changed little over time. After 1 hour of breathing, the airflow resistance changed by 2% at the most.

**DISCUSSION**

Several researchers have measured the airflow resistance of TSVs and shunt valves but the airflow resistance of HME filters has not been measured extensively.

In addition to the closing behavior of TSVs and the HME capacity of HME filters, the airflow resistance of TSVs and HME filters is another important characteristic of these devices. The lower the airflow resistance, the more comfortable the patient will be. Breathing is a constantly repeated, and normally unconscious, activity. An increased airflow resistance caused by a TSV and an HME filter could make breathing effortful, and the problem would be compounded as the labored breathing became more conscious.

In healthy persons, the pressure drop and airflow resistance of the nasal, pharyngeal, and laryngeal cavities have been measured by several researchers. In some cases, airflow resistance is defined as pressure drop divided by airflow, and not, as in the present article, by the squared airflow, which is a better way to describe airflow resistance. Table 2 summarizes the airflow resistances that have been calculated from the results of these studies. Airflow resistance is defined as pressure drop divided by the squared airflow and is, when possible, calculated for a mean airflow of 0.5 L/s as representative of quiet breathing. The mean nasal airflow (nasal passage, pharynx, and larynx) resistance ranged from 304 to 742 Pa • s²/L² during inspiration and from 266 to 722 Pa • s²/L² during expiration. The wide ranges and large SDs that have been reported are an indication that it is either very difficult to measure airflow resistance accurately or that large variations between subjects occur. Unfortunately, only a small number of subjects participated in the studies cited above.

The airflow resistance of the analyzed devices, again defined as pressure drop divided by the squared airflow, was derived from the measured data and summarized in Table 1 to compare it with the mean airflow resistance of the nasal airway. In general, the airflow resistance of the analyzed devices is lower than the reported mean airflow resistance of the nasal airway. Only when the data of Ferris et al and that of the Blom-Singer HumidiFilter higher than the mean nasal airway resistance.

Some amount of airflow resistance is beneficial, because the pressure that builds up during exhalation keeps the lungs expanded, avoiding alveolar collapse.

Our measurements in Fig 4 show that a quadratic relationship between the airflow and pressure drop of HME filters and TSVs characterizes airflow behavior very well. Breathing time has little influence. Differences between specimens do exist. In particular, the airflow characteristics of the Free Vent and the Stom-Vent 2 HME filters show a large variation, probably caused by variations in the thickness and pore size of the applied foams. Despite these variations, distinct differences exist among the 4 HME filters...
TABLE 2. MEAN AIRFLOW RESISTANCE FOR INHALATION AND EXHALATION DERIVED FROM VARIOUS AIRFLOW RESISTANCE STUDIES

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<tr>
<td>Nasal passages</td>
<td>Inhalation</td>
<td>256 ± 86</td>
<td>278 ± 311</td>
<td>582</td>
<td>NI</td>
<td>660 ± 60</td>
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<tr>
<td></td>
<td>Exhalation</td>
<td>304 ± 94</td>
<td>238 ± 267</td>
<td>582</td>
<td>NI</td>
<td>640 ± 60</td>
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<tr>
<td>Oral cavity</td>
<td>Inhalation</td>
<td>NI</td>
<td>20 ± 22</td>
<td>NI</td>
<td>96 ± 38</td>
<td>168 ± 38</td>
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<td></td>
<td>Exhalation</td>
<td>NI</td>
<td>22 ± 25</td>
<td>NI</td>
<td>108 (44-236)</td>
<td>176 ± 34</td>
</tr>
<tr>
<td>Pharynx and larynx</td>
<td>Inhalation</td>
<td>232 ± 1,046</td>
<td>26 ± 29</td>
<td>NI</td>
<td>108 (24-320)</td>
<td>NI</td>
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<tr>
<td></td>
<td>Exhalation</td>
<td>412 ± 1,694</td>
<td>28 ± 31</td>
<td>NI</td>
<td>34 (16-68)</td>
<td>NI</td>
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<tr>
<td>Nasal airway (nasal passage, pharynx, larynx)</td>
<td>Inhalation</td>
<td>488 ± 1,132</td>
<td>304 ± 1,140</td>
<td>742 (678-900)</td>
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<tr>
<td>with mouth closed</td>
<td>Exhalation</td>
<td>716 ± 1,188</td>
<td>266 ± 298</td>
<td>722 (662-832)</td>
<td>NI</td>
<td>NI</td>
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<tr>
<td>Oral airway (oral cavity, pharynx, larynx)</td>
<td>Inhalation</td>
<td>NI</td>
<td>46 ± 52</td>
<td>NI</td>
<td>222 (108-452)</td>
<td>NI</td>
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<tr>
<td>with velum closed</td>
<td>Exhalation</td>
<td>NI</td>
<td>50 ± 56</td>
<td>NI</td>
<td>150 (100-216)</td>
<td>NI</td>
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<td>Airflow (L/s)*</td>
<td>NI</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
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<tr>
<td>No. of subjects</td>
<td>4</td>
<td>9</td>
<td>16</td>
<td>4-6</td>
<td>5</td>
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</table>

Data are Pa • s²/L². Range or SD is given when available.
NI — not included in report cited.
*For which data are valid.

filters.

When we compare our data on the HumidiFilter, Free Vent, Stoma Filter, and Stom-Vent 2 with the data of Grolman et al. (Table 1), the same trends are found, but for 2 of the 4 HME filters, the airflow resistance values of Grolman et al clearly fall out of our range of data. Differences in the measuring setup could have caused the discrepancies in flow resistance. When pressure is measured at a point at which the flow profile is not fully developed, for instance, errors could occur. Also, the connection to the pressure transducer could disturb the flow profile and therefore cause errors. Another reason for discrepancies could be measuring only 1 specimen at a single moment. The description of the measurement setup and method of Grolman is not precise enough for us to check for these errors.

When we compare our data on the Blom-Singer ATV with the data of Grolman et al (Table 1), the same trends are found, but our mean values are higher. Again, the reason could be a different measurement setup or method.

The valve position of the Blom-Singer ATV is a crucial factor in its airflow resistance. Airflow resistance can increase by a factor of more than 4 as a result of changing the valve position.

For TSVs with an HME filter, in general, airflow resistance is clearly dominated by the HME filter. The combination of the HME filter and TSV causes a slightly higher airflow resistance than does the use of only an HME filter, except for the 0 position of the Blom-Singer ATV with the HumidiFilter, which has a lower airflow resistance than a HumidiFilter alone. This is most probably caused by the fact that the HumidiFilter holder has a smaller airway passage than does the Blom-Singer ATV adjusted in the 0 position.

The airflow resistance data reported in this article, in combination with other characteristics such as the heat- and moisture-retaining capabilities of HME filters and the closing behavior of TSVs, will determine which device is best for a patient.

CONCLUSION

For HME filters and TSVs, there is a linear relationship between the pressure drop over the device and the squared airflow through the device.

The Stom-Vent 2 clearly has the lowest airflow resistance, less than half that of either the HumidiFilter or the Provox Stoma Filter. Airflow resistance varies considerably among the specimens, up to 28%.

In general, the Adeva Window has a lower airflow resistance than the Blom-Singer ATV. The airflow resistance of the Blom-Singer ATV depends highly on the valve position. The combination of an HME filter and a TSV has a slightly higher airflow resis-
tance than an HME filter used alone.

In comparison with the reported mean airflow resistance of the nasal airway, most of the analyzed devices have a lower airflow resistance. However, the data on nasal airway resistance show a wide range, probably caused by external influences or by a large variation in patient characteristics.

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REFERENCES