Reducing HAIs Through Continuous $PM_{2.5}$ Particle Counting

By Larry Clark, CEA, LEED AP

The importance of clean air for human health was recognized even in ancient Rome.[1] And documented examples of the use of ventilation in hospitals, as a means of reducing illness, date back to at least 1784.[2] By 1855, nursing and epidemiology pioneer Florence Nightingale had correlated reduced military hospital death rates with improvements in ventilation[3] and in the 1840s, Dr. Ignaz Phillipp Semmelweis identified the phenomena of nosocomial infection.[4]

Nosocomial infections are hospital-acquired infections, defined as those "for which there is no evidence that the infection was present or incubating at the time of hospital admission," and have long been recognized by healthcare professionals as a major source of morbidity and mortality.[5] In 1970, the Centers for Disease Control and Prevention (CDC) established the National Nosocomial Infection Surveillance System (NNIS), so that confidential patient data reported by individual hospitals could be aggregated into a national database. In 1999, the Institute of Medicine estimated that preventable "adverse health events," a category that includes nosocomial infections, were responsible for 44,000 to 98,000 annual deaths at a cost of $17 billion to $29 billion.[6] According to Weinstein,[7] in 1995, nosocomial infections caused an estimated 88,000 deaths – one every six minutes – at a cost of $4.5 billion.

There are three primary modes of transmission for hospital-acquired infections: Contact, which may be direct (i.e., between a care provider and a patient; between a visitor and a patient; or between two patients) or indirect, such as those caused by contaminated instruments or fluids; droplet, which may occur as a result of eating, talking, coughing or sneezing, or by the performance of certain medical procedures (e.g., bronchoscopy). It's important to note that, although the droplets containing the microorganisms are propelled a short distance (generally <3 feet) through the air, it differs from airborne transmission in that the droplets do not remain suspended in the air and ventilation does not play a major role in their control; and airborne transmission. It is the airborne mode that lends itself to ventilation/filtration control.

Respirable fraction particles in the diameter range of ≤ 2.5 µm ($PM_{2.5}$), are constituents of fine-particle aerosols and, as such, have a major role in airborne microbial infection transmission. Because these small-particle aerosols are too small to be filtered by the nasal cilia and are inhaled directly into the lungs, once a virus suspended on a $PM_{2.5}$ contaminates an air space, the degree of transmission of the infection is limited only by the survival of the virus and the ventilation in the space. Thus, $PM_{2.5}$ particles are a significant contributor to nosocomial infections.[8] Also, unlike "active" droplets, the small-particle – generally ≤5 µm in diameter — residue of evaporated droplets (nuclei) that still contain microbes are also capable of remaining suspended in the air for long periods of time.

The relationship between ventilation/filter efficacy and infection rates was established by Jamriska, et al.[9] in a study of particle size distribution and concentrations in the surgical theaters at the Royal Children's Hospital and the adjacent Royal Brisbane Hospital in Brisbane, Australia. One of the series of measurements conducted by them involved the identification of the particulate sources in the surgical areas, during both surgical procedures and periods of nonuse. In constructing their mathematical model, they concluded that the most important parameter in predicting particle concentration was the efficiency of the filters.

The Wells-Riley equation demonstrates the relationship between higher ventilation rates and lower infection rates:

C = S(1-e-LQRT/V) where C = rate of infection
S = number of susceptible patients in the space
L = number of infected individuals (infectors)
Q = number of added airborne infections
R = pulmonary respiration rate
T = time of exposure
V = ventilation rate

Myatt, et al.[10] in a study of the linkage between nosocomial fungal infections (in this case, Aspergillus, an opportunistic fungus that can cause invasive infections in immuno-suppressed patients) and hospital construction activities, found that by substituting the average number of colony-forming units per infectious dose (CFU/D) into the Wells-Riley equation, the risk of infection – with a constant ventilation rate — was directly proportional to the concentration of infectious organisms; the exposure time; and the patient's respiratory rate. Since consistently controlling surgical exposure time and patients' pulmonary function is not practical, managing the concentration of infectious organisms by limiting $PM_{2.5}$ provides in this case the greatest opportunity to reduce the risk of airborne-transmitted infection.

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Since an operating room (OR) is one of the areas in a hospital that is most susceptible to those types of infections, it follows that adequate, efficient air handling and filtering are vital in that environment. According to Monge, et al.[11] surgical site infections (SSI) were the most common nosocomial infections among surgical patients and the second most frequently-reported in general. As one would expect for spaces in which indoor air quality (IAQ) is critical, there are a plethora of standards that address OR ventilation requirements. Melhado, et al.[12] have done an excellent job of compiling and examining a number of these standards applicable to ORs throughout the western world and their relationship

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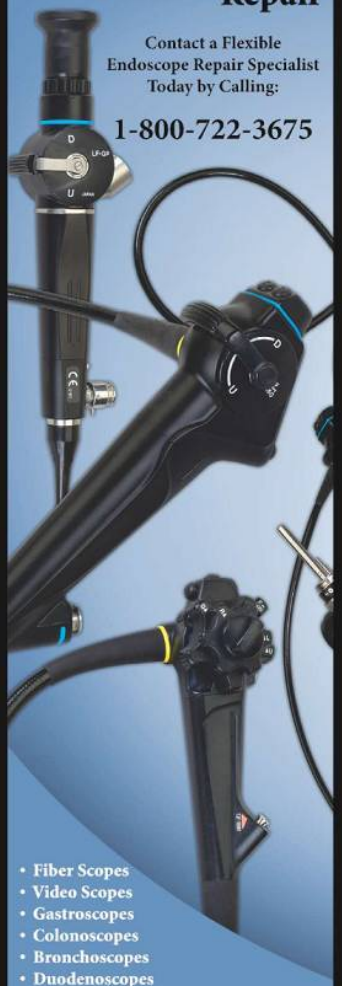

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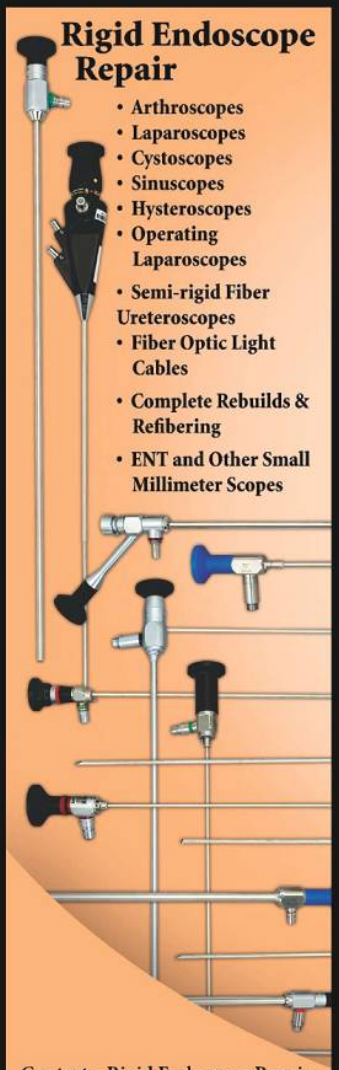

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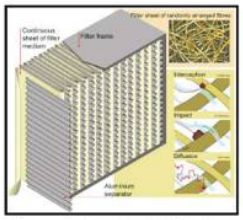

Figure 1 – Typical HEPA filter

Figure 2 – Ceiling-mounted HEPA filter

to infection. They also point out that IAQ in an OR is not just limited to airborne microbial infection control, but must also address such pollutants as anesthesia gases and the smoke resulting from laser and electro-surgery procedures. The prevailing standards address both comfort and safety in the OR by prescribing requirements for temperature; relative humidity; ventilation rates (air changes per hour or ACH) and limitations, if any, on recirculation; filtration efficiency; and, maintenance of a positive differential pressure relative to adjacent areas, to prevent infiltration. So, in addition to efficient filtration, control of air pressure distribution to ensure that airflows are always from a clean to a less-clean area is also an important consideration in preventing nonsocomial infections.[13]

Typically, high-efficiency particulate air (HEPA) filters with efficiencies of 99.97 percent (on 0.3 µm particles) may be installed in general hospital spaces. Figure 1 depicts the major elements of a typical HEPA filter. Critical areas, such as the OR, should have HEPA filters with an efficiency of 99.99 percent on 0.3 µm and/or ultra-low penetration air (ULPA) filters that are 99.999 percent efficient on 0.1-.02 µm. Depending on the design of the particular OR, the filter installation may be integral with the air handling unit, in a separate filter rack, or in the ceiling of the individual OR, as shown in Figure 2. High minimum efficiency reporting value (MERV) prefilters (MERV 8 with 30 percent to 40 percent efficiency to MERV 13, with 85 percent efficiency) can be installed to protect the more critical – and expensive – HEPA filters.

Surprisingly, there is generally little or no instrumentation to monitor filter performance included with hospital air filtration systems. The most common instrument used in these applications is a manometer or differential pressure switch (as the filter becomes loaded, the airflow becomes restricted, resulting in an increase in ΔP), to indicate when the filter is too "dirty" and depending on the type of filter needs to be replaced or cleaned. Most filters – even in critical areas like ORs – are serviced, absent a high ΔP, on the basis of an arbitrary time-interval schedule or as a result of an unsatisfactory microbiological sample. There are several potentially adverse consequences to this approach. If the filter is not excessively loaded and there has been no bypass or breakthrough, resulting in contaminants emerging in the filtered airstream, then there is no reason to service the filter. Most filters are actually more efficient with some degree of loading and the poor economics of premature filter service are obvious.

On the other hand, without measuring the particle count upstream and downstream of the filter, there is no way, save by a manual microbiology procedure, to detect that bypass or breakthrough has occurred, and the IAQ in the OR could be significantly compromised before the next scheduled sampling or filter service. For example, if the particle event were to occur during a surgery, it would in all likelihood go undetected until the next regularly scheduled microbiology sample or filter service occurred. So the need for both ΔP and continuous particle monitoring, particularly in critical filter applications like ORs, is evident. How best to reliably accomplish this monitoring will depend on several factors, including the hospital's ventilation scheme, its building management system (BMS) and the type(s) of air conditioning equipment in place (i.e., chilled water, DX, or a combination of both), often a function of the size and age of the facility.

There are a number of ventilation strategies – both constant and variable — that may be employed in a hospital environment. With constant ventilation, ACH are fixed at a value based upon the relevant standards and accepted engineering calculations. If a variable ventilation strategy is employed, it may include some type of demand-controlled ventilation (DCV) system. In the case of a multi-parameter DCV system, $PM_{2.5}$ may be one of the pollutants being detected.[14] In that case, it would be relatively simple to add sample points before and after the contemplated filters, if those are points are not already being sampled. If there is not an existing particle counting capability in place, individual particle counters having the ability to communicate with the BMS, would have to be installed. These instruments would typically use the same technology as in a multi-parameter DCV system, typically an optical (laser) counter for particles in the size range of 0.3 to 2.5 µm diameter and concentration range of 100-10x106 particles/FT3. A typical counter of this type in shown in Figure 3. The particles entering the counting chamber block a laser beam, producing a reduction in light intensity at the detector that is proportional to the size of the particle. A reasonable response time and degree of accuracy are presumed and the tubing carrying the air samples to the counter must be electrically conductive in order to prevent the buildup of an electrostatic charge on the particles.

This system, by immediately reporting high particle counts to the BMS and triggering an alarm would ensure the integrity of the filters, regardless of the service interval, and would reduce the cost of unnecessary filter service (perhaps paying for the cost of the system). Since the relationship between nosocomial infection rates and IAQ is clear, a reduction in infection rates should follow implementation of this monitoring.

It is important to note that filter particle counters cannot — and should not — eliminate the need for routine microbiological sampling. A three-month study comparing microbiological sampling and manual particle counting failed to establish a correlation between the two methods.[15] Conversely, however, it is equally important to understand that the particle counting strategy presented here utilizes dedicated particle counters as part of a real-time, continuous, process that will immediately respond to high particle counts regardless of the time or cause of the occurrence. Unlike the microbiological method, this is an automated function generally requiring no human intervention until a particle event occurs. ICT

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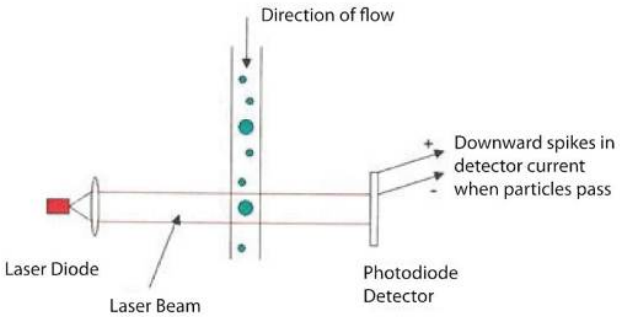

Figure 3 – Principle of operation of typical optical (laser) particle counter (Courtesy of CPS Instruments Europe)

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