Effect of a Microaerosol Barrier Filter on the Measurement of Lung Function*

David P. Johns, CBiol, MIBiol; Corrie Ingram, BSc; Helen Booth, MBBS; Trevor J. Williams, MBBS; and E. Haydn Walters, BM, BCh, FCCP

**Study objective:** A disposable barrier filter (Pall Biomedical, United Kingdom) was developed to prevent the contamination of lung function equipment in clinical use. The aims of this study were to examine its resistance characteristics and to determine the effect of the filter on clinical measurements of lung function.

**Measurements:** Twenty-one randomly selected patients and four normal subjects had lung function measured with and without the filter between the mouth and measuring equipment. Measurements of ventilatory function were made with a pneumotachograph (Lilly; Hoechberg, Germany), total lung capacity and airway resistance by constant volume plethysmography, and diffusing capacity for carbon monoxide by the single breath method. Resistance was determined in five unused filters over the flow range 1 to 12 L/s and at a single flow rate (12 L/s) just after a normal subject expired 20 forced vital capacity (FVC) breaths through each of them.

**Results:** The resistance (mean ± SD) of unused filters was 0.19 ± 0.02 cm H₂O/L/s at 1 L/s and increased linearly to 0.56 ± 0.02 cm H₂O/L/s at 12 L/s. There was no significant increase in resistance after use. The additional resistance of the filter to the breathing circuit caused statistically significant decreases in forced expiratory volume in 1 s (FEV₁) (0.044 ± 0.08 L, p=0.014) and peak expiratory flow rate (PEFR) (0.47 ± 0.073 L/s, p=0.004). The filter did not affect other indices of lung function.

**Conclusion:** The filter caused a statistically significant reduction in FEV₁ and PEFR; however, this difference was believed not to affect the clinical utility of routine lung function testing. *(Chest 1995; 107:1045-48)*

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**Key words:** cross-infection; flow resistance; lung function testing

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Routine lung function tests require patients to perform maximal inspiratory and expiratory breathing maneuvers and to rebreathe via complex breathing circuits and equipment that are difficult to effectively clean and disinfect between patients. During these tests, patients often generate flow rates in excess of 10 L/s that can easily mobilize saliva and airway mucus and create aerosols by entrainment of fluid lining the mucous membranes that can be deposited in lung function equipment. Thus, there is a risk of cross-infection between patients performing lung function tests unless the equipment is decontaminated between patients.

The risks of cross-infection are growing because an increasing number of immunosuppressed patients are being tested, such as patients with HIV and those who have received chemotherapy for malignant diseases or organ or bone marrow transplants.¹ ² Organisms capable of surviving for prolonged periods, eg, *Mycobacterium avium-intracellulare*, *Mycobacterium tuberculosis*, and Aspergillus species, pose particular threats to such patients. The incidence of mycobacterial infection, both typical and atypical, is again on the increase.

The problem of equipment decontamination is compounded by the fact that most testing equipment consists of breathing tubes and several instruments that must be disassembled to some extent for effective decontamination and must be thoroughly dried, reassembled, and recalibrated before being returned to routine use. Also, for many spirometers and circuits involving gas analyzers and pressure transducers, it is seldom possible to thoroughly decontaminate all interior surfaces as these are generally inaccessible and damage may occur. Such cleaning procedures, where possible, are time consuming and render the equipment unusable for a period. Since according to current recommendations for practicing "universal precautions" all patients must now be assumed to be HIV...

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*From the Department of Respiratory Medicine, Alfred Hospital, Prahran, Victoria, Australia. Manuscript received February 22, 1994; revision accepted August 5.*

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ATS=American Thoracic Society; Dco=diffusing capacity of the lung for carbon monoxide; FEF₂₅₋₇₅%=forced expiratory flow rate during the middle half of the FVC maneuver; FEF₅₀%=forced expired flow rate when half the FVC has been expired; FEV₁=forced expired volume in 1 s; FRC=functional residual capacity; FVC=forced expired vital capacity; KCO=Dco/VA; PEFR=peak expiratory flow rate; Raw=airway resistance; RV=residual volume; TLC=total lung capacity; VA=alveolar gas volume
positive until proven otherwise, it can be argued that the equipment and tubing must be decontaminated between each patient. Yet, considering the high patient workload of most laboratories, this approach is largely impractical.

A better solution would be to prevent the contamination of the equipment. This approach has been taken by one laboratory that has introduced elaborate techniques to prevent expired breath from entering equipment, but these techniques do not appear to have been widely adopted.

A more attractive preventive strategy is to use a disposable filter to protect the equipment from contamination. A disposable microaerosol barrier filter has been developed for in-line use during lung function testing (PF30S, Pall Biomedical, Portsmouth, United Kingdom). The filter consists of three layers of pleated polypropylene that is reported to reduce the chance of cross-infection to negligible levels by acting as a barrier to exhaled and inhaled droplets. The efficiency of the filter at removing exhaled bacteria has been confirmed by several studies and it can be expected that the transmission of viral and fungal vectors would also be reduced to negligible levels. Previous studies, which have investigated the effect of the filter on the measurement of ventilatory capacity in children and adolescents and in one normal subject, concluded that although expired flows and volumes were reduced, the reduction was not clinically significant. No study appears to have determined the effect of the filter on other lung function indices such as diffusing capacity where the resistance of the filter and additional 55 mL of dead-space could potentially alter lung physiology and the associated calculation algorithms.

The aims of this study were to examine the resistance characteristics and to determine the effect of the microaerosol barrier filter (PF30S) on the clinical measurement of detailed lung function.

**METHODS**

**Resistance Characteristics**

The pressure drop across five new filters (PF30S) was measured with a calibrated differential pressure transducer (Validyne) at eight accurately known constant flow rates (1 to 12 L/s) generated by a computer-controlled sliding seal spirometer. The flow resistance of each filter was calculated at each flow rate. The mean of three measurements at each flow rate was used for analysis.

To assess whether the resistance of the filter changed during use due to the retention of water droplets and secretions, the resistance of the five new filters was compared with measurements performed after a normal subject exhaled 20 forced vital capacity (FVC) maneuvers through each of them. To minimize evaporation of retained droplets and secretions, the flow resistance of each filter was determined at a single flow rate (12 L/s) within 1 min of completing the 20 FVC maneuvers.

**Effects on Measurements of Lung Function**

Twenty-one consecutive patients attending the laboratory and four normal subjects underwent detailed lung function testing (FEV₁, FVC, FEV₁/FVC, peak expiratory flow rate [PEFR], FEF25-75%, FEF50%, diffusing capacity of the lung for carbon monoxide [Dco], KCO [Dco/VA]), alveolar volume [VA], airway resistance [RAW], residual volume [RV], thoracic gas volume [TGV], and total lung capacity [TLC]) with and without a filter attached between the testing equipment and lips. The plastic port of the filter was used as the mouthpiece. The subject population (13 female, 12 male) had a median age of 46 years (range, 22 to 79 years) and a wide range of lung function (Table 1). The order of testing (with or without filter) was randomized to prevent an order effect. The best of at least three measures of ventilatory function, i.e., expired curve with the highest FEV₁ plus FVC, whereas the mean of duplicate measurements of Dco, KCO, VA, RAW, RV, TGV, and TLC was used for analysis. A new unused filter was used for each patient to perform all tests. The effect of the filter on the various indices of lung function was analysed using paired t tests.

Ventilatory function was measured with a pneumotachograph (Lilly; Hoechberg, Germany) of known resistance characteristics and diffusing capacity by the single breath method using an automated system (MasterLab, Jaeger, Germany). Both ventilatory
function and diffusing capacity were measured according to the American Thoracic Society (ATS) recommendations.10,11 Lung volumes and Raw were determined by constant-volume plethysmography (PK Morgan, United Kingdom). All measurements were made without correction for the additional resistance and 55 mL of dead-space of the filter. To exclude the possibility that the addition of the filter to the breathing circuit would alter the accuracy of the pneumotachograph, we used it to measure the volume of a 3-L syringe both with and without the filter present. The volumes recorded with (3.00 ± 0.03 L) and without (3.02 ± 0.03 L) the filter were not statistically different.

**RESULTS**

**Resistance Characteristics**

The flow resistance of the filter (mean ± SD) was 0.19 ± 0.02 cm H$_2$O/L/s at 1 L/s, decreased slightly to 0.18 ± 0.01 cm H$_2$O/L/s at 2 L/s, and then increased linearly to 0.56 ± 0.02 cm H$_2$O/L/s at 12 L/s (Fig 1). After use, the resistance of the filters at 12 L/s increased by only 0.01 ± 0.002 cm H$_2$O/L/s, which was not significant. The resistance characteristics of different filters was similar with a mean coefficient of variation over the flow range 1 to 12 L/s of 4.6%.

At 12 L/s, the resistance of the pneumotachograph system was 0.87 cm H$_2$O/L/s (Fig 1) and with the filter attached it increased to 1.43 cm H$_2$O/L/s. Thus, the pneumotachograph system with the filter attached was within the upper limit (1.5 cm H$_2$O/L/s at 12 L/s) recommended by the ATS for the measurement of spirometry.11

**Effect on the Measurement of Lung Function**

The addition of the filter to the testing circuit was well tolerated by all patients despite the increase in resistance and 55 mL of dead-space of the breathing circuit. However, three patients did comment that they had difficulty maintaining a tight seal around the plastic port of the filter.

The effect of the filter on lung function measurements is given in Table 1 and shows that its addition to the breathing circuit caused a significant decrease in FEV$_1$ and PEFR with all other indices remaining unchanged. The mean change in FEV$_1$ was −0.044 ± 0.08 L (p=0.014) and PEFR was −0.47 ± 0.073 L/s (p=0.004). There were no significant correlations between the change in FEV$_1$ or PEFR and the degree of airflow limitation as defined by the baseline FEV$_1$/FVC%.

**DISCUSSION**

This study shows that the addition of the microaerosol barrier filter (PF30S) to the breathing circuit does not significantly affect the measurement of single breath Dco, KCO, and VA, and plethysmographically determined RV, TGV, TLC, and Raw. Our data also show that for clinical measurements, no correction for the filter’s resistance or 55 mL of dead-space, which were similar between filters, need be applied.

The overall effect of the filter on the measurements of ventilatory function, however, was to reduce FEV$_1$ by 1.7% and PEFR by 5.3%. A similar reduction in FEV$_1$ was found by Grupper et al.7 However, they also found a 3.4% reduction in FEF50% compared with ours of only 1.3%.7 Guimond and Gibson8 found that in the single normal subject they studied, all indices (FVC, FEV$_1$, FEF25-75%, and PEFR) decreased by only 1% or less. We consider the decrease we observed in FEV$_1$ to be clinically unimportant, while those of PEFR may be of marginal importance, particularly if this is the only measurement of airway function available. Our data showed the sensitivity of PEFR to equipment resistance and suggest that for accurate comparison of PEFR between spirometers, the resistance of the equipment should be closely matched and that the ATS resistance specification of <1.5 cm H$_2$O/L/s may be too lenient. It also emphasized the importance of selecting normal values obtained using equipment with very similar resistance characteristics. Further, the addition of the filter to some spirometers may result in an overall resistance that exceeds the ATS specification.

A variety of nonpathogenic and potentially pathogenic microorganisms have been recovered from lung function equipment,12-14 indicating that cross-infection could occur unless precautions are taken to decontaminate the circuits and equipment between patients. Rutala et al12 studied the risk of cross-infection associated with a dry rolling seal spirometer and concluded that the spirometer’s piston surface did not become contaminated but the mouthpiece and connecting tubing did. Houston et al13 studied the pathogens isolated from the tubing and interior surfaces of a wedge-bellows spirometer and isolated...
many organisms, including Streptococcus species, *Klebsiella pneumoniae*, and a variety of fungi. Nonpathogenic organisms were recovered from the breathing tubes of three wedge-bellows spirometers in routine use.  

Lung function equipment has also been linked to the transmission of microorganisms. Isles et al.\(^{15}\) reported an unusually high incidence of *Pseudomonas cepacia* infection in patients with cystic fibrosis sharing a spirometer, and Hazaleus et al.\(^{16}\) reported the possible transmission of *M. tuberculosis* via a rolling seal spirometer.

Similar studies do not appear to have been conducted on pneumotachograph-type spirometers that are in routine use in most lung function laboratories. These spirometers utilize a resistive element consisting of a fine mesh screen or bundle of capillaries, sited a few centimeters from the mouth, through which the patient exhales and inhales. The risk of contamination from such spirometers is theoretically much greater than for a bellows or rolling seal system as expired fluid can be readily trapped onto the fine mesh surface or within the capillaries that could then be inhaled by subsequent patients. In a busy laboratory, it is impractical to decontaminate the resistive element of the pneumotachograph between patients. The only effective method of preventing their contamination and hence potential to transmit diseases is to prevent microorganisms entering the equipment in the first place.

Despite the lack of direct evidence of disease transmission but because of the heightened anxiety associated with the “AIDS epidemic” and increasing incidence of multiple drug-resistant pulmonary tuberculosis, many laboratories are reviewing their cleaning and disinfection protocols or are looking at other solutions (such as a filter) to the problem of potential equipment contamination. We believe that despite the effect of the filter (PF30S) on FEFR, it can be used with lung function testing equipment without adversely affecting the clinical measurements of lung function across a very wide range.

**REFERENCES**