Review Article

Infection control in the pulmonary function test laboratory

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ABSTRACT

Pulmonary function testing plays a crucial role in the diagnostic evaluation of patients with lung diseases. Cases of cross infection acquired from the pulmonary function laboratory, although rare, have been reported from various countries. It is therefore imperative to identify the risks and potential organisms implicated in cross infections in a pulmonary function test (PFT) laboratory and implement better and more effective infection control procedures, which will help in preventing cross infections. The infrastructure, the daily patient flow, and the prevalent disinfection techniques used in a PFT laboratory, all play a significant role in transmission of infections. Simple measures to tackle the cross infection potential in a PFT laboratory can help reduce this risk to a bare minimum. Use of specialized techniques and equipment can also be of much use in a set up that has a high turnover of patients. This review aims at creating awareness about the possible pathogens and situations commonly encountered in a PFT laboratory. We have attempted to suggest some relevant and useful infection control measures with regard to disinfection, sterilization, and patient planning and segregation to help minimize the risk of cross infections in a PFT laboratory. The review also highlights the lacuna in the current scenario of PFT laboratories in India and the need to develop newer and better methods of infection control, which will be more user-friendly and cost effective. Further studies to study the possible pathogens in a PFT laboratory and evaluate the prevalent infection control strategies will be needed to enable us to draw more precious conclusions, which can lead to more relevant, contextual recommendations for cross infections control in PFT lab in India.

KEY WORDS: Cross infection in a PFT lab, potential pathogens, preventive and control strategies

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INTRODUCTION

Pulmonary function test (PFT) laboratories play a crucial role in the diagnostic evaluation of patients with various lung diseases, such as obstructive airways diseases, restrictive lung diseases, neuromuscular disorders, vocal cord disorders, and upper airways obstructions. Lung function evaluation is also useful in the assessment of preoperative risk for thoracic and abdominal surgeries. PFT is also used as a routine screening and diagnostic test for various occupational lung disorders. Healthy individuals undergo PFT for routine medical checkups. Clinical trials evaluating and comparing the efficacies of drug for various respiratory disorders often use PFTs, which are objective research tools and are routinely used in clinical trials.

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METHODS

We searched through various medical databases, namely, Pubmed, Pubmed central, Medline Plus, and Cochrane library. We collected literature that included review articles, letters to editor, editorials, commentaries, case summaries, and original research articles published in English language. We used specific search words, which included PFT lab hygiene, cross infection in a PFT lab, changes of contamination during spirometry or lung function testing, pathogens transmitted in a PFT lab, pathogens transmitted during sputum induction, risk of infection with tuuberculosis (TB), Human Immunodeficiency Virus (HIV) and other viruses in a PFT lab, disinfection practices in a PFT lab, protective equipment in a PFT lab, newer methods of PFT disinfection, bacterial filters in spirometry and PFTs, waste segregation minimizes cross infection in a PFT lab, droplet and airborne precautions during PFT testing, waste

disposal in a PFT lab, protection of immunocompromised patient in a PFT lab and reusable equipment in a PFT lab with sterilization and disinfection techniques. Due to a paucity of Indian literature, our search was extended to global literature without a time bound interval. We could retrieve a total of 247 articles. Of these, 113 were of relevance to our topic. We had access to 67 full text articles and 46 abstracts. Based on these available papers, we have attempted to write this review article.

PFTs include Spirometry; Impulse Oscillometry; Body Plethysmography; Diffusing Lung Co-efficient for Carbon Monoxide; bronchial challenge testing for measuring bronchial hyper-responsiveness, sputum induction, and cardiopulmonary exercise testing; and the six-minute walk test. While performing these tests, patients need to perform varied breathing maneuvers such as tidal breathing, forced expiratory maneuvers, as well as deep inspiratory and expiratory maneuvers. Some patients cough into the test device while performing the above maneuvers either due to an underlying infection or bronchospasm. This increases the risk of transmitting aerosolized bacterial infections from one person to another via the PFT instruments. Although the risks of transmission of infection through a PFT laboratory seem real, there is limited documented evidence for the same. There have been a few rare case reports of nosocomial cross infections acquired in the PFT laboratory.[1] There have been some empirical recommendations on maintaining hygiene in a PFT lab. However, scientific data on cross contamination through a PFT lab and recommendations to maintain hygiene are not widely available.

It is imperative that every institute should have their own infection control policy, which should cover all techniques, including cleaning, sterilization, use of personal protective equipments, and adequate training to technicians. The American Thoracic Society (ATS) has recommended referring to the guidelines developed by National Committee for Clinical Laboratory Standards (NCCLS) and Centre for Disease Control and Prevention (CDC) for controlling nosocomial infections in a laboratory and hospital setting.[2] The NCCLS has published guidelines addressing laboratory worker protection from biohazards,[3] and the CDC has published recommendations on how to control nosocomial-acquired pneumonia in hospital settings.[4] These should be present and followed in all PFT laboratories. Health care workers must be adequately trained on relevant safety precautions and guidelines.

Infection control helps in preventing the transmission of infectious pathogens, thus protecting patients and health care workers and providing a safe and healthy work environment. This review aims at summarizing the sources of infection, a brief outlay of the common pathogens involved in such nosocomial infections in the PFT laboratories and simple techniques to prevent cross infections in people undergoing the tests.

SOURCES AND CAUSATIVE ORGANISMS OF INFECTION IN THE PFT LABORATORY

Sources of cross infection in a PFT laboratory are varied and include direct contact, aerosolized particles, saliva, and skin contact. Among these, cross infections via direct contact and via transfer of contaminated saliva and body fluid confer the highest risk.[5]

The virulence of organisms is dependent on numerous factors, which include the source of the pathogen, the strain of the pathogen, inoculation rate, viability of the pathogen at exposed room temperatures, carriers of the pathogens, fomites, routes of infectivity, particle size of the pathogen inoculated aerosol, and the actual infective dose of the pathogen. Host factors also play a significant role in the risk of getting infected and developing a disease in a PFT laboratory. Table 1 identifies the possible pathogens and their sources in a PFT lab.

Droplets and aerosolized particles

This is by far the most common mode of spread of infection in the PFT laboratory. Droplets released from the infected upper respiratory tract may contain a wide variety of microorganisms, including viruses, bacteria, and mycobacteria, which have the potential to cause respiratory viral infections, influenza, measles, chicken pox, pneumonias, and tuberculosis.[6] Saliva and sputum serve as major sources of infection in the PFT laboratory. Use of equipment by infected patient leaves behind infection droplets. When used again without adequate cleaning measures, the next patient is naturally predisposed to develop a cross infection.

Airborne organisms may be contained in droplet nuclei on epithelial cells that have been shed or as suspended airborne dust particles, which can be inhaled into the respiratory tract in people in close vicinity. Airborne droplet nuclei evaporated from larger droplets remain suspended in the air for many hours and when dispersed can infect other distant hosts.[7]

There have been reports of cross infections with *Mycobacterium tuberculosis* through lung function testing.[8] In one study, scrapings and washings from spirometer tube assess for microbiological studies found a growth on culture of acid fast bacilli.[9]

Transmission is likely through active organisms suspended in droplets, which may be produced by an infectious host through coughing or during a forced expiratory maneuver. These infected droplets have been found to remain viable for up to 9 h at room temperature (60% remain viable after 3 h, 48% after 6 h and 28% after 9 h). Their viability increases with increasing droplet size. However, infected

Table 1: Potential pathogens in a PFT laboratory with suggested precautions

Microorganism	High-risk group/condition	Precautions
Mycobacterium tuberculosis[8]	All individuals in room. Droplets remain viable for many hours in air.[8,7]	*Airborne precautions[8,7]
Pseudomonas cepacia[6]	Person to person contact Contact with contaminated surfaces Immunocompromised patients	Testing should be done in separate room #Contact precautions
Branhamella catarrhalis[10]	Immune-suppressed patients[10]	§Droplet precautions
Respiratory viruses[10]	Children and elderly person or	*Airborne precautions plus #contact precautions should be taken
S. pneumoniae, S. aureus (MRSA)[6]	immune-suppressed patients May be Infectious to immune-suppressed patients	for such microorganism
Haemophilus influenza[11]	May be infectious to immune-suppressed patients	
Legionella[20]	All individual in room	Regular cleaning of cooling towers prevent spread of Legionella spp
Neisseria sp.[18]	Immunocompromised patients	*Airborne precautions plus §droplet precautions should be taken
Human immunodeficiency virus[2]	Immunocompromised patients	§Droplet precautions and #contact precautions should be taken for such patients
Hepatitis B, C virus[2]	Immunocompromised patients	Infection can be controlled by immunization of health care workers §Droplet precautions can prevent infection
Varicella zoster[23]	All individual	*Airborne precautions No recommendation for use of surgical mask or respirator
Measles[6,23]	All individual	*Airborne precautions plus #contact precautions
Aspergillus[9]	Immunocompromised patients Patients suffering from other lung diseases	*Airborne precautions should be taken
Cryptococcal meningitis[2]	Patients with defect in cell-mediated immunity	*Airborne precautions

*Airborne precautions include[23], 1. Use of personal protective equipment, 2. Use of respirator (N95), 3. Use of separate equipments for these patients. Dissemble and disinfect immediately after testing, 4. Testing should be done in separate rooms and with negative pressure rooms, 5. Testing should be done at the end of the day, #Contact precautions include, 1. Health care workers should wash their hands after every test, 2. Mouthpiece should be changed after every test, 3. Patients should wash their hand before and after testing or use a hand sanitizer, 4. Increase the distance of mouthpiece from the sensor to minimize contamination of equipment, 5. Health care workers with active infection must refrain from the use of the PFT laboratories as far as possible. Whenever possible, only vaccinated staff should deal with infected patients, §Droplet precautions include[28], 1. Use of personal protective equipment, 2. Allow the droplet to settle down by allowing time gap between two tests, 3. Clean surfaces after every test. PFT: Pulmonary function test

droplets remain airborne longer when the particle size is smaller. Cross contamination with tuberculosis remains of much concern with the emergence of multidrug resistant and totally drug-resistant tuberculosis, especially in developing countries such as India.

Skin contact

Direct skin contact is a major source of infection with rhinoviruses and Burkholderia (also known as *Pseudomonas cepacia*).[10] *Burkholderia*, though nonpathogenic in humans, affects patients with cystic fibrosis. Although the exact prevalence of cystic fibrosis in India has not been an estimated, 1 in 10,000 to 1 in 40,000 Indian immigrants in the USA and UK, respectively, suffer from cystic fibrosis. These cystic fibrosis patients, who need frequent and repetitive lung function assessment tests are extremely prone to develop cross infections with *Burkholderia cepacia* through a simple handshake (medium risk).[10] Immunocompromised patients are also at a high risk of developing cross infections with the normal flora of the upper respiratory tract, which includes *Haemophilus influenza*, *Branhamella catarrhalis*, and *Streptococcus pneumoniae*.

Equipments

Transmission of infection through pulmonary function equipment has been of major concern and therefore it has been recommended that the connections between the patient and the PFT apparatus, which includes the tubing, the rebreathing valves, and mouthpieces, are changed between patients and cleaned or disinfected before re-use.[11-13] In fact, disposable waste generated in the pulmonary function laboratory such as used mouth pieces, paper napkins, and so on, may act as reservoirs of microorganisms, thus increasing the risk of cross infection.

Spirometer

The spirometer is the most commonly used instrument in the PFT laboratory. Among the various components of the spirometer, mouthpieces have the greatest risk of bacterial contamination (92%), followed by the proximal tubing (50%). No contamination has so far been reported from samples taken from within the equipment.[11] Houston *et al.* observed that during four one-week periods when 1000 patients used a vitalograph spirometer, over 10,000 million microorganisms per week were recovered from the breathing circuits while the reservoir of infection was believed to be within the spirometer and valve section of the apparatus.[14,15] As this confers a high risk of cross infection, not only to the patients but also to the health care workers, use of contaminated equipment or reusing disposable mouthpieces, is strongly discouraged.

Water-sealed spirometers, now rarely used in clinical practice, have been a common site for bacterial colonization. However, it has not been demonstrated that this increases the risk of transmission of respiratory infections from the machine to patients or health care workers. On the other hand, the risk of transmission of infection is minimal with an ultrasonic sensor-based spirometer. The mouthpiece, which is the only part of the spirometer that comes in direct contact with the patient, is replaced after

every use. This reduces the risk of cross infection to a minimum. There is no information available on the risk of bacterial contamination of flow sensor-based spirometers, such as the turbine-based spirometer and unheated pneumotachographs.

Consumables

These include mouthpieces, rebreathing valves and tubings used in the pulmonary function laboratory. Mouthpieces are by far the commonest cause of cross infection in a PFT laboratory.[1,12,16] These get contaminated with patients' saliva, which is a rich source of normal healthy flora as well as pathogenic organisms. It has been a concern that viruses such as HIV, HBV, HCV, HDV, and so on, are transmitted through contaminated body fluids. However, saliva is an unlikely medium for HIV transmission.[10] Nevertheless, studies have shown that HBV may occasionally be transmitted through saliva.[17]

Pseudomonas stutzeria, coagulase-negative staphylococci, diptheroids, and *Neisseria* sp. are some of the other organisms that may be transmitted through infected mouthpieces and tubing of PFT equipments.[18]

Ill-maintained tubes and mouth pieces serve as reservoirs for fungi and yeasts such as *Aspergillus* and *Cryptococcus*. Inhalation of these fungal spores leads to fatal pulmonary infections as well as infections of the central nervous system.

Nebulizers and spacers

Used often in the lung function laboratory for bronchial challenge testing, sputum induction and reversibility testing, nebulizers and spacers may contribute to cross infection in the PFT laboratory. It has been shown that when not cleaned and maintained well, nebulizers may be colonized with Pseudomonas species, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus cereus*, and *B. cepacia*.[10] However, this colonization is more often seen in nebulizers for home use and is directly linked to sanitation and hygiene measures employed by the patients. There have been no records of cross infections with nebulizers used in diagnostics as of now either due to under-reporting or due to healthy sanitation practices. Hospital water supplies often get contaminated with *Legionella* and infection is likely through inhalation of infected aerosols. However, maintenance of nebulizers in the diagnostic arena is imperative.

Peak flow meters

Peak flow meters in respiratory practice have been likened to glucometers in diabetic practice. This is a crucial outpatient diagnostic tool, which may also be a potential source of infection in the PFT laboratory. Multiple users of the same device with disposable mouthpieces may confer a high risk of transmission of respiratory viral infections, methicillin-resistant *Staphylococcus aureas* (MRSA) infection and fungal infections. Although expected to confer a high risk of transmission of infection, only one study so far has demonstrated fungal contamination of the peak flow meter and yet it did not report cross infection.[19] The role of long-term use of contaminated peak flow meters remains to be investigated.

Laboratory infrastructure

The infrastructure of a PFT laboratory plays a significant role in the transmission of infections. The surface areas exposed, general clutter, quality of upholstery, air conditioning (if present), temperature and humidity conditions, and frequency of use are known to have an effect on cross infection in the PFT laboratory. Dusty work surfaces harbor various pathogens and increase this risk of cross contamination further. High temperature and humidity provide a suitable environment for growth of pathogens. Upholstery, such as thick carpets and curtains, provide for a fertile ground for pathogens, particularly MRSA.

Air conditioners in the PFT laboratory must be maintained regularly. *Legionella*, a gram-negative bacillus, has been found widely in air-conditioning cooling towers and water systems. Hospital water supplies have also been found to be contaminated with *Mycobacterium* and *P. aeruginosa*.[20] This poses a major risk to patients with compromised cellular immunity (immunocompromised patients, chronic smokers, COPD patients) or respiratory function (elderly, cystic fibrosis).

PREVENTIVE METHODS FOR INFECTION CONTROL IN THE PFT LABORATORY

To control infection, it is necessary to find out communicability of diseases within lung function laboratory. This is determined by numerous factors, which include the source of the pathogen (eg, blood, saliva), persistence of pathogen viability outside the host, the possible routes of spread of infection and the infectivity dose required to infect the host and cause disease. Many of these factors further affect the infective dose, which includes the underlying clinical condition of the patient and immune status of the host as well as the particle size of aerosols encountered during respiratory testing.[10] Table 1 highlights the methods of prevention and control of infection in the PFT laboratory.

Personal hygiene

Use of personal protective equipments act as barriers between skin/clothing and reduces the risk of cross contamination. This holds true specifically for testing of infected patients such as TB, various viral infections, opportunistic infections, and nosocomial pneumonia. Gloves should be worn when handling contaminated equipment.

Simple procedures such as hand washing between two patients can reduce bacterial load on the hands by 77%, whereas hand washing with soap and water can reduce

the bacterial load by 92%[21] Hand washing helps to render strongly adherent microorganisms of the transient bacterial skin flora inactive/nonviable [Figure 1a and b]. Iodophors, chlorhexidine gluconate, triclosan, biphenylol, and chloroxylenol are the various active agents used in preparing detergents for hand sanitizers. A one-minute hygienic hand wash with povidone–iodine (0.75%), chlorhexidine (4%), and a triclosan-based (0.1%) soap reduces the release of transient bacteria from artificially contaminated hands by 3.5, 3.1, or by 2.8 log, respectively.[22] Soap containing emollients are available and help prevent drying and cracking of the skin. Hand washing sinks should have hand elbow or wrist lever operated mixer taps or automated controls.

Patients screening and segregation

For most patients, lung function testing confers almost none to minimal risk of cross infection. Acquisition of common cold is possible in many patients and yet this is categorized as a very low risk. The risk of development of tuberculosis, however, is considered a high risk. The commonest problem faced by most PFT laboratories is identifying patients at increased risk of cross contamination.

Health care workers, who are the first point of contact in facilities, should be trained to ask questions that will facilitate identification of patients with signs and symptoms suggestive of TB, immunocompromised status and patients with a significant exposure to communicable diseases such as chicken pox and measles. Identification of possibly infected technicians and patients can aid in reduction of the risk of cross infection. In a recent audit of two teaching hospital laboratories, both of whom requested this information before performing any breathing tests, approximately 84% of patients were referred with no known infection, 10% were immunocompromised, 2% had chest infections, and the remaining 4% tested positive for MRSA, HBV/HCV, or TB.[10] Segregation of patients helps in controlling spread of infection in a PFT laboratory. Immunocompromised patients should be scheduled for testing at the start of day, before other patients arrive, whereas infected patients should be scheduled for testing at the end of the day or week taking adequate precautions to prevent cross infection. Infected patients should be encouraged to wear surgical masks while in transit in the PFT laboratory. Patients with known susceptible disease should be placed in a separate room, if possible.[2]

Separation of patients by at least 1 m distance can help control infection effectively.[7] Contact in waiting room with potentially infectious patients should be minimized. Surgical facemasks, tissues, and waste container, alcohol-based sanitizers should be made easily available for infectious patients.[23]

The equipment used for testing infected patients should be disassembled and disinfected after use. Specific equipment may be reserved for testing infected patients (TB or multi-resistant *Staphylococcus aureus*.[1] Persons involved in sterilization and disinfection should be immunized against Hepatitis B. Hepatitis B vaccination (Heptavax-B), (Engerix B, Recombivax HB) is a three dose series at zero, one, and six months, and if require booster dose. Post-immunization testing for anti-HBs 1–6 months after the last dose, help to ensure immunity. Special precautions should be taken when testing patients with open sores or hemoptysis.

Equipment

Mouth pieces, nose clips

Many studies have shown that mouthpieces are the most contaminated PFT equipments and they should not be shared between patients. Use of disposable mouthpieces helps in preventing cross infection in patients. Disposable mouthpieces, nose clips, and flow sensors should be discarded after single use. If reusable mouthpieces are used for testing, they should be sterilized before every use [Figure 2a and b]. One-way valve mouthpieces avoid inhalation of pathogens from infected equipment. However, they hamper the measurement of inspiratory flow when used with peak flow meters. Alternatively, barrier filters may be used with mouth pieces. Barrier filters protect the equipment from contamination and prevent inhalation from the circuit, thus assisting in infection control. If the equipment is contaminated with blood or sputum, it must be sterilized immediately. It is practically difficult to disinfect lung function equipments in between two patients. This can be overcome by using microbial filters in the mouth pieces. Recently, the use of bacterial filters in pulmonary function laboratories has increased [Figure 3]. The choice of filter is important. Early filters had reported to have a bacterial retention efficiency of approximately 67%. Recently, filters using more efficient filters have been

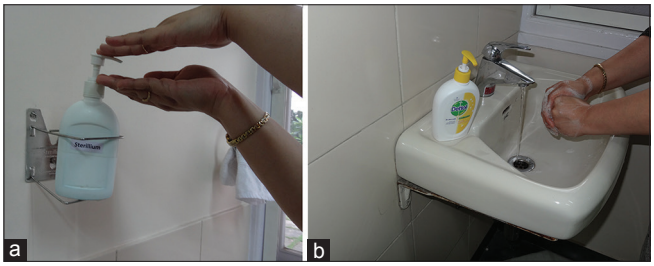

Figure 1: (a) Use of hand sanitizers between patients (b) Regular hand washing between patients

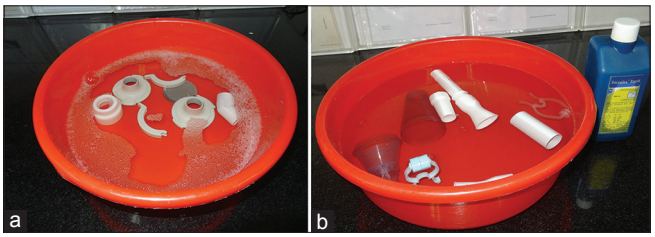

Figure 2: (a) Disinfection of reusable sensors (b) Disinfection of reusable mouth pieces, spacers and nose clips

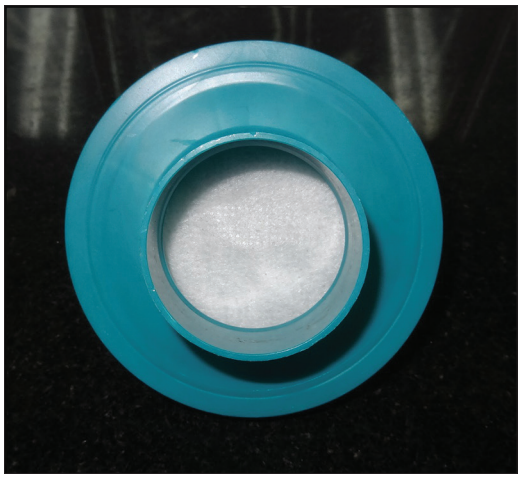

Figure 3: Bacterial filters used in the mouthpiece during spirometry

demonstrated to be approximately 99.9% efficient at flow rates up to 750 L/min and approximately 97% efficient at removing bacterial colony-forming particles when patients perform forced expiratory maneuvers through them.[10] Filters, containing pleated filters, have been shown to have a unidirectional microbial removal efficacy of greater than 99.9%. As the device is bi-directional, this means that the probability of cross-contamination is one in million, that is, negligible. Roe *et al*. published a cost comparison of filters versus the current Thoracic Society of Australian and New Zealand guidelines.[15] This analysis showed that in busy laboratory, the cost per test of using a barrier filter was on average approximately five times cheaper than the implementation of the guidelines. Use of a bacterial filter is reassuring for the overly concerned patients. Although significant differences between measurements with and without filters have been demonstrated for FVC, FEV1, airway resistance, and specific airway conductance (sGaw), these differences were unrelated to the average values of measurements (except for sGaw) and limits of agreement were within the range of intra-individual short-term repeatability for almost all of the function indices. Use of filters reduce measured lung volume (2%–4% of FEV1 and FVC, 6% Peak Expiratory Flow [PEF]), which is small and clinically irrelevant.[24] Use of filters during calibration is another method to add resistance provided by the filters in calculation.

Spirometers

Manufacturer recommendations (eg, frequency of disinfection of spirometer parts, method of disinfection, drying of spirometer parts) must be followed for proper cleaning of spirometers. Frequency of use of the spirometer will largely decide the frequency of cleaning. Heat sterilization or cold sterilization may damage flow sensors, tubing, or seals. For open circuit system, only rebreathing parts through which air moves should be decontaminated. If an infected patient needs to be tested, a flow sensor–based spirometer with detachable pneumotachometer is extremely useful. Inspiration from the flow-sensing element of the device should be avoided. Disinfection of mouthpieces, use of disposable sensors is easiest way of preventing cross contamination in such open circuit systems. A 5-min gap between two patient tests helps to remove microorganisms by gravitational sedimentation.[25] Modern spirometers provide a fan, which speeds up the process of gravitational sedimentation. Some of instruments offer pneumotachometers, which can be changed between two patient's tests. This is advantageous when possibly infected patients have to be tested in peak laboratory testing intervals. Flow sensor–based spirometers require more frequent cleaning.

Air flushing of a volume displacement spirometer at least 5 times after every patient test is a recommended method for infection control.[26] It is necessary to routinely clean the interior surface of volume–displacement spirometers.

Use of ultrasonic spirometers minimizes the chances of cross infection. Changing the flow head used for testing after every patient test ensures adequate infection control.

Soda lime absorber, used in dry rolling spirometers, kills microorganism and reduces infection effectively. Soda lime dust must be removed from rolling seal spirometers by vacuuming on a regular basis.

Body plethysmograph

The body plethysmograph has an in-built and detachable heated pnemotachograph, which provides a dry environment that is hostile to microorganisms. This also reduces the viability of microorganisms. Wet mopping of inner surfaces of the body plethysmograph with an appropriate disinfectant is extremely useful in infection control.

Peak flow meter

Infections via peak flow meters can be prevented by using a one-way valve mouthpiece which avoids inspiration from the peak flow meter. Appropriate counselling of patients to only exhale forcefully into the peak flow meter helps eliminate the risk of transmission of infection through the peak flow meter.

Sputum induction equipment and accessories

Personal protective equipment should be use by health care worker during sputum induction and processing. It is imperative to keep the door closed during sputum induction and minimizing entry and exit during the procedure. Use of local exhaust ventilation or room having same ventilation characteristics as negative pressure isolation rooms is recommended for use during sputum induction.[27] Fluid condensed on the tubing should never be drained back into the humidifier or nebulizer.

Tubing, petri-dishes, funnels, cryo-vial, Eppendorf tubes, and polypropylene centrifuge tubes used in induced sputum testing should be autoclaved. Liquid waste should be inactivated in accordance with state-approved treatment.

Efficient housekeeping

Dirt provides culture media for the growth of bacteria and fungi. Therefore, general cleaning of the PFT laboratory is also an important step in infection control. High-quality cleaning removes 90% of microorganisms (hospital hygiene and infection control). Currently, there is little evidence that wipes can control infection.[28] Biological waste generated in pulmonary lab should be properly handled and disposed. Health care CDC infection control practices advisory committee and National Institute of Occupational Safety and Health provide a recommendation regarding discarding of waste generated in health care settings.[29,30] Separation of infectious and noninfectious waste at the point of generation helps to control infection. Discard solid infectious waste except sharps in Red or Pink container or plastic bag with universal symbol of biological hazards, it signifies infectious waste items. Medical waste requiring storage should be stored in leak-proof containers and should be kept in a well-ventilated area. Air sterilizers may be used to sterilize the air in the PFT laboratory as well [Figure 4].

Figure 4: Air sterilizer

Sterilization and disinfection

Disinfection and sterilizations are decontamination methods used in pulmonary function laboratories. The method which is easy to use, compatible with equipment, and feasible should be preferred. Manufacturer's recommendations on material provide valuable advice for decontamination. Cleaning is an important step before sterilization or disinfection. Dust, dirt, and other foreign materials neutralize the action of disinfectant or sterilant; hence cleaning increases the quality of disinfection. Pulmonary function equipment is classified as semi-critical items, which require high-level disinfection. Use of biological indicators, containing bacterial spores, located inside a glass capsules should always be used during sterilization of critical items or at least once a week, which assures the quality of sterilization. Sterilized equipments should be stored in clean, dry, closed shelves. Material Safety Data Sheet [MSDS] should be a part of infection control policy. Table 2 discusses the details of types of sterilization and techniques of disinfection.

NEWER METHODS AND THE FUTURE OF INFECTION CONTROL

There is a need to assess the organisms to which patients are exposed in the PFT laboratory and then followed up to evaluate the degree of virulence of these identified organisms. Currently, there is no evidence regarding safety of long-term use of reused equipments. Adequate research would provide an insight into the life of using such equipment. Due to high cost of breathing filter, disposable equipments are being used in lung function laboratory.

As mentioned previously, there is insufficient literature on infection control in a PFT laboratory, especially in the Indian setting. We will be conducting a study in the near future to understand the possible pathogens in PFT

Table 2: Methods of infection control in a pulmonary function test laboratory

Equipment	Type of disinfection/ sterilization	Method	Eliminates infection of	Quality control/precautions
Mouthpieces, nose clips, valves, tubing, spacers used for reversibility testing	Chemical disinfection (2% activated glutaraldehyde)	Rinse in running tap water. Then dip in solution for 40-60 min and finally rinse in sterile water Keep in solution for 3 h, same remaining steps	Vegetative bacteria including TB, viruses including HIV and Hepatitis viruses. Bacterial spores	Use good ventilated room for procedure Wear personal protective equipment For Q.C. Equipment should be keep in solution for adequate time
Tubing, petri-dishes, funnels, cryo-vial, Eppendorf tubes, polypropylene centrifuge tubes (autoclavable)	Steam under pressure (autoclave)	Autoclave at 121°C at 15 psi for 15 minutes	Vegetative bacteria including TB, viruses including HIV and Hepatitis viruses and bacterial spores	Wear a personal protective equipment For Q.C. Use Of biological indicator Use of chemical indicator
Mopping of floor Equipment surfaces and work surfaces	Phenols Ethanol or isopropanol	As per instructions Wipe the surfaces	Disinfection	Use personal protective equipment
Infected/isolation rooms	Fumigation (150g $KMnO_4$ + Formalin 500 mL for a 1000 sq. ft room)	Mix the solution and leave it in a well-sealed and packed room for 24 h. Ensure adequate ventilation before the next patient testing	Vegetative bacteria including TB, viruses including HIV and Hepatitis viruses and bacterial spores	Use personal protective equipment

HIV: Human Immunodeficiency virus, TB: Tuberculosis

laboratories across India. We will also be evaluating the infection control strategies used in these laboratories and their effectiveness in doing so. This will enable us to draw more precious conclusions, which can lead to more relevant, contextual recommendations for cross infections control in PFT lab in India.

We need to find out new methods or long time, reusable, safe equipments, which will be cost effective. Production of new equipment by manufacturers that will be easy to disinfect and clean will help in improving infection control. The future may hold equipments that can detect pathogenic microorganisms and thus help in control of cross infection and contamination.

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