Heat and moisture exchangers (HMEs) have been used for more than 30 years for heat and moisture retention during general anesthesia. Studies about bacteriostatic vs nonbacteriostatic HMEs (BHMEs/NHMEs) have been conducted to assess their role in preventing bacterial transmission to the anesthesia breathing circuit; none have been done on anesthetized patients in the operating room. The present study adds to existing knowledge about the HME’s ability to prevent transmission of bacteria, with implications for cost reduction resulting from reuse of anesthesia breathing circuits among patients.

The χ² test revealed no statistically significant differences between groups in transmission of bacteria from endotracheal tube (ETT) to anesthesia breathing circuit (P = .48). However, both groups showed statistically significant differences between presence of bacteria in ETTs and anesthesia breathing circuits: Group 1, BHME (P < .005) and group 2, NHME (P < .005).

Neither HME prevented contamination of the machine side of the circuit. These results support not reusing breathing circuits. Of 53 participants in group 2, 28 had positive ETT cultures with 7 showing transmission to anesthesia breathing circuit. Of 46 participants in group 1, 28 had positive ETT cultures with 9 showing transmission to anesthesia breathing circuit.

Key words: Anesthesia breathing circuit, bacteriostatic heat and moisture exchanger, endotracheal tube, nonbacteriostatic heat and moisture exchanger.

Introduction

Anesthesia breathing circuits, the inspiratory and expiratory circle tubing placed between the anesthetized patient and the anesthesia machine, have been implicated as a source of nosocomial infection. Concurrently, the increasing incidence of drug-resistant strains of mycobacteria and other infective agents have heightened awareness of the role bacterial airflow filters and heat and moisture exchangers (HMEs) may have in reducing infection. Although controversial, the current recommended standard of practice for reducing the risk of infection is the single-use disposable breathing circuit with a bacterial airflow filter placed on the inspiratory or expiratory limb.

Heat and moisture exchangers have been in
clinical use for more than 30 years. Practitioners, based on individual experience and preference, use HMEs for heat and moisture retention. During general anesthesia, the endotracheal tube (ETT) circumvents the heating and humidifying of inspiratory gases by the nose and pharynx. The inhalation of dry gases during anesthesia leads to tracheal damage and heat loss. The HME functions as an “artificial nose” in the anesthetic breathing circuit to retain heat and moisture within the patient’s respiratory system.\(^1\)

Bacteriostatic HMEs (BHMEs) and nonbacteriostatic HMEs (NHMEs) are currently available. The original design featured multiple layers of wire gauze mesh or polished metal tubes placed in parallel at the condensation surface; however, those lead to increased resistance to gas flow. Hygroscopic HME filters consisting of wool, foam, or paper-like material, often coated with moisture-retaining chemicals, such as calcium chloride or lithium chloride, possess little resistance to gas flow because of their large pore size but may have limited filtration properties. Paper-based HMEs were found to be the most efficient.\(^4\)

An additional benefit of some new HMEs is the hydrophobic filter membranes that prevent bacterial movement past the filter. Filtration of bacteria is a valuable asset because it can protect the breathing circuit from contamination. The filtering capabilities in BHMEs are characterized by their small pore size—approximately 0.3µm, which is considered to be an effective barrier to the transmission of bacteria.\(^5\)

Laboratory studies not involving live participants have used known bacterial challenges to a BHME filter at the Y-connector; findings support the practice of replacing the HME filter after each anesthetic patient and reusing the breathing circuit.\(^4\,5\) These investigators, while recommending clinically based studies, reported a projected $18,418 per-year savings with the use of an HME and the reuse of breathing circuits.\(^6\,7\) The only patient-based studies of the HME filter placed at the Y-connector have involved long-term ventilator patients in the critical care setting.\(^6\,8\) Studies using anesthetized patients in the operating room need to be done to make recommendations concerning the reuse of breathing circuits.

**Hypothesis 1.** There is no difference in the rate of positive cultures from the machine side of the BHME and the NHME. There were 56 ETTs with positive cultures. Of this group, 6 of 28 BHMEs had positive breathing circuit cultures. Four of 28 NHMEs had positive breathing circuit cultures. The results had a \(\chi^2\) value of 0.5, \(P=.48\). No difference was found between the rate of positive cultures from the machine side of the BHME and the NHME.

**Hypothesis 2.** There is a difference in the rate of positive cultures from the patient side and the anesthesia machine side in the NHME group (group 2). Of the 53 NHME group samples, there were 28 positive cultures on the patient side and 7 positive cultures on the anesthesia machine side. The \(\chi^2\) value was 18.8, with \(P<.005\). A difference was found between the rate of positive cultures from the patient side and the anesthesia machine side of group 2.

**Hypothesis 3.** There is a difference in the rate of positive cultures from the patient side and the anesthesia machine side in the BHME group (group 1). Of the 46 group 1 samples, there were 28 positive cultures on the patient side and 9 positive cultures on the anesthesia machine side. The \(\chi^2\) value for this analysis was 16.3, \(P<.005\). A difference was found between the rate of positive cultures from the patient side and the machine side of group 1.

**Material and methods**

A pilot study was done to determine the sample size and optimal culture sites to be used in the definitive study. Institutional approval was obtained, and a pilot study was conducted consisting of 2 groups with 8 patients in each HME group. Cultures were obtained from the 2 groups by culture swabbing 6 sites: the ETT (1), the HME (4), and the Y-connector (1). Throughout the pilot and definitive phases of the present study, the BHME used was the Sims 2835 and the NHME used was the Thermovent 600 (both Smiths Industries/Medical Systems, Keene, NH). Pore size was not defined for these HMEs.

The pilot study proved to be inconclusive in that only 3 of the 16 ETTs, where positive cultures would be expected, were in fact positive. We determined that a new method of investigating microorganisms within the ETT and breathing circuit needed to be developed. We decided to submit the ETTs, HMEs, breathing circuits, and airflow filters used by 5 patients to the microbiology section of the hospital’s Department of Clinical Investigations (DCI) for analysis via the washing method. In contrast to the swabbing method used previously, this method was successful (producing positive cultures), and data collection proceeded. The washing method used involved clamping the ETTs and breathing circuits.
taped closed, and packaged with the HME, breathing circuit, and airflow filters in a clean bag.
4. These materials were then transported, within 2 hours, to DCI for analysis. Once in DCI, the study materials were processed in the following manner. The ETTs and the breathing circuits were clamped at predetermined points and washed with Todd-Hewitt broth, a bacterial culture medium. The wash was then centrifuged and plated. The plated washings were evaluated for bacterial growth in 24 hours.

A quasi-experimental study using a split-plot design with filter type as the main plot factor and sampling site as the sub-plot factor was used to measure the effectiveness of a BHME vs an NHME in preventing the transmission of bacteria from the patient side to the machine side of both types of HMEs. Patients were randomized to filter type in permutations of 2 within blocks, using a random number table. The 5 available operating rooms served as blocks. The manipulated variable in the present study was the placement of 1 of 2 different HMEs.

Initially, the data were analyzed using \( t \) tests to show significant differences between the 2 HME groups. However, when the DCI sampled the number of bacteria colony forming units (BCFUs) in the ETTs and the anesthesia breathing circuits, the results showed “too numerous to count” results for the ETTs. Therefore, it was determined that results would be reported as “positive” or “negative” cultures for both the ETTs and breathing circuits, given the central research hypothesis that the BHME vs NHME would have a differential effect on the transmission of BCFUs from the patient to the anesthesia breathing circuit, from the breathing circuit to the anesthesia machine, and ultimately to the next patient. The 2 HME groups were analyzed for equivalency so that any significant differences in the variable of interest, which is bacterial growth, could be attributed to HME assignment. No statistically significant differences were found between the 2 groups on the following variables: operating room location, smoking history, coughing during
### Table.

Summary of frequencies for variables analyzed for equivalency of samples

<table>
<thead>
<tr>
<th>OR* (No. procedures)</th>
<th>Diagnosis (No. procedures)</th>
<th>No. Smokers</th>
<th>No. Coughing</th>
<th>Machine, No. procedures</th>
<th>Sputum</th>
<th>FGF* ≤ 3 L/min</th>
<th>Positive ETT* cultures</th>
<th>Position (No. procedures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (6)</td>
<td>Orthopedic (6)</td>
<td>1 (2')</td>
<td>1 (5')</td>
<td>Ohmeda 4 (2')</td>
<td>2 (2')</td>
<td>3 (3')</td>
<td>1</td>
<td>Supine (2)</td>
</tr>
<tr>
<td>2 (8)</td>
<td>GYN* (7)</td>
<td>1</td>
<td>2</td>
<td>6 (2)</td>
<td>6</td>
<td>6 (2')</td>
<td>2</td>
<td>Supine (2)</td>
</tr>
<tr>
<td>3 (13)</td>
<td>Orthopedic (2)</td>
<td>3</td>
<td>6</td>
<td>13</td>
<td>5</td>
<td>12 (1')</td>
<td>6</td>
<td>Supine (4)</td>
</tr>
<tr>
<td>4 (12)</td>
<td>General (11)</td>
<td>3</td>
<td>4 (6')</td>
<td>12</td>
<td>1 (1')</td>
<td>12</td>
<td>8</td>
<td>Supine (8)</td>
</tr>
<tr>
<td>5 (33)</td>
<td>General (6)</td>
<td>5</td>
<td>4 (9')</td>
<td>30</td>
<td>16 (1')</td>
<td>28 (5')</td>
<td>18</td>
<td>Supine (28)</td>
</tr>
<tr>
<td>6 (6)</td>
<td>General (1)</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>4 (4)</td>
<td>3</td>
<td>Supine (5)</td>
</tr>
<tr>
<td>7 (12)</td>
<td>General (10)</td>
<td>2</td>
<td>5 (3')</td>
<td>12</td>
<td>8</td>
<td>2 (2)</td>
<td>12</td>
<td>Supine (9)</td>
</tr>
<tr>
<td>8 (6)</td>
<td>Neuro* (6)</td>
<td>2</td>
<td>6</td>
<td>2 (2)</td>
<td>2</td>
<td>6 (3)</td>
<td>3</td>
<td>Supine (3)</td>
</tr>
</tbody>
</table>

*OR indicates operating room; FGF, free gas flow; ETT, endotracheal tube; GYN, gynecological; ENT, ear, nose and throat; and neuro, neurosurgery.

†Data are missing.

(The Ohmeda and 885A machines are products of Ohmeda Inc., Madison, Wis.)
emergence, HME use time, fresh gas flow, data collector, patient position, and sputum production.

There were 46 patients in the group 1 and 53 patients in the group 2. Five patients were deleted from the original sample of 104 due to technical problems processing data at DCI during the initial phases of the study. Of the 99 participants sampled, group 1 yielded 60.9% positive ETT cultures and 19.6% positive circuit cultures. Group 2 yielded 52.8% positive ETT cultures and 13.2% positive circuit cultures (Figure). Bacteria were classified by number and not by type.

The results of the study supported the following conclusions:

1. Positive cultures were obtained from breathing circuits in 13.2% of the cases where NHMEs were used. While this number was found to be statistically significant ($P<.005$), most clinicians would consider it too high to tolerate with respect to reuse of the breathing circuit.

2. Positive cultures were obtained from breathing circuits in 19.6 of the cases where BHMEs were used. Again, while this number was found to be statistically significant ($P<.005$), most clinicians would consider it too high to recommend reuse of the breathing circuit.

3. Based on the results of the present study, reuse of the anesthesia breathing circuit while using a BHME or NHME cannot be recommended. Although both filters were found to have a statistically significant ability to filter bacteria, the current practice of using a new circuit for each patient should be continued because of the occurrences of positive cultures in both groups.

4. Coughing and sputum production were found to be related with a $P=.001$. Smoking and sputum production were found to be related ($P=.013$). Therefore patients who smoked produced more sputum, and patients who produced sputum coughed more. We examined this issue because we suspected that increased sputum production produced more positive cultures. The data analysis did not support this position ($P=.38$).

Discussion

Studies involving HMEs used in the operating room with actual patients were not found in the literature. The objective of the present study was to determine whether there were differences in bacterial contamination of the anesthesia breathing circuit when using a NHME as compared to a BHME placed between the ETT and the breathing circuit. The findings of the present study showed that the HME prevented transmission of most bacteria from the patient to the breathing circuit; however, no statistically significant difference in bacterial contamination of the breathing circuit existed between the 2 groups.

The conceptual framework for this research was based upon the Nightingale Environmental Theory of Nursing and the chain of infection model. Nightingale promotes cleanliness of the physical environment as having a direct bearing on the prevention of disease and mortality. Nosocomial infection remains a bacterial source of morbidity and mortality and has been responsible for prolonged hospitalizations. Preventing nosocomial infection promotes a healing environment. The chain of infection illustrates the transmission of a pathogen to a susceptible host. According to this model, successful transmission of a pathogen requires a pathogen, reservoir, portal of exit, mode of transmission, portal of entry, and susceptible host.

This research supports both the Nightingale Theory of Nursing and the chain of infection. Group 2 had 13.2% positive cultures in the breathing circuit, and group 1 had 19.5% positive cultures in the breathing circuit. Therefore, using an HME (bacteriostatic or nonbacteriostatic) blocked the majority of pathogens from entering the breathing circuit. However, the HME filters need to be improved so that pathogens would be completely prevented from moving into the breathing circuit.
As Nightingale demonstrated that environmental pathogens are decreased through cleanliness, our findings demonstrate that pathogen movement was decreased with the placement of an HME.

Our research findings supported the results reported by other studies. duMoulin and Sauberman cultured 18 breathing circuits taken from unopened packages to reveal bacteria.7 The fact that, in our study, 4 cases had negative ETT cultures and positive circuit cultures may validate that aspect of the duMoulin and Sauberman study. Shelly and associates evaluated 5 HMEs and found only 1 to be 99% effective in removing spores passing through it.14 However, tests of statistical significance showed that both HMEs were effective \( P<.005 \).

Our study also presents inconclusive data regarding recommendations made by other studies found in the literature review. This may be due to the fact that other studies focused on: (a) the Pall bacterial/viral HME (Pall Biomedical Products Corporation, East Hills, NY),16,9 (b) mechanically ventilated intensive care patients,16 or (c) location of cultures or HME placement.15 Furthermore, every study in the literature review (except the study performed by Lee et al15) used spot cultures instead of washings. Our study used washings. Washings are more inclusive than spot cultures because they cover more surface area. Consequently, our pilot study results indicated that the results obtained from washings may be more accurate.

Variations in instrumentation and selection bias were potential threats to internal validity.16 Five individuals collected data. While a standardized method of collection was used, individual variation could have occurred. However, the investigators reviewed the standardized data collection techniques in a group setting to ensure consistency. Selection bias could have occurred with regard to the types of patients because of our inability to control types of patients scheduled for surgery, presence or absence of preexisting disease states, or treatment with medications that may affect their pulmonary systems.

The effect of selection threatens external validity due to the unpredictable characteristics of the participants (ie, age, preexisting disease states, and drug therapy). Thus, it may be difficult to generalize the findings of the present study to a variety of patient groups.

Future investigators should be cognizant of the present study’s limitations. These limitations included the use of multiple data collectors, the sample being restricted to adults only, the investigators not being blinded to the type of HME used, suctioning not being documented during data collection, and fresh gas flows of greater than 3 L/min being used before extubation by all investigators. Recommendations for further research include the following. Heat and moisture exchangers from various manufacturers should be evaluated to determine if all HMEs function in the same manner as those used in the present study. Heat and moisture exchangers should be evaluated for their efficacy in filtering viruses and fungi. Breathing circuits should be evaluated for their contamination rates before opening and after cleaning. Perhaps, with further research, disposable breathing circuits could be reused after proper cleaning and decontamination. Heat and moisture exchangers of various construction, treated with different solutions, should be evaluated in an operating room environment with patients to determine the optimal design.

The following implications for anesthesia nursing practice are derived from the results of the present study:

1. Historically, nursing has been involved in infection control and the prevention of nosocomial infection. The present study demonstrated that the use of a BHME or NHME may not be beneficial in infection control and controlling the spread of infectious agents to patients. While both filters were found to have a statistically significant ability to filter bacteria, neither blocked 100% of bacteria. Therefore, broad conclusions cannot be made about the HME and the role it may play in infection control.

2. In the present healthcare environment, rising costs and the use of medical supplies are under scrutiny. Nurse anesthesia administrators can cut costs by using less expensive NHMEs as opposed to more expensive BHMEs. Since both HMEs permitted the passage of bacteria from the ETT to the anesthesia breathing circuit, neither can be used with the intent of preventing bacterial contamination of the breathing circuit. Therefore, either HME can be used for the purpose of retaining heat and moisture. If a less expensive NHME is chosen instead of a more expensive BHME, then money can be saved. Based on the results of our study, each patient must have his or her own breathing circuit, therefore a large cost savings cannot be realized.

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