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Cleaning and infection control of airway clearance devices used by CF patients

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Abstract

Respiratory treatment for cystic fibrosis (CF) patients includes use of respiratory devices. Contamination of airway clearance devices has not been adequately explored. We aimed to determine whether airway clearance devices are contaminated after use and whether cleaning guidelines for nebulizers are as effective for airway clearance devices. Patients brought their airway clearance devices to the clinic. Swabs from the devices were taken before and after cleaning and were cultured for bacterial counts. Total colony-forming units (CFU) was determined, and predominant colonies were identified using Matrix-Assisted Laser Desorption Ionization Time-of-Flight Mass Spectrometry technology. Thirty devices were collected from 23 patients. Most of the devices (28/30) were contaminated when brought to the clinic. Complete bacterial eradication was achieved in 15 (50%) samples and partial eradication in 9 (30%). The cleaning was totally ineffective in four samples. Median CFU decreased significantly from 1250 (IQR 25–75% 175–10.000) to 0 (IQR 25–75% 0–700) before and after cleaning ($p < 0.0001$). The predominant organisms were identified in five samples only, and there was no concordance with sputum culture results. Airway clearance devices are contaminated after use, and appropriate cleaning can reduce contamination. The effect on disease progression in CF patients is unclear. There is a need for infection prevention and control guidelines for the growing number of respiratory devices.

Keywords

Cleaning, cystic fibrosis, airway clearance devices, infection control, physiotherapy

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Introduction

Cystic fibrosis (CF) is the most common life-threatening autosomal recessive disorder. Mutations in the CF transmembrane conductance regulator gene result in the absence or dysfunction of the protein that regulates ion transport across the apical membrane of certain epithelial cells. In the lungs, viscous secretions obstruct the airways, resulting in infection, inflammation, and eventual bronchiectasis.[1,2]

Pulmonary insufficiency is responsible for most CF-related deaths; thus, airway clearance is considered an integral and crucial component in the management of CF.[1]

CF pulmonary guidelines recommend daily airway clearance for all patients to maintain lung health and to decrease and treat exacerbations.[1,3] Airway clearance sessions are usually time consuming and increase the treatment burden of the patients.[4] The

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development of respiratory devices is intended to achieve higher compliance, improve efficiency, and optimize outcomes of airway clearance.[3,5–7] There are various airway clearance techniques available to CF patients, such as autogenic drainage and positive expiratory pressure (PEP) therapy. There are a growing number of airway clearance devices, such as PEP masks, Flutter, and intrapulmonary percussive ventilation (IPV), aiming to facilitate airway clearance.[7,8] Many CF patients use at least one respiratory therapy device, for example, nebulizer, Flutter, and Acapella, at least once daily. The devices are made from different types of plastic. Neely et al. found that both Gram-positive and Gram-negative bacteria can survive on plastic surfaces for more than 90 days.[9,10] Moreover, there is evidence that bacteria, such as *Pseudomonas aeruginosa*, *Stenotrophomonas maltophilia* and *Achromobacter xylosoxidans,* can infect patients through contact with surfaces.[11] A recent systematic review found that nosocomial pathogens may survive on surfaces for months and can therefore be a course of transmission of infections.[12]

Most of the literature refers to the contamination and cleaning and disinfection of nebulizers for which there are infection prevention and control guidelines. The guidelines recommend cleaning with soap, disinfection, rinsing with water (tap, clean, or sterile), and air-drying. Airway clearance devices were added to the general guidelines in recent years, without specific recommendations. Manufacturers' instructions for the respiratory devices are highly variable with regard to the type of water (sterile, clean, or tap) and the requirement for disinfection (ranging from daily to weekly).[13–15] Our aim was to determine if airway clearance devices become contaminated after use and if the cleaning guidelines for nebulizers are effective for airway clearance devices.

Patients and methods

Participants

This was a single-center study, performed at our CF center. The institutional board reviewed and approved the study with verbal informed consent. The inclusion criteria were CF patients treated in our center who use at least one respiratory device. Patients who did not bring their devices and patients who use a device which cannot be taken apart were excluded from the study. Notably, due to the risk of contamination, we recommend that our patients acquire devices that can be taken apart.

Study design

Patients were asked to bring their respiratory device for their routine clinic visit, after use and before cleaning. Due to the risk of bacterial cross-infection between CF patients, they were not allowed to be in the cleaning area and to do the cleaning themselves. Therefore, the physiotherapist solely cleaned the devices. The device was sampled using an SRK swab system (SRK Tube 10 ml solution, Sterile, COPAN Italia S.p.A). The physiotherapist took a swab from several inner parts of the device, including the mouthpiece. These areas come in direct contact with the patient and were presumed to be infected. Thereafter, the physiotherapist took the device apart and soaked it in hot clean water and standard dishwashing detergent for 10 min; after cleaning, it was rinsed with clean (filtered) hot water and left to air-dry on a clean surface. After complete drying, a second swab was used to sample the device. In order to minimize environmental contamination, the physiotherapist wore gloves throughout the cleaning process, and the device was soaked in a clean bowl, which had previously been cleaned with chloride.

Swabs were transferred to the microbiology laboratory within 2 h from sampling. Aliquots 100 µl were spread on brain-heart infusion agar plates and were incubated for 48 h at 37°C with 5% CO_2. Total count colony-forming unit (CFU) was determined from the plates, and predominant colonies were identified using Matrix-Assisted Laser Desorption Ionization Time-of-Flight Mass Spectrometry technology (Vitek-MS, Biomerioux, France). The physiotherapist asked the patients about the frequency of using their airway clearance devices and the frequency and method of cleaning.

Airway clearance devices differ in their mechanism of action. The following are short descriptions of the devices investigated in the study.

IPV-HC® (Intrapulmonary percussive ventilation-home care) is an electronic device, a gentle alternative to conventional or high-frequency pressure ventilation. It creates air exchange, more homogenized ventilation, leading to airways recruitment, loosening, and mobilizing secretions toward the upper airways and pharynx. It can be used via a mouthpiece or mask.[16]

Resistex® PEP Therapy device facilitates airway opening in patients with chronic lung diseases. It has a variable resistance setting that can be adjusted to meet individual expiratory requirements. It can be used via a mouthpiece or mask.[17]

Aerobika® Oscillating PEP Therapy System provides intermittent resistance and creates positive pressure and oscillations simultaneously, thus opening collapsed airways and assisting in mobilization of secretions. It is used via a mouthpiece and can connect to a Pari nebulizer.[18]

PipePTH Breathing Exerciser is intended for inspiratory and/or expiratory breathing exercises. It has resistors for PEP or PIP. It can be used via a mouthpiece or mask.[19]

Dofin™ echo® Percussor provides 20–25 Hz oscillation frequency. It has a built-in adjustable expiratory muscle training mechanism and flexible extension tube for bedridden patients.[20]

ShurClear® PEP Therapy device assists in loosening, mobilization, and elimination of mucus. It has easy assembly, oscillation frequencies of 6–20 Hz, and is gravity dependent.[21]

Acapella® Choice Vibratory PEP Therapy System combines the benefits of both PEP therapy and airway vibrations to mobilize pulmonary secretions. It can be used in virtually any position, allowing patients to move freely and sit, stand, or recline. It can be used via a mouthpiece or mask.[22]

Statistical methods

Descriptive statistics were used for the demographic variables, FEV_1, and CFU counts. Data are presented as mean $\pm$ *SD* and median (interquartile range [IQR]). Association between cleaning and CFU number was evaluated using the Wilcoxon signed-rank test. A p value of <0.05 was considered significant.

Results

Twenty-three patients with 30 airway clearance devices participated in the study. The mean age of the CF patients was 16.99 $\pm$ 11.24 years, and their mean FEV_1 was 58.6 $\pm$ 19.3% predicted. Table 1 lists the devices that were used by the patients, their principal mechanisms of action, and manufacturers' instructions for cleaning. As can be seen, a variety of devices are used at home. Seven different types of airway clearance devices, used by 23 patients, were examined.

The patients were instructed to clean their devices daily. Indeed, most of them reported using and cleaning their devices on a daily basis. Of 23 patients, 14 (61%) reported using the device on a daily basis. Eight (57%) of these reported cleaning the device daily and another 5 (36%) at least weekly.

Prior to cleaning, most (28/30) of the devices were contaminated. When examining the CFU after cleaning compared to that before, complete eradication of the organisms was achieved in 50% (15/30) of the samples and partial eradication in 30% (9/30). In two samples, there were no CFU before cleaning, and in four the cleaning was totally ineffective. Median CFU decreased significantly from 1250 (IQR 25–75% 175–10.000) to 0 (IQR 25–75% 0–700) before and after cleaning ($p < 0.0001$).

The laboratory was able to identify predominant pathogenic bacteria in five samples only. In the other samples, multiple environmental/commensal bacteria were found. The results of these five samples before and after cleaning, as well as the sputum culture results from these patients, are presented in Table 2. Pathogenic organisms were defined as implicated in CF lung disease, as opposed to environmental organisms, which are not known to damage the host. As may be seen, there was no change after cleaning in two samples, the same bacteria were found in one but the CFU count decreased by a 100-fold, and the culture after cleaning was negative in two samples. Interestingly, there was no correlation between the bacteria in the sputum and those sampled from the airway clearance devices.

Discussion

In this preliminary single-center study, we were aiming to determine whether airway clearance devices are contaminated after routine use and whether the cleaning guidelines for nebulizers are effective for airway clearance devices. The issue of contamination of airway clearance devices after use has not been directly addressed before. The majority (28/30) of devices in our study were found to be contaminated prior to cleaning. Cleaning resulted in complete eradication in 50% of the samples, partial eradication in 30%, and failure in four samples. Only in five samples were the predominant organisms identified, and there was no concordance with sputum culture results.

Nebulizer and airway clearance therapy comprise an essential aspect of care in CF patients. The choice of the device is related to the individual's and the physiotherapist's preferences with respect to airway clearance techniques and the selection of the optimal device. The handling and care of the nebulizers and airway clearance devices are of the utmost importance, as these devices deliver aerosols and

Table 1. Respiratory devices sampled in the study, their principal use, and manufacturers' cleaning instructions.

Devices	Mechanics	Breathing phase	Cleaning instructions
IPV-HC® ($n = 15$)[a]	Specific mode of ventilation with rates of approximately 100 –300bpm	Exp+Ins	Rinse with sterile water after each use. Disinfect weekly.
Resistex® PEP Therapy device ($n = 4$)[a]	PEP device with four resistance degrees.	Exp+Ins	Daily wash warm water with a liquid soap. Rinse with warm tap water. Use disinfectant recommended by practitioner.
Aerobika® Oscillating PEP Therapy System ($n = 4$)[a]	Oscillation PEP device with five resistance degrees	Exp+Ins	Soak 15 minutes in soapy water, agitate gently and rinse. Shake out water and dry after performing cleaning.
PipeP™ Breathing Exerciser ($n = 3$)[a]	Respiratory exercise system with eight resistance degrees.	Exp+Ins	Manual/washing machine. Wash in warm water using a detergent. Rinse thoroughly in clean water. Disinfection—boil with clean water for at least 10 minutes.
Dofin™ echo® Percussor ($n = 2$)[a]	Oscillation PEP, two resistance degrees. Gravity dependent	Exp	Soak all components in soapy water or mild detergent and rinse with boiled or distilled water. Wipe with clean cloth and allow to air dry.
ShurClear® PEP Therapy device ($n = 1$)[a]	Oscillation PEP device. Gravity dependent.	Exp	After each use soak in warm tap water and dishwashing detergent using warm tap water. Wash parts with a lint free cloth. Rinse with lukewarm tap water. Let dry on a clean towel.
Acapella® Choice Vibratory PEP Therapy System ($n = 1$)[a]	Oscillation PEP device, has five resistance degrees.	Exp+Ins	Soak in warm water with liquid dish detergent. Rinse with sterile water. Disinfecting: Boil in water up to twice daily for five minutes; Automatic Dishwasher; Alcohol—Soak five minutes, twice daily.

IPV: intrapulmonary percussive ventilation; HC: home care; PEP: positive expiratory pressure; Exp: expirium; Ins: inspirium.
[a]Number of devices sampled in the study.

medications which potentially may harbor infections.[15] In 2003, the Cystic Fibrosis Foundation published infection-control recommendations for CF patients, which were updated in 2013. The recommendations for nebulizer care include four steps—cleaning, disinfection, rinsing, and air-drying between uses.[14,15] There are several disinfection options: cold disinfection can be achieved using 70% isopropyl alcohol or 3% hydrogen peroxide, whereas heat methods include boiling, microwave, or dishwasher use.[15] Acetic acid was found to be noneffective against *Staphylococcus aureus*, thus it is not a recommended disinfectant.[11,13,15] After cold disinfection, equipment should be rinsed with sterile water, because tap water or distilled water may harbor pathogenic organisms.[11,14] In order to maintain the integrity and function of the devices, it is important to check the manufacturers' instructions, which are not always in line with the cleaning guidelines.[11,15]

Nebulizer and airway clearance devices are defined as semicritical devices, coming in contact with mucous membranes or nonintact skin.[15] According to the Centers for Disease Control (CDC), medical devices such as spacers, valve holding chambers, and PEP devices, should undergo high-level disinfection[23]; however, there are no specific recommendations regarding the frequency and methods of disinfection these devices should undergo.

We found that most airway clearance devices are contaminated with potentially pathogenic bacteria after routine use. The predominant organisms could be identified in five patients only, and there was no concordance with sputum culture results of the same patients. Several studies have examined the

Table 2. Results of five samples with identification of bacteria before and after cleaning, compared to sputum culture results.

Before cleaning	After cleaning	Sputum culture
Staphylococus pasteuri	Same findings	*Candida albicans*
Pseudomonas stuzeri; Staphylococus warneri; Corynebacterium sp.	Same organisms; 1/100 amount of colonies	*Aspergillus flavus; Candida tropica; Pseudomonas aeruginosa; Staphylococus aureus*
Corynebacterium sp.	Same findings	*Aspergillus niger; Candida albicans; Pseudomonas aeruginosa*
Moraxella sp.	Negative culture	*Candida albicans; Aspergillus niger*
Streptococci	Negative culture	*Candida albicans; Serratia marcescens*

contamination of nebulizers. Hutchinson et al. examined the home nebulizers of 35 CF patients; three were contaminated with *Burkholderia cepacia*, four with *S. maltophilia*, and only one had concordance with sputum culture results.[24] Blau et al. found 19 of 29 contaminated nebulizers,[25] and Vasaal et al. found that two-thirds of the nebulizers were contaminated after a single use.[26] Peckman et al. found fungi in 57% of devices examined, with no obvious correlation with sputum cultures.[27] When examining other devices, Mutagi et al. did not find significant contamination of noninvasive ventilation devices.[28] Peled et al. examined hypertonic saline (HS) inhalation solution. Thirty of 76 of used solutions were contaminated with non-CF-associated pathogens.[29]

When dealing with contamination of respiratory therapy devices, a question arises about their role in disease progression. There are two putative mechanisms; the first is direct transmission of pathogens from the respiratory therapy device to the respiratory tract. It is feasible that contaminated equipment could play a role in the acquisition of potential pathogens; however, to date, there are no published reports of CF patients acquiring infections in this manner during home use.[30] Second, contaminated secretions from the patient may be transmitted to the nebulizer. Later, inhalation back to the patient could increase the risk for permanent infection.[29] Hence, transmission may be due to a contaminated device itself or from patient to patient through a contaminated device.[30]

P. aeruginosa is found in water sources (sinks, baths) in pediatric hospital wards for CF patients and also on toys, hand soaps, and pulmonary equipment.[11] Most CF patients have a unique strain of *P. aeruginosa*. Thus, it is postulated that acquisition of this micro-organism is from the environment, but it is unclear if the patient infects the environment or vice versa.[11,31] The ability of the pathogen to be transmitted is highly dependent on its ability to survive in respiratory solutions and on surfaces of airway clearance devices. *Staphylococci* and *Enterococci* were found to survive for days to weeks after drying on fabrics and plastic.[9] *Mucoid Pseudomonas* strains were found to survive for 48 h when suspended in saline, and up to 8 days on a dry surface.[11] *Mycobacterium abscessus, Burkholderia cenocepacia, and P. aeruginosa* survived for 6 weeks in HS 3%.[29]

It is also plausible that contaminated devices may affect the CF microbiome and, thereby, affect disease progression. CF airways and gut are colonized by a polymicrobial community of organisms, termed the CF microbiota. Many of these organisms are unidentified by culture-dependent techniques. There is an interaction of resident microbiota and the immune system as well as competition with the invading pathogens. Alteration and loss of diversity of the microbiota affect the immune system and probably disease progression.[32]

A recent study assessed microbial constituents at home and found that the home environment (although rarely) can serve as either a source of infection or a persistent reservoir for reinfection.[33]

In our study, cleaning was effective in most cases. We used simple cleaning and air-drying without disinfection, because this technique is more feasible for implementation by patients. As mentioned earlier, cleaning was not effective for four different devices. The reason for this is not clear; we may postulate that cleaning without disinfection or the length of soaking was not effective for these particular devices. In the study by Hutchinson mentioned earlier, patients who followed recommendations for good nebulizer hygiene, with particular attention to drying, had minimal or no contamination of nebulizers.[24] Patients and families can be educated on the importance of aseptic techniques.[11] The instructions should include a visual demonstration on taking the device apart, the stages of cleaning and putting the device back together. Clearly, optimizing safe use of respiratory devices (nebulizers and airway clearance devices) from an infection control point of view requires a team effort.

The involvement of various parties, for example, device manufacturers, hospital infection control teams, physicians, nurses, therapists,and so on is needed.[15] Of note, the CDC does not recommend routine cultures of equipment or devices, unless there is a microbial outbreak that requires investigation of the source.[23] Our study has several limitations. The main limitation is the small number of patients and the heterogeneity of the devices which vary in their design. We evaluated more than one device from some of the patients; this may result in bias, as it reflects differences in cleaning habits. However, it was a real-life study, reflecting the situation in the patients' homes. The swabs were cultured only for bacteria; swabs were not cultured for fungi or for mycobacteria. Although we asked the patients not to clean the device before bringing it to the clinic, there is a possibility that they cleaned it before being "tested." This could explain the two devices with no CFU before cleaning. Lastly, in most cases the environmental swabs could not identify specific bacteria.

Noteworthy, this study raised the awareness of our team and the patients to the issue of device handling and cleaning. As the physiotherapist realized that not all patients were adherent to the cleaning instructions, we have given this issue a stronger emphasis since the study was concluded.

In conclusion, airway clearance devices are contaminated following use, and appropriate cleaning reduces contamination. It is unknown if CF patients can be cross-infected from these devices. The possibility that contaminated devices may alter the CF microbiome and thereby alter disease progression should be also explored. There is a need for clear infection prevention and control guidelines for the growing number of respiratory devices.

Author note

Eynav Manor and Michal Gur have equal contribution to the manuscript.

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