

Analysis of Microorganisms in Hospital Environments and Potential Risks

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Introduction

The term hospital environment includes hospital buildings and healthcare settings with all indoor components that differentiate them: occupying people (sick people, visitors and hospital staff), indoor air, surfaces, medical equipment, drugs, medical devices, food and wastes (Bottero et al. 2015; Capolongo et al. 2016).

All these components may potentially support survival and growth of biological agents. How microbial communities persist and change in indoor environments is of great concern to public health. In fact, recent studies demonstrated that when humans occupy a space, human being there alters the microbiota of that space (Smith et al. 2013; Capolongo et al. 2015b).

Within hospitals, people can be exposed to bioaerosols, particles of biological origin suspended in the air, and the potential for contracting a microbial pathogen is high. The human exposure to pathogens may be associated with a wide range of major public health issues, such as infectious diseases, acute toxic effects and allergies.

Hospital environments are characterized by high infective risk, firstly cause of the compromised immunologic conditions of the patients that make them vulnerable to bacterial, viral, parasitological and fungal opportunistic infections (D'Alessandro et al. 2016). The potential transmission of biological matter during surgery operations and medical treatments of infected individuals makes hospital

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environments strongly designated to become easily contaminated with spread of pathogens among patients (Baglioni and Capolongo 2002).

Furthermore, in the last decades, if the use of antibiotics has been an excellent tool into preventing nosocomial infections, the extensive employ of these drugs has inevitably conducted to the insurgence of antibiotic resistance events.

Hospital buildings may be considered as dynamic environments affected by several factors that actively contribute to define the infective risk for patients. Aspects that have to be considered are represented by the number of occupants (in addition to patients, medical employees and visitors), their effective state of health, hygienic habits and activity occurring at any time in the hospital (Capolongo et al. 2015a; Astley et al. 2015). Hygienic conditions of sites and rooms, building materials and equipment, furnishings also influence the microbial community composition (Signorelli et al. 2016). In addition, technological devices such as hydraulic, heating and air-conditioning systems may represent a potential source of bacteria, fungi (moulds), virus and other organisms if not adequately designed and submitted to a planned preventive maintenance.

Microclimatic conditions and accidental events can support microbial and fungal growth (water infiltration and condensation) causing harmful indoor conditions (Buffoli et al. 2007). Outdoor microbial load and seasonal climatic characteristics also affect the microbiological quality of the hospital indoor air.

Sources of Hospital-Acquired Infections and Routes of Transmission

Hospital-acquired infections are emerging as important cause of morbidity and mortality in immunocompromised patients and severe underlying illnesses. Each year, 2 million patients suffer from hospital-acquired infections and nearly 100,000 of them die (Klevens et al. 2007). Data from the World Health Organization show that on 100 hospitalized patients, 7–10 are expected to contract, at least, one healthcare-associated infection (WHO 2011). However, the real burden is unknown because of the difficulty to gather reliable data. In fact, the diagnosis of nosocomial infections is complex and based on multiple criteria and not on a single laboratory test.

In healthcare facilities, the main sources of infection are the patients and the healthcare employees, although the environment plays also an important role. In fact, environment may act as a reservoir for potential infective microorganisms and may contribute to their dissemination. Consequently, bacteria are also common on inanimate surfaces, equipment and indoor air.

Infected patients spread microorganisms in the hospital sites through the release of expectorate drops, fluids from infected wounds, excrements, urine, blood, other corporeal fluids, but also through clothes and blankets. In addition to pathogenic microorganisms, the patients' endogenous flora could be a consistent source of microbes.

Microbial spread occurs mostly via large droplets, direct contact with infectious material or through contact with inanimate objects contaminated by infectious material. The direct contact between patients is rare; hands of clinical personnel can spread infective microorganisms and represent the most frequent vehicle of nosocomial infections. Thus, hand hygiene is recognized as the primary measure to reduce infections.

Even healthy people and staff may act as carriers when infected or colonized. Pathogens such as *Staphylococcus aureus*, *Staphylococcus pyogenes*, *Neisseria meningitidis*, *Corynebacterium diphtheriae*, hepatitis B virus, cytomegalovirus can be transmitted by symptomless carriers.

Pathogens and opportunistic pathogens may be present in water distribution systems and in aerosol released by water-cooling systems (e.g. *Legionella* sp., *Mycobacterium* sp.). Microbial contamination can also occur in pharmaceuticals during the distribution among patients and in improperly processed food. In addition, hospital wastes not rightly and quickly eliminated can become a harmful contamination source.

Microorganisms that can be spread by contact include those associated with impetigo, abscess, diarrhoeal diseases, scabies and antibiotic-resistant organisms (methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci). Vectorborne transmission is limited to areas in which insects, arthropods and parasites are widespread.

Water and aqueous solutions used in healthcare facilities are often associated with the hospital-acquired infections. Despite water treatment and chlorination, water entering in the hospital distribution systems may contain low concentrations of various autochthonous microorganisms such as *Pseudomonas* sp., *Legionella* sp., nontuberculous mycobacteria, *Acinetobacter* sp., *Aeromonas* sp., *Sphingomonas* sp., *Enterobacter* sp., *Aspergillus* sp. and amoebae, which may cause clinically important opportunistic infections. Remaining embedded in a matrix of extracellular organic polymers combined with nonorganic particles, these microorganisms can induce the development of biofilms in the plumbing system of healthcare facilities, hot water tanks, air-conditioning cooling towers, sinks, shower heads and faucet aerators. In addition to own each group characteristics, the biofilm constitutes a barrier, thus preventing both the complete cleaning of the environment that the total elimination of the microorganisms, with the consequent presence of survivors that, in the same time, can develop resistance to biocides and transmit this resistance, whether genetic, even in microorganisms of other species.

Some biofilm-forming bacteria such as *Legionella*, *Klebsiella*, *Pantoea agglomerans*, *Acinetobacter baumannii* and *Enterobacter cloacae* can cause hospital infections and are more resistant to disinfectants and antibiotics than their planktonic states. Biofilm can act as microbial reservoir that constantly releases viable microbes into the water stream. Tap water may then contaminate surfaces, medical devices and instruments as well as endoscopes, dialysis machines, nebulizers, humidifiers and ventilators (Exner et al. 2005).

The routes of transmission of waterborne pathogens include direct contact, ingestion of water, indirect contact and inhalation of bioaerosols. *Pseudomonas*

aeruginosa and *Legionella pneumophila* are the most significant waterborne pathogens in healthcare facilities.

P. aeruginosa is an environmental common microorganism. It is frequently associated with nosocomial infections, particularly among mechanically ventilated or immunocompromised patients in intensive care units. The major reservoir of *P. aeruginosa* is considered the patients' endogenous flora, and horizontal transmissions among patients have long been considered the most frequent source of *P. aeruginosa* infections. Other studies have shown patient-to-patient spread via hands of healthcare workers, or via fomites.

However, during the last years, the application of molecular typing methods made it possible to identify tap water supplied by intensive care units as a significant source of exogenous *P. aeruginosa* isolates. A review of prospective studies showed that between 14.2 and 50% of infection/colonization episodes in patients were due to genotypes found in intensive care unit water (Trautmann et al. 2005).

L. pneumophila has been recognized as the first emerging waterborne pathogen transmitted by inhalation. Its transmission represents a considerable risk for patients with chronic lung disease and those who undergo general anaesthesia. In hospitals, the immunosuppressive status of patients and other risk factors induce not only a higher risk of infection but also a higher incidence of lethality than in other settings. From 5 to 20% of notified legionellosis are of healthcare-associated origin (Exner et al. 2005). In healthcare settings, not only humidifiers, respiratory devices and cooling towers, but also showers and taps are specific reservoirs of *Legionella* (Joly and Alary 1994; WHO 2007; ANSI/ASHRAE 2015).

Nontuberculous mycobacteria (NTM), even called environmental mycobacteria, are also responsible for healthcare-associated infection by inhalation route and direct contact. The structure of their cellular wall particularly rich of long-chain lipids and the ability to form biofilms contribute to their resistance to chemicals and support their persistence. Indeed, NTM are frequently found in water distribution systems and can be aerosolized through showers and taps. A microbiological survey carried out by the authors confirmed NTM presence in the water plumbing of a hospital after the occurrence of some cases of atypical mycobacteriosis in a hospital wards. The NTM load ranged between 2×10^2 and 4×10^4 cfu/L and human pathogenic opportunistic NMT species (*M. intracellulare*, *M. chelonae*, *M. llatzerense* and *M. gordonae*) were found in addition to other harmless environmental species (Briancesco et al. 2014).

Since the risk resulting from the presence of NTM in water is not controllable by classical water disinfection procedures, filters at the point-of-use are now recommended to be the best option for minimizing the risk.

Moreover, water distribution systems may be potential indoor reservoirs of moulds such as *Aspergillus* sp., zygomycetes, *Fusarium* sp. and other fungi. Showers and taps can be the sources of risk for aerosolization of fungal spores (Anaissie et al. 2003). Moulds are ubiquitous in nature and grow almost anywhere indoors or outdoors. Persons can be exposed to mould through skin contact, inhalation or ingestion. Because of the ubiquity of mould in the environment, some level of exposure is inevitable. Inhalation is usually presumed to be the most

important mechanism of exposure to viable (live) or nonviable (dead) fungi, fungal fragments or components. The majority of fungal spores have aerodynamic diameters of 2–10 μm , which are in the size range that allow particles to be deposited in the upper and lower respiratory tract. Inhalation exposure to a fungal spore requires that the spore be initially aerosolized at the site of growth. In general, persons with impaired host defences suffer the most severe types of fungal infections.

Spread of Airborne Microorganisms

Airborne hospital microorganisms are apparently harmless to healthy people. Nevertheless, they can cause adverse health effects in immunocompromised individuals.

The hospital itself and its technological systems can offer detrimental sources to the indoor air quality. Air-conditioning systems and aeraulic plants can become contaminated over time and trap various contaminants such as dust and biological organisms. Moisture from them can condense within the ducts and support microbial growth. Thus in hospitals, special air handling and ventilation are required to prevent airborne transmission (ANSI/ASHRAE 2016). Inadequate ventilation is implicated in the airborne transmission of bacteria (Obbard and Fang 2003).

Bioaerosol spread through the air cover in a wide size range. Droplets are larger than 5 μm and their source is primarily the act of coughing, sneezing or talking. In hospitals, particular medical performances such as suctioning and bronchoscopy spread particles of this size. Among droplet-transmitted infections, smallpox, measles, chickenpox, tuberculosis, meningococcal disease, pneumonia caused by *mycoplasma*, SARS and flu are the most relevant.

Small particles residual from evaporated droplets (5 μm or smaller in size) and dust particles containing infectious agents may remain suspended in air for a long time. In this way, microorganisms can be dispersed widely by air currents over a longer distance from the source. The airborne transmission of infections regards only microorganisms spread in large number into the air with low infective dose. Key factors influencing the level of airborne microbial burden are the occupant density and dampness depending on the particular location within the hospital.

In hospital indoor air quality moulds are frequently recovered, especially during the construction/repair activities. Fungal spores have low settling velocities remaining in the air for a long time.

The hospitalized weakened patients are more susceptible to infections from naturally occurring mesophilic fungi, and in last decades, high mortality rates have been reported in transplant patients and leukaemia patients (Taccone et al. 2015).

In a survey study that followed the occurrence of numerous post-surgery infections at a transplant centre of a hospital in Rome, the levels of bacteria and fungi occurring in air and surface samples from an operating block (operating rooms, intensive care units, surgery recovery rooms and annexes corridors) were assessed.

Low concentrations of fungi were found in air and surface samples (ranging from 0 to 70 cfu/m³ and from 0 to 21 cfu/cm², respectively). Other than numerous pathogenic opportunistic species were isolated (*Alternaria infectoria*, *Alternaria tenuissima*, *Epicoccum nigrum*, *Purpureocillum lilacinum*, *Cryptococcus laurentii*), many other environmental opportunistic fungi belonging to the genera *Penicillium*, *Aspergillus*, *Cladosporium*, *Mucor*, *Stemphylium*, *Conidiobolus* and *Trichoderma* were found. Bacterial densities in bioaerosol ranged from 9 to 174 cfu/m³ with the highest values characterizing an emergency room. *Staphylococcus aureus* and other opportunistic *Staphylococcus* species were isolated in many areas. Several bacterial opportunistic species were also recovered (*Leclercia adecarboxylata*, *Enterobacter cloacae*, *Bacillus cereus* and *Kokuria varians*). In general, a moderate microbial pollution affected the examined surfaces with the exception of a massive bacterial density ($>1 \times 10^3$ cfu/cm²) observed on a drug carriage where *Pseudomonas stutzeri*, opportunistic pathogenic bacteria, was isolated as prevalent microbial species (Bonadonna et al. 2015).

Although recommendations exist, there is a regulatory lack of a referential standard for microbiological parameters of indoor air quality in healthcare facilities because of the deficiency in the relationship between microbiological survey data and their epidemiological implications.

Surfaces as Potential Sources of Infection

In hospital rooms, the surfaces are frequently contaminated with pathogens able to survive for a long time on room surfaces (beds, sheets, floors, walls and furniture) and medical equipment (de Oliveira and Damasceno 2010; Capolongo et al. 2013).

Biological agents may be transmitted to the patients by personnel gloves and visitor hands or through dust that, once deposited on the surfaces, may be contaminated and then resuspended by natural convection or conditioning air systems.

Hospitalization in a room in which the previous patient had been colonized or infected with methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), *Clostridium difficile*, multidrug-resistant *Acinetobacter*, multidrug-resistant *Pseudomonas* or yeasts as *Candida auris* can represent an additional risk factor for the next patient admitted to the room.

The most relevant nosocomial pathogens persisting on dry inanimate surfaces and the duration of their persistence are reported in How long do nosocomial pathogens persist on inanimate surfaces? A systematic review by Kramer et al. (2006). Gram-negative bacteria persist longer than gram-positive bacteria. Moisture improves the persistence for several types of bacteria (e.g. *Chlamydia trachomatis*, *Listeria monocytogenes*, *Salmonella typhimurium*, *Pseudomonas aeruginosa* and *Escherichia coli*) while only *Staphylococcus aureus* persists longer at low dampness.

Prevention

No health-based standards or exposure limits for indoor biological agents exist. Differences in season; climatic and meteorological conditions; type, construction, age and use of the building and ventilation systems; and differences in measurement protocols used in the various studies (e.g. viable versus nonviable microorganism sampling, sampler type and analysis) make it difficult to interpret sampling data relative to information from the medical literature (Alfonsi et al. 2014).

These difficulties are exacerbated in hospitals where the patient health status, the activities that take place and the potential spread of pathogenic biological agents increase the level of complexity respect to other indoor environments. Moreover, the global burden of healthcare-associated infection is unknown because of the difficulty of gathering reliable diagnostic data.

The definition of the role that the environment has on the acquisition of hospital infections is highlighted by the need for multiple strategies to control the dissemination of pathogenic microorganisms and the adoption of prevention measures.

Because nearly 10^6 skin flakes containing viable microorganisms are shed daily from normal skin, it is not unexpected that patients—through gowns, bed linen, bedside furniture and other objects close to them—become contaminated with other patient flora.

The clarification of the role that surfaces have in the spread of infections could provide support to increase adherence to control measures. Improving and intensifying the cleaning routine may reduce the dissemination of pathogens. More attention should be given to the adequacy of the length, the frequency and specific care when cleaning surfaces, because removing dirt helps to reduce biofilms. The spread of pathogens could be prevented by using engineering and environment control strategies. Thus, in addition to cleaning and disinfection standard procedures, the maintenance of appropriate hygienic targets may be obtained by employment of durable antimicrobial materials, such as copper and copper alloys (brasses and bronzes), especially for high-touch surfaces.

Antimicrobial copper touch surfaces can lower the number of microbes on surfaces, reducing the risk and preventing the transfer of antibiotic resistance between bacterial species (Michels et al. 2015; Gião et al. 2015).

Cause of microbial biocide multiresistance issue, in recent years new sanitation procedures, based on the use of probiotic products, have been studied. This technique connoted as biostabilization is based on the principle of competitive microbial exclusion and does not imply a biocidal action. Surfaces sanitizing probiotic products containing vegetative and spore forms of *Bacillus* species, in association with good hygienic practices, seem to provide 80–90% reduction of pathogenic agents and more than 60% reduction of infection events (Mazzacane et al. 2014; Caselli et al. 2016).

In order to avoid infections caused by airborne microorganisms, it is very important to maintain protective barriers that control the microbiological quality of the air. For aerosolized waterborne pathogens, faucets are easily accessible for

preventive measures, and the installation of single-use filters on hospital water outlets appears to be an effective concept to reduce water-to-patient transmissions of nosocomial pathogens.

Infection control programs have been defined by WHO and the Centres for Disease Control. The improvement of the surveillance systems for hospital infections and the implementation of standard procedures for reduction of microbial spread represent the main commitments (WHO 2011; CDC 2003).

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