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BACTERIAL/VIRAL FILTERS IN PULMONARY FUNCTION DEPARTMENTS

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Routine pulmonary function tests may require patients to perform maximal inspiratory and expiratory breathing manoeuvres. They may be asked to rebreathe *via* the breathing circuits and equipment, which may be difficult to disinfect between patients. Infection can be transmitted by direct or indirect contact *via* mouthpieces and immediate proximal surfaces of the valves or tubing within the equipment, and possibly by aerosol droplet formation.

Patients performing pulmonary function tests may generate flows (peak expiratory flows) as high as 12 $L \cdot s^{-1}$ (720 $L \cdot min^{-1}$). Infective droplets may be expelled during these forced expirations, which could contaminate the pulmonary function equipment. A subsequent patient carrying out the same manoeuvre on this equipment could inhale these infective droplets during the forced inspiratory phase. Very few bacteria are required to facilitate the infectious process of some diseases, such as tuberculosis, and therefore the potential risk of cross-infection using this particular type of equipment may be comparatively high [1].

In order to essentially eliminate any potential risk of cross-infection, a bacterial/viral filter can be placed between the patient's mouth and the test equipment. It is common practice to use bacterial/viral filters when patients are known to be infectious or immunocompromised. However, as the infectious status of many patients is unknown, it may be prudent to presuppose that any patient performing the tests could be infectious. Using a single-use bacterial/viral filter for all patients overcomes this issue. ▶

What are bacterial/viral filters? And how do they work?

Filters used in pulmonary function laboratories are consumable items used for trapping bacteria and viruses, ensuring prevention of any cross-contamination. The filters generally consist of a flat wad of electrostatically charged fibres or pleats formed from a wad of fibres. These filters may/should have hydrophobic properties.

The electrostatically charged fibres are of two types: fibrillated or tribocharged. Fibrillated fibres are made by splitting sheets of electrostatically charged polypropylene. Tribocharged fibres are created by rubbing two types of fibre together (polypropylene and modified acrylic) [1]. In the first instance, bacteria and viruses are trapped as they pass through the interlocking fibres of the filter material. They are further attracted to these fibres by the positive and negative electrostatic charges on the fibres.

The pleated filters, also known as mechanical filters, achieve their efficiency by making use of tightly packed layers of mixed strands of fibres that physically prevent bacteria and viruses from passing through. These fibres have a hydrophobic coating that repels any water droplets containing bacteria or viruses thus preventing the passage of these organisms.

The efficiency of filtration depends on the density of the fibres, the depth of the filter layer and the velocity of the gas to be filtered. Direct interception or filtration removes large particles (>1 μm) whose diameter is greater than that of the pores of the filter membrane. Inertial impaction results in the removal of smaller particles (0.5–1.0 μm in diameter) by collision within the filter material. Diffusional interception removes very small particles (<0.5 μm) due to their Brownian motion, which increases the likelihood that they will collide with the filter material [2].

Issues for consideration when making a choice of filters

There are several factors to consider prior to purchasing bacterial/viral filters.

Bacterial removal efficiency (BRE)

A system has been developed at the Centre for Emergency Preparedness and Response (Porton Down, UK) enabling the efficiencies of many types of microbial filters to be assessed, including filters used with pulmonary function equipment.

An apparatus developed originally by HENDERSON [3] and DRUETT [4] to study experimental airborne infection is used. A suspension of micro-organisms in aqueous solution is nebulised by a three-jet collision spray forming a fine aerosol containing viable microbes. It is designed to deliver a challenge of $>10^7$ *Bacillus subtilis* spores in aerosol at a relative humidity of ≥96% at 30 L·min^{-1}.

The efficiencies of the filters are calculated by determining the airborne concentration of viable micro-organisms upstream and downstream of the filter using suitable aerosol sampling techniques and microbial assay methods.

More recently, an alternative system for assessing BRE was developed at the National Institute for Occupational Safety and Health (Atlanta, GA, USA) [5]. An aerosol of sodium chloride particles with a median diameter of 0.07 μm is generated from a 2% sodium chloride solution. Samples of air are drawn from the upstream (challenge) and downstream (penetration) sides of the filter through two laser photometers. These photometers measure the concentration (mass of sodium

chloride particles per unit volume of air) in the challenge and in the air that passes through the filter [6]. Manufacturers can currently offer filters with efficiency levels of >99.9%.

Resistance

A filter must have maximal efficiency in trapping and removing bacteria and viruses, but it should also have a low resistance to airflow. Depending on the type of breathing manoeuvre being performed, resistance must be checked at the appropriate flow rates (peaking >12 $L \cdot s^{-1}$, 720 $L \cdot min^{-1}$ in some subjects). The American Thoracic Society criteria for pulmonary function testing state that the resistance of the respiratory circuit (including the bacterial/viral filter) must not exceed 1.5 $cmH_2O \cdot L^{-1} \cdot s^{-1}$ for flows up to 14 $L \cdot s^{-1}$ [7]. During measurement of airway resistance using a plethysmograph, the resistance of the filter in the circuit should be established. With most modern software, the additional resistance offered by the filter should be taken into account when carrying out the calculations. If filters are used during pulmonary function tests, when calibrating pneumotachograph devices for volume it is essential to place a filter between the calibration syringe and the instrument, as the added resistance of the filter will affect pressure changes across the pneumotachograph.

It appears that the filters with the lowest resistances to flow are those with the poorest BRE, implying that BRE may be sacrificed for a low resistance. If the resistance of the respiratory circuit is too high, there may be clinically significant effects on the pulmonary function results ▶

							
Name	KoKo Moe	Spirobac	Microguard	BVF	ErgoFilter SP1	All_flow	Protec 30s
Company	nSpire	Tyco	Viasys	Vitalograph	Pulmolink	Clement Clarke	Pall
Bacterial filtration %	>99.99	>99.9	>99.9	99.5	>99.98	99.99	-
Viral filtration %	>99.9	>99.9	>99.0	99.4	>99.98	99.99	-
Resistance $kPa \cdot L^{-1} \cdot s^{-1}$	0.038–0.067	0.09 @12 $L \cdot s^{-1}$	<0.70	0.08 @12 $L \cdot s^{-1}$	0.06 @12 $L \cdot s^{-1}$	0.023	<0.15
Dead space mL	50	56	50	65	65	35	40
Material	3M Filtrete	Electrostatic	-	Electrostatic	3M Electrostatic	Electrostatic	
Weight g	-	14	-	-	-	-	-
Single patient use	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dimensions mm	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.*	30F–33M. Adaptors available	30 ID; 30 OD	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.*	30 ID; 33 OD	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.*	30 ID

obtained, particularly peak flow rates [8, 9].

Dead space

Generally the dead space of the bacterial/viral filter should be as small as possible in order that no detriment to the work of breathing is experienced by the patient. For some patients with small lung volumes (young children or patients with severe pulmonary disease), it is even more important that the dead space is reduced to its minimum, otherwise rebreathing issues may occur. Currently manufacturers supplying bacterial/viral filters for pulmonary function equipment can offer dead spaces on their equipment of between 50–75 mL.

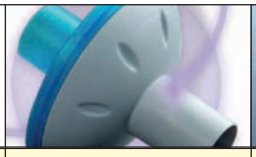
Single use

Clearly, the bacterial/viral filters are solely intended for single-patient use. This is absolutely necessary to prevent any cross-contamination.

However, the filter can be used for the same patient for several manoeuvres. In reality, this generally means that a patient can use the same bacterial/viral filter for the duration of the pulmonary function tests. After the tests are completed, the filter must be disposed of according to local infection-control procedures. Some manufacturers will supply a filter with a reusable filter housing and a disposable pad. The filter housing must be disinfected between patients in accordance with local infection-control procedures and the pad must be disposed of accordingly.

Multiple equipment use

It is appropriate that the filters can be adapted to fit the multiple types of pulmonary function equipment that is currently available. Also, many of the filters now available, allow the patient to use the filter itself as a mouthpiece, consequently reducing dead space and cost.

				
Name	Spirosafe	Spiroguard 2800/22	Spiroguard 2800/R	Spiroguard 2800/21
Company	Micro Medical	Air Safety	Air Safety	Air Safety
Bacterial filtration %	99.99	99.999	99.999	99.999
Viral filtration %	99.99	99.999	99.999	99.999
Resistance $kPa \cdot L^{-1} \cdot s^{-1}$	-	0.07 @12 $L \cdot s^{-1}$	0.07 @12 $L \cdot s^{-1}$	0.07 @12 $L \cdot s^{-1}$
Dead space mL	-	75	75	75
Material	-	Electrostatic	Electrostatic	Electrostatic
Weight g	-	-	-	-
Single patient use	Yes	Yes	Re-usable	Yes
Dimensions (ID; OD mm)	30	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.*	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.*	Depends on system to be used with, *i.e.* Jaeger, KoKo *etc.* Includes integral mouthpiece

Why use bacterial/viral filters?

All patients are susceptible to the risk of infection after performing pulmonary function tests. Pre-pulmonary function test screening for infection by request form, although helpful, cannot be a substitute for more effective control measures. Most outpatients visiting pulmonary function departments are not routinely screened for infectious diseases prior to performing tests. Even when patients are screened, there may be a significant time interval between obtaining culture results and performing the tests. It is very difficult to identify all the patients with infectious diseases or who are immunocompromised. A recent study showed as many as 40% of patients with chronic obstructive pulmonary disease (COPD) had positive sputum cultures to potentially pathogenic micro-organisms [10]. Therefore, universal stringent precautions for everyone needing pulmonary function tests are necessary [11]. A previous paper has shown that ultra-clean techniques can be used when performing most routine pulmonary function tests [12]. However, the most practical and cost-effective way to ensure that there is no risk of cross-infection between patients is to use bacterial/viral filters.

Other advantages offered by using bacterial/viral filters are as follows: protection of breathing circuits, especially flow sensors, from contamination with droplets of saliva and mucus that may introduce errors in test measurement and contain micro-organisms [13, 14]; and protection for patients and staff from inhaling pathogens from the breathing circuitry. (Many centres now use staff to perform pulmonary function tests on the equipment (biological controls), which can be used as part of the quality-assurance programme.)

It is widely recognised that respiratory equipment is not ▶

sterile [15] and that exposure to normal levels of environmental organisms during testing poses no greater risk than being in public areas [16]. However, as already suggested, some patients are colonised with potentially dangerous levels of pathogenic organisms and in order to minimise any potential risks to patients it is prudent to use bacterial/viral filters when performing pulmonary function tests. A recent study assessed the efficacy of a single use bacterial/viral filter (Spiroguard 2800, Air Safety Ltd, Morecambe, UK) for the prevention of equipment contamination during pulmonary function assessment [17]. The outcome of the study which included two groups of patients (infectious and noninfectious) showed that it was very important to use filters when performing pulmonary function tests as bacteria, including pathogenic organisms, can freely be transmitted to the equipment. The study results indicated a significantly greater bacterial growth on the proximal side of the filter compared with the distal side.

Where and when can bacterial/viral filters be used?

It appears that many pulmonary function departments in hospitals are now using bacterial/viral filters and awareness of the necessity for suitable infection control procedures is well promoted. There are still, however, many hospitals where bacterial/viral filters are not being used, either because of cost or because there is insufficient awareness or knowledge regarding infection control. Nowadays, infection-control nurses play an important role in educating staff about the importance of reducing risk for patients undergoing pulmonary function tests.

In the general practitioner setting, however, it would seem that relatively few patients are given bacterial/viral filters when performing pulmonary function tests. This is an area where very little screening of the patient's infectious status has been carried out prior to testing and the use of universal stringent precautions would seem appropriate. Again, cost appears to be the reason that bacterial/viral filters are not more readily used, even though most disposable filters cost <£1 (<€1.5) each. It may also be a question of educating doctors and practice nurses.

As more spirometry is performed in the community, it is clearly very important that the practice of using bacterial/viral filters on all patients is adopted universally. Patient benefit, while paramount, is not the only consideration: we live in a very litigious society and consequently hospitals are on occasion sued for large sums of money. By using bacterial/viral filters, the risk of any cross-infection between patients during pulmonary function testing is reduced and therefore at the same time, so are the chances of a patient trying to sue the hospital trust over poor infection control in the pulmonary function laboratory. ■

Filter in use

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