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Disease resulting from contaminated equipment and invasive procedures

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As ubiquitous inhabitants of the environment and frequent colonizers/contaminants in nosocomial settings, PEM are an important and emerging cause of human disease. The persistence of these organisms in municipal and hospital water supplies coupled with their intrinsic resistance to disinfection is the likely explanation for these cases (Falkinham 2002). Procedures that place people at risk of infection are commonly performed every day in large numbers in health care and cosmetic settings throughout the world. Fortunately, rates of acquiring infection are relatively low, but laboratories and clinicians will occasionally be faced with such patients. Due to the ubiquity of the organisms in the environment, microbiological specimens can become contaminated. It is sometimes difficult to determine accurately if the isolation of mycobacteria is associated with disease, or if it is an accidental

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contaminant. In addition to these unique individual patient considerations, such cases could also herald a “real” or “pseudo-outbreak” resulting from a shared contaminated device or solution. Laboratory workers, infection control practitioners, clinicians, and occasionally even public health personnel play important roles in the evaluation of each case.

This chapter outlines exposures resulting from contaminated devices and invasive procedures and gives representative examples of each. Selected aspects of the clinical presentation, treatments and outcomes will be highlighted. While infections due to various members of the PEM are addressed, special attention is given to the rapidly growing species due to the central role these organisms play in the etiology of device-related infection. In some cases there is overlap with the data presented in the accompanying skin infection chapter in this book and the reader is referred to this chapter for complementary information (Chapter 8). Finally, there are several excellent recent reviews on nosocomial outbreaks/pseudo-outbreaks that have been published recently (Fraser 1981; Wallace *et al.* 1998; Phillips & von Reyn 2001).

10.1 CLINICAL ASPECTS

10.1.1 General Comments

Though the problem has been recognized for decades, the number of reports of pathogenic mycobacterial disease caused by the use of contaminated devices or from an invasive procedure has been increasing. Some of the highest rates of potable water contamination are found in hospitals, dental offices and hemodialysis units (Carson *et al.* 1988; Schulze-Röbbecke *et al.* 1995; Fujita *et al.* 2002).

Difficulty can arise in making a diagnosis due to the indolent nature of the clinical presentation and a long incubation period. Because the original exposure may have occurred some time before clinical presentation, heightened clinical suspicion is often needed to make a proper diagnosis. Once considered, the organisms are usually not difficult to cultivate in the laboratory.

When a microbiological specimen yields PEM, it is important to discriminate between colonization, true infection and pseudo-infection (Phillips & von Reyn 2001). Colonization indicates the presence of the organism within or on the patient but, by definition, occurs in the absence of any identifiable disease. Pseudo-infection results when mycobacteria are isolated in culture from a clinical specimen as a result of contamination. In pseudo-infection, there is no evidence of infection or disease. Pseudo-infections can represent an isolated event or a pseudo-outbreak involving many people. These scenarios are summarized in Table 10.1.

Table 10.1 Potential situations associated with PEM isolation from a clinical specimen (Adapted from Phillips & von Reyn 2001)

Situation	Definition
Colonization	Isolation of potentially pathogenic EM without signs or symptoms of disease attributed to the organism.
Infection/disease	Clinical evidence of infection attributed to the organism.
Pseudo-infection	No evidence of infection or colonization and isolation in the laboratory has resulted from contamination of the environment (can occur at any point: from a contaminated device, in obtaining the specimen, or up through the final cultivation in the laboratory).

These scenarios are important to identify because the patient(s) could be spared unnecessary antimicrobial agents if a "pseudo-infection" is present. Examples of pseudo-outbreaks include contaminated endoscopes and bronchoscopes as well as other types of instrumentation (CDC 1991; Canadian Disease Weekly 1991; Maloney *et al.* 1994; Griffiths *et al.* 1997). Bronchoscopic contamination is a common source and can occur due to inadequate cleaning and disinfection of the scope or by contaminated solutions or water used in the process (Sniadack *et al.* 1993). The organisms most commonly involved in bronchoscopic pseudo-outbreaks include *M. abscessus, M. fortuitum,* MAC (both *M. avium* and *M. intracellulare*), *M. gordonae* and *M. xenopi*. Automated bronchoscope disinfecting machines can become heavily contaminated with mycobacteria that are resistant to normal disinfection procedures (Wallace *et al.* 1998). Bronchoscopes contain components that are small and difficult to sterilize. For example, contamination of the suction valve (an area of the scope that is not easily accessible) has been documented (Wheeler *et al.* 1989). There exists potential for biofilm growth in many areas of the scope including the small lumens and multiple ports. In addition to pseudo-infection, there is a theoretical risk of true infection upon exposure to a contaminated instrument especially if a patient is immunocompromised or has a significant underlying lung disease (Prakash 1993). In this situation the patient should be monitored carefully for signs of disease. Other cases of pseudo-outbreaks have been reported as a result of laboratory cross-contamination, contaminated microbiological equipment, media, supplements and tap water (Wallace *et al.* 1998). Laboratories and practitioners need to be aware of these possibilities and in the absence of a compatible clinical syndrome a pseudo-infection should be considered.

True infection/disease has occurred in many different types of clinical settings. While not meant to be comprehensive, some examples of disease due to PEM are shown in Table 10.2.

Table 10.2 A representative listing of mycobacterial species associated with infections in the nosocomial setting.

Type of infection	***Mycobacterial species***	**Source**
Venous catheter infection	*M. fortuitum* *M. abscessus* *M. chelonae* *M. avium*	Catheter or solutions
Pacemaker or automatic implantable cardiac defibrillator infection	*M. avium* *M. abscessus*	Device
Sternal wound infection	*M. fortuitum, M. abscessus*	Water/ice cardioplegic solution
Cardiac porcine valve infection	*M. chelonae*	Contamination during sterilization of valve
Abscess after adrenal cortex extract (ACE)	*M. abscessus*	Contaminated ACE (non-FDA approved)
Plastic surgery (facial blepharoplasty and augmentation mammoplasty) wound infection	*M. abscessus*	Contaminated instruments, or solutions (i.e. gentian violet)
Peritonitis in peritoneal dialysis patients	*M. abscessus*	Identical to water isolate by strain typing
Haemodialysis related infection	*M. abscessus and M. mucogenicum*	Water used in rinsing dialysis equipment
Otitis media	*M. abscessus*	Possible contaminated instruments or tap water
Discitis	*M. xenopi*	Hospital hot water

Some species are rarely associated with disease, such as the occurrence of *M. kansasii* and *M. gordonae* with peritoneal dialysis infections. Other less commonly isolated species include *M. smegmatis, M. neoaurm, M. gastri, M. genavense, M. szulgai* and *M. immunogenicum.* Excellent reviews of this subject are available (Wallace *et al.* 1998; Phillips & von Reyn 2001).

10.1.2 Specific infections

10.1.2.1 Infection of intravascular catheters, pacemakers

Vascular devices such as indwelling venous access lines and vascular shunts can become infected with both RGM and other species (Katz *et al.* 2000; Schinsky *et al.* 2000; Rodriguez-Gancedo *et al.* 2001; Bouza *et al.* 2002). Infections can result in skin and soft tissue involvement (including tunnel site infections) with or without bacteraemia. Symptoms include local manifestations of line infections such as erythema and occasionally drainage at the site. There may be fever and other signs and symptoms of bacteraemia. The usual treatment is to remove the device and administer appropriate antibiotics (typically for a period of 2-12 weeks or more). Pocket infections involving pacemakers have also been seen with PEM, with MAC and especially *M. abscessus* predominating (Amin *et al.* 1991; Katona *et al.* 1992; Cutay *et al.* 1998; Verghese *et al.* 1998).

10.1.2.2 Dialysis related infection

Dialysis related PEM infection has been reported in both intravascular and peritoneal mechanisms of renal replacement therapy. RGM species are the most commonly implicated. Contaminated aqueous solutions used to sterilize the re-usable dialysis filters have been involved in many cases. PEM representatives have been isolated from water supplies of haemodialysis centres (Carson *et al.* 1988). In 1982, 27/140 patients receiving haemodialysis developed infection after being exposed to mycobacteria in water used to prepare dialysis fluids (Bolan *et al.* 1985).

Peritonitis can occur in patients undergoing chronic ambulatory peritoneal dialysis (Band *et al.* 1982). In this setting it can involve the catheter insertion site, tunnelling tract and/or the peritoneum itself. MAC and the rapid growers are the most commonly isolated species (Band *et al.* 1982; Soriano *et al.* 1989; Lowry *et al.* 1990; Vera & Lew 1999). Patients with end stage renal disease from any cause are likely to be more prone to infection due to impaired lymphocyte and neutrophil activity in the face of uraemia.

Overall, NTM accounts for a relatively small number of peritonitis infections, but this may be an underestimate given the frequency of culture negative cases. In fact if routine cultures are negative one should consider the diagnosis of PEM peritonitis (Hakim *et al.* 1993). Symptoms are insidious and often involve fever, abdominal pain and cloudy dialysate fluids. There can be catheter dysfunction, nausea, vomiting, diarrhoea and weight loss. The white blood cell can be elevated and is often of neutrophilic predominance. Catheter removal improves the rate of cure and antibiotics are necessary to prevent clinical failure. Sequelae include adhesions and sometimes difficulty replacing the catheter (Hakim *et al.* 1993).

10.1.2.3 Injection abscesses

Injection site abscesses have been caused by a variety of contaminated materials (Vandepitte *et al.* 1969; Wenger *et al*. 1990; Villanueva *et al.* 1997; Galil *et al.* 1999). Complementary and alternative medicine settings, such as injection of non-FDA approved substances that are contaminated by environmental mycobacteria, have been implicated as the source of infection (Wallace *et al.* 1998). For example, post-injection infection occurred in a large number of individuals who received adrenal cortex injection as part of a programme to lose weight (Galil *et al.* 1999). These contaminated substances have led to localized skin and soft tissue abscesses. The solutions themselves may be contaminated, and needles that are re-used or rinsed in tap water have also been implicated (Nolan *et al.* 1991). Contaminated multiple-use vials are especially suspect if there is more than one similar case. Self-administered cutaneous injections (i.e. patients with diabetes) can also present with PEM skin abscess. One diabetic patient developed *M. smegmatis* from insulin injections self-administered immediately after sitting in a hot tub that probably was contaminated with mycobacteria (De Groote, unpublished observation). A report of an outbreak of *M. abscessus* in an alternative medicine practice involving young Hispanic females undergoing cosmetic procedures with non-traditional agents including avocado products (D. Ashford, CDC, unpublished) is an example of this emerging problem. A case of *M. chelonae* infection as a result of acupuncture needles has been reported (Woo *et al.* 2001). This category of infections is likely to increase with enhanced utilization of alternative and complementary medical practitioners.

Often the diagnosis is not immediately obvious and obtaining proper cultures is delayed. It is not infrequent that a patient presents with an indolent inflammatory lesion that is unresponsive to antimicrobials. Administration of inappropriate antibiotics or corticosteroids can delay the diagnosis and may be misleading because it can temporarily provide some clinical relief and improvement. Because they are anti-inflammatory, corticosteroids can also worsen disease (Kermosh *et al.* 1979; Hellinger *et al.* 1995; Zenone *et al.* 1999). A heightened awareness, especially if there is a history of an injection, will help to ensure an accurate and timely diagnosis. Symptoms after injection can be very indolent with incubation period of 7-120 days. The lesions are reddened and vary in consistency. There is often some mild discomfort from the lesions, but in rare cases, the pain can be more severe. Antimicrobial agents and occasionally surgical incision and drainage are indicated.

10.1.2.4 Cosmetic industry

While strictly not an invasive device, an outbreak of RGM involving a whirlpool footbath used in a pedicure salon is presented as an example of contaminated equipment that can result in a large community outbreak (Winthrop *et al.* 2002). The outbreak involved over 100 pedicure salon customers who developed furunculosis in the lower extremity. Patrons routinely underwent a period of soaking the lower extremity in the bath prior to the pedicure. A major risk factor for acquisition of infection was shaving the legs prior to the footbath treatment. Shaving probably caused micro-abrasions that provided the organism with a means of access into the skin. Multiple species of RGM were isolated from the footbath and the skin lesions of affected patients. Strain typing of *M. fortuitum* obtained from selected samples of the footbaths and patients revealed identical patterns. In this outbreak it was concluded that the contamination resulted from the municipal water which supplied the footbath. It was speculated that further growth on sloughed skin and other organic debris present in the bath resulted in high numbers of organisms. Infections ranged from mild to severe. Most patients were treated with antimicrobials and all resolved the infection, although some were left with scars.

Cases of PEM infections after body piercing have been documented (Jacobs *et al.* 2002). For example, one healthy young female presented with a breast mass that resulted from a nipple piercing carried out 10 months previously. On tissue pathology, no acid-fast organisms were seen in the granulomatous inflammation, but *M. abscessus/ chelonae* was isolated in culture (Trupiano *et al.* 2001).

10.1.2.5 Miscellaneous medical and surgical procedures

Post-surgical infections with PEM have been reported in many settings (Robicsek *et al.* 1977, 1978, 1988; Hoffman *et al.* 1981; Safranek *et al.* 1987; Wallace *et al.* 1989; Jarvis 1991; Grange 1992; Syed *et al.* 1997). They typically arise from solutions or instruments that have been inadequately sterilized (Phillips & von Reyn 2001). Mediastinitis and sternal wound infections due to *M. fortuitum* or *M. chelonae* have been reported after cardiothoracic surgery (Hoffman *et al.* 1981; Kuritsky *et al.* 1983). One outbreak was traced to contaminated iced cardioplegic solution used during the procedures. Prosthetic or implantable material such as porcine heart valves have been contaminated with RGM and are associated with a particularly bad outcome (Robicsek *et al.* 1988; Grange 1992).

An outbreak of otitis media in children has been reported after placement of tympanic membrane tubes. Infection due to *M. chelonae* was felt to have resulted by transmission between patients from contaminated instruments (Lowry *et al.* 1988).

Spinal infections have been reported after epidural injections and also after spinal surgery. A large outbreak after discovertebral surgery in France involving 58 patients in a single hospital in Paris occurred over a period of more than 10 years. This was a result of chronic contamination of the hospital water supply with *M. xenopi* (Astagneau *et al.* 2001).

An emerging scenario involves the development of mycobacterial infection after laser vision correction surgery. One example is keratitis after *in situ* keratomileusis surgery (Frueh *et al.* 2000; Chandra *et al.* 2001; Garg *et al.* 2001; Solomon *et al.* 2001; Alvarenga *et al.* 2002; Fulcher *et al.* 2002; Giaconi *et al.* 2002; Holmes *et al.* 2002; Maloney, 2002; Pushker *et al.* 2002; Seo *et al.* 2002). Even though mycobacteria are presumably of low virulence, a sight-threatening infection can occur (Bullington *et al.* 1992). A typical case is one of indolent, slowly progressive corneal disease. Reports of crystalline opacities seen in the corneal stroma are thought to be highly suggestive of mycobacterial infection (Alvarenga *et al.* 2002). Inflammation is rare. Whether the absence of inflammatory changes is due to a particular feature of the mycobacterial organisms causing the corneal infections or the use of topical corticosteroids is uncertain.

Other surgical procedures reported to result in PEM infection include augmentation mammoplasty, liposuction, and other plastic surgical procedures (Murillo *et al.* 2000). *M. abscessus, M. chelonae* and *M. fortuitum* infection after such procedures have all been described. In liposuction, for example, the cannulae used for tissue suctioning can become contaminated, with infected tracts appearing in areas where the cannulae were introduced (Murillo *et al.* 2000). Clinically, the patients present with localized abscesses including microabscess formation, purulent drainage and fistulae formation. Cellulitis has also been reported. Fever can be present or absent.

Many different types of aqueous solutions have been reported as the source of infection (epidural injections, steroids, tap water). Wound infections have been reported post surgery after using contaminated gentian violet skin marking solution. This outbreak of wound infections was caused by *M. abscessus,* and the organism was recovered from the solution (Safranek *et al.* 1987). In addition to solutions, instrumentation and implants that have been implicated include lacrimal duct probes, tympanostomy tubes, epidural catheters and graft materials. The potential for contamination exists in a multitude of surgical procedures (Wallace *et al.* 1998; Phillips & von Reyn 2001).

These infections can be very difficult to eradicate. They require cooperative management between those with infectious disease expertise and surgical colleagues to ensure adequate debridement and appropriate antimicrobial therapy. All surgical instruments should be sterilized according to manufacturer regulations, conform to standard practice, and should be overseen by the hospital infection control committee. If an outbreak is confirmed in the US, related to a device or product, the incident is reported to the MedWatch programme at the Food and Drug Administration (http://www.fda.gov).

10.1.3 Selected microbial factors

For reasons that are not entirely clear, RGM species, including *M. abscessus, M. chelonae* and *M. fortuitum* have a propensity for iatrogenic infections. As mentioned above, they account for most infections reported with post injection infection and wound infection post-procedures. Potential explanations include the ability of these organisms to adapt to a low nutrient tap water environment, to form biofilms as a successful mode of growth, and their relative resistance to standard disinfection.

10.1.3.1 The role of disinfectant resistance

Contamination of hospital water has been recognized for many years, especially hot water systems (du Moulin *et al.* 1988; El Sahly *et al.* 2002; Fujita *et al.* 2002; Labombardi *et al.* 2002; Zhang *et al.* 2002). These waters can become a source of infection for patients. Rapidly growing and other mycobacteria are difficult to eradicate with common decontamination practices and can continue to exist in water pipes in hospitals and operating rooms (Lowry *et al.* 1990; Wenger *et al.* 1990). Most PEM are relatively resistant to standard disinfectants such as benzalkonium chloride, CPC and quaternary ammonium compounds, chlorine, glutaraldehyde, formaldehyde, heavy metals, alcohols, peroxides and iodophores (Russell 1996; Griffiths *et al.* 1997, 1999; Manzoor *et al*. 1999; Falkinham 2002). A thorough review of this topic is presented in recent papers (Wallace *et al.* 1998; Phillips & von Reyn 2001), and in chapter 11. At their recommended concentrations for use, however, many of these agents can be mycobactericidal. Even when adequate disinfection has occurred, regrowth of the organism could again result in human infection. An interesting idea has been put forward by Falkinham that, given the relative resistance of certain PEM to disinfection, it survives relative to its competitors and is able to acquire nutrients that it would not otherwise have access to in the absence of disinfectants. It is important to not reuse disinfectants.

10.1.3.2 The role of biofilms

A biofilm is a consortium of microbes that adhere to either abiotic or biotic surfaces. Rapidly growing species are especially adept at forming biofilms (Hall-Stoodley & Lappin-Scott 1998). They produce an extracellular matrix that makes them more difficult to eradicate compared to their planktonic counterparts. Different species vary in their susceptibility to biocides (e.g. *M. marinum* biofilm cells are more sensitive, and *M. fortuitum* is more resistant to biocides than their single cell forms) dictating that each needs to be studied and considered separately (Bardouniotis *et al.* 2003). Some of the PEM are thermotolerant and likely also to form biofilms, especially *M. avium* and *M. xenopi*, which can grow at temperatures around 45 ^{o}C (Falkinham 2002). In addition, RGM can readily form biofilms on silastic rubber, which is a common material used in medial instruments. NTM has been recovered from dental instruments at 400 times the concentration in drinking-water (Schulze-Röbbecke *et al.* 1995).

10.1.3.3 Role of water temperature

Multiple mycobacterial species have been described in piped water systems. *M. avium* and *M. xenopi* prefer hot water systems and can grow at temperatures around 45 ^{o}C (Falkinham 2002). In hot water systems several of these thermophilic mycobacteria can survive and have been reported to cause outbreaks or pseudo-outbreaks (du Moulin *et al.* 1988). In some cases temperatures of up to 70 ^{o}C are required to inhibit the organism. However, this high water temperature creates a risk of scalding injury. In cold water systems, *M. kansasii, M. gordonae, M. fortuitum, M. chelonae, M. abscessus* and *M. mucogenicum* have been found. Since cold and hot water temperatures exist in hospital settings, it is not surprising to see an array of mycobacterial species responsible for nosocomial infection. As an example of the remarkable spectrum of persistence, mycobacterial organisms have been isolated from taps, numerous contaminated instruments, solutions, showerheads and a hospital ice machine (du Moulin *et al.* 1988; Labombardi *et al.* 2002).

10.2 OVERALL BURDEN OF DISEASE

In many countries precise incidence and prevalence data is not available. Several laboratory surveys have been conducted in the United States and Europe. However, the limitation of these surveys is that most are culture-based, not patient-based, so it is difficult to know if each isolate represents a single individual occurrence. Since 1993, there has been a reporting system for State Health Department Laboratories, which has yielded important insights (Bean *et al.* 1992). Short of a standardized, mandatory reporting of outbreaks and individual case infections, we are often left with anecdotal reports. Despite such limitations, infection due to contaminated fluids and devices continue to be reported from all across the globe. Nevertheless, it is likely that the incidence of disease is underreported. In areas of the world where there is inadequate mycobacteriology laboratory support the true incidence may be even higher than is currently recognized.

Care providers make frequent changes to their practices and it is likely that alternative medicines and traditional medical practices will become more popular among their patients. Patients are making more frequent visits to providers of alternative medicine and placing more reliance on outpatient procedures, including those that are done outside a large hospital facility. Some of these centres are not routinely monitored by the infection control committees or equivalent oversight bodies. If these centres use less rigorous disinfection protocols, the incidence could become even higher. As advances in medical technology occur and as the population of immunosuppressed patient continues to increase there will undoubtedly be more cases reported.

10.3 DISTRIBUTION

Information regarding the distribution of infection is difficult to obtain. An analysis of data from the United States Emerging Infectious Diseases Network relating to RGM infections showed that invasive infections have been reported from all regions of the country (De Groote *et al.* 2002). RGM infection associated with medical procedures was the most common predisposing condition for infection. Given the ubiquity of these environmental pathogens and their relative resistance to disinfectants it is not surprising to find such outbreaks scattered around the globe. Disease has also been reported from Europe, Africa, Central America, Australia and Asia.

10.4 DESCRIPTIVE EPIDEMIOLOGY

Males and females appear to be equally susceptible to these infections. However, in adrenal cortex injection infections and pedicure salon infections the majority of patients are females, reflecting the group who are most likely to seek out such treatments. In other outbreaks such as post-surgical infections, there is no race or gender bias reported. There has been no person-to-person transmission demonstrated for these infections.

10.5 RISK FACTORS

In the majority of cases no high-risk group has been identified and most people are healthy. Presumably all people exposed to contaminated solutions or equipment are at risk, but the attack rate is not always the majority and the reasons for this are not completely known (Astagneau *et al.* 2001). However, underlying disease or immunosuppression would predispose the patient to more severe disease. Any exposure to contaminated solutions, medical or surgical devices, or other equipment is a risk, especially if there is disruption of defensive barriers caused by invasive procedures or microtrauma (Winthrop *et al.* 2002). Certainly those of increasing age, underlying immunosuppression and those who simply have more contact with the health care setting are more likely to become infected. However, many of the examples presented in this chapter include perfectly healthy young individuals. Unifying problems with specific disinfectants, instruments, etc., has not been uniformly observed.

10.6 CAUSALITY AND ASSOCIATED MICROBES

The microorganisms that are associated with infection are numerous and our understanding of disease mechanisms is likely to improve with better tools for species identification and molecular epidemiology. The RGM have been implicated most often. *M. abscessus, M. chelonae* and *M. fortuitum* appear to have the greatest propensity for iatrogenic infections related to contaminated devices or solutions. *M. avium, M. mucogenicum* and *M. xenopi* are also common isolates in nosocomial disease. New species are being described all the time. A recent paper by Wilson *et al*. (2001) demonstrates that a newly described rapidly growing species, *M. immunogenicum* is responsible for a significant percentage of pseudo-outbreaks. *M. simiae, M. terrae, M. haemophilum, M. genavense* and *M. malmoense* are also capable of survival in water and have the potential to cause nosocomial outbreaks. It is important to point out that sometimes laboratories do not differentiate between the very closely related *M. chelonae* and *M. abscessus* making species-specific conclusions somewhat difficult (Wallace *et al.* 1997).

10.7 KEY RESEARCH ISSUES

In the future, timely recognition and reporting of real infections or pseudo-outbreaks will continue to be important. Updating and adding new surveillance methods within institutions will be important. Good communication between laboratory workers, clinicians and infection control practitioners will be a significant contribution to the care of our patients. With more PEM species described all the time, the laboratory and clinicians will need to be ever diligent, and incorporate accurate species identification into the routine workload in the laboratory. If such capabilities are not present in the laboratory where the infections occur, sending the isolate to a reference facility for identification and susceptibility testing may be indicated. Also, an enhanced role for strain typing in outbreak investigation will be important to track epidemics, common source exposures, and “pseudo-infections”. If feasible, setting up a national and possibly an international cooperative system for reporting and tracking will be important for outbreak investigation. Investigations into the relative virulence of the organisms responsible for outbreaks should be carried out. Toward this end, strain collections should be maintained, so that in the future they may help to advance our understanding of such infections.

Studies into the dose response will be important when setting guidelines for standard disinfection (i.e. what is an acceptable contamination level to prevent infections). With this in mind, proper protocols for disinfection of instrumentation are very important. Easier and more effective sterilization solutions should be investigated, as well as more attention to proper training of personnel involved in instrument decontamination and reprocessing. Protocols for proper disinfection of equipment outside of the hospital setting are important (e.g. nail salon whirlpool baths). A greater understanding of the role of biofilms in and on devices and how to perform efficient eradication of biofilm cells will be paramount.