Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Chapter 6

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History of infection prevention and control

In the United States, the hospital discipline of infection control was established in the 1950s in response to a nationwide epidemic of nosocomial *Staphylococcus aureus* and the recognition of the need for nosocomial infection surveillance.[1] As a concept, however, the epidemiology and prevention of infection has its roots in a time prior to the understanding of the germ theory of disease. In 1846 Semmelweis, a Hungarian physician, noted that the mortality from childbed fever among women who had babies delivered by midwives was lower than among mothers with babies delivered by physicians. After in-depth analysis of differences between the groups, Semmelweis concluded that the high rate of childbed fever was caused by cadaverous materials on the hands of medical students who came to the obstetric clinic directly from the autopsy chamber. A policy of hand washing in chlorinated lime solution before maternal contact was instituted, and the mortality rate among mothers cared for by physicians dropped.[2] John Snow, a British physician, applied statistics and epidemiologic approaches to determine and eradicate the source of a cholera outbreak in 1854 in London. The theories underlying the findings of both Semmelweis and Snow – that disease could be spread by hand contamination and fecal–oral transmission – were soundly rejected by the medical community in favor of the miasma or 'bad air' theory of disease causation. These two examples highlight not only some of the conceptual framework for medical epidemiology and infection control but also some of the challenges that face public health and infection control practitioners.

TRENDS AND COMPLEXITY OF CURRENT HEALTH CARE IN DEVELOPED COUNTRIES

Health-care-associated infections (HAIs) are a significant cause of morbidity and mortality in developed countries. It is estimated that between 5% and 10% of patients admitted to acute care hospitals acquire one or more infections. Using a multistep approach and three data sources, the Division of Healthcare Quality Promotion of the Centers for Disease Control and Prevention (CDC) estimated that the number of HAIs in US hospitals in 2002 was approximately 1.7 million. Thirty-two percent of all HAIs were urinary tract infections, 22% surgical site infections, 15% pneumonia and 14% bloodstream infections. The estimated number of deaths associated with HAIs in US hospitals in this study was approximately 99 000. The total number of deaths associated with HAIs by major site was highest for pneumonia (35 967) and bloodstream infection (30 655). The additional cost of patient care attributable to these infections was estimated to be $4.5–5.7 billion per year.[3,4] In the UK in 2000, it was estimated that 100 000 cases of hospital-acquired infection occurred in England with 5000 deaths, costing the National Health Services (NHS) as much as £1bn ($1.4bn) a year.[5]

In addition to the challenges posed by the numbers of HAIs, the complexity of these HAIs and the measures required to prevent them have become more complicated. Additional challenges that come under the umbrella of hospital infection prevention also continue to be identified. Such challenges include:

- controlling antimicrobial resistance and spread of multidrug-resistant pathogens;
- addressing emerging infections such as severe acute respiratory syndrome (SARS) and avian flu;
- providing constantly updated data for an increasingly sophisticated public;
- attempting to modernize surveillance and reporting systems, often with limited resources available;
- addressing the infectious consequences of ever more complicated medical procedures, with special populations such as highly immunosuppressed transplant patients, gene therapy, xenotransplantation; and
- maintaining a safe workplace in an ever more complex medical system.

ORGANIZATION OF INFECTION PREVENTION AND CONTROL

Infection prevention and control is a discipline in which epidemiologic and statistical principles are used in order to prevent or control the incidence and prevalence of infection. The primary role of an infection prevention and control program (IPCP) is to reduce the risk of acquisition of hospital-acquired infection, thereby protecting both patients and staff from adverse infection-related outcomes. In order to ensure that an infection control program is successful, the appropriate infrastructure and institutional support, both material and administrative, needs to be made available to hospital epidemiology staff.

The functions and structure of a hospital epidemiology program may vary between institutions. The critical functions that often fall under the umbrella of a hospital epidemiology program are listed in Table 6.1.[1,6,7]

Managing critical data and information

Developing, implementing and monitoring surveillance based upon an institution-specific risk assessment

The importance of surveillance as a part of hospital infection control programs was established by the 1976 Study on the Efficacy of Nosocomial Infection Control (SENIC). SENIC found that hospitals reduced their nosocomial infection rates by about 32% if their surveillance and control plan included the following components:

Table 6.1 Critical functions often managed by hospital epidemiology

- Managing critical data and information
  - Developing, implementing and monitoring surveillance based upon an institution-specific risk assessment
  - Reporting of surveillance results/infection rates to monitoring services, administration and regulatory bodies
- Developing and implementing policies and procedures to prevent or minimize infection risk (e.g. isolation precaution policies, etc.)
- Intervening to prevent disease transmission
  - Outbreak investigation and control
  - Education and training
- Collaborating with other programs to achieve common goals
  - Occupational and employee health
    - Postexposure prophylaxis in the health-care setting
    - Management of the infected health-care worker
  - Environmental health and safety
    - Construction infection control
    - Infectious waste management
    - Environmental cleaning service
    - Air and water handling
    - Respiratory protection
  - Disinfection and sterilization
  - Microbiology laboratory
    - Monitoring for isolation of sentinel organisms
    - Monitoring antibiotic resistance profiles
  - Pharmacy and therapeutics
    - Antibiotic utilization
  - Safety, quality and public reporting
  - Disaster preparedness committee
    - Bioterrorism preparedness

appropriate emphasis on surveillance activities and control efforts; appropriate staffing of the infection control program; and, for surgical site infections, feedback of wound infection rates to practicing surgeons.[8] Surveillance for nosocomial infection is critical for infection control programs, but must be paired with appropriate risk assessment at any given institution or setting, assessment of the need for intervention and strategies for implementation of control measures.[9]

Hospital infection surveillance should be a systematic, ongoing process to monitor identifiable events (such as surgical site infection) in a defined population. This will initially require a risk stratification to determine what the critical targets of surveillance should be. In the USA and other developed countries, many surveillance activities will be mandated by local or federal authorities, such as the Centers for Disease Control and Prevention (CDC), the American Hospital Association and the regulatory efforts of the Joint Commission (TJC). Other surveillance activities will vary, based on an understanding of the epidemiology and risk at a particular institution. For instance, surveillance for invasive aspergillosis in an institution undergoing new construction and with a large compromised host population might be rated a higher priority than the long-term monitoring of *Legionella* in an institution where *Legionella* has not been identified for years. Each hospital must tailor its surveillance activities based on risk assessment of the population as well as the available resources within the infection control team and hospital. Such 'targeted' surveillance should be defined for each hospital.[10]

A number of components are critical for an effective surveillance system.

1. Clear and uniform definitions of the infection or other outcome should be developed. Often, standardized definitions such as those defined by the CDC are the most useful so that comparisons can be made both within the system and with other institutions.[11]
2. Surveillance should be an active process that includes review of microbiologic data, clinical and nursing records, pharmacologic and pathologic data, readmission and reoperation data following surgery for selected procedures, etc. These data are made more easily accessible by computer-based patient records and other electronic systems for data retrieval and coordination. Indeed, automated surveillance systems for infection control may provide a sensitive, specific, time-efficient and cost-effective mechanism for surveillance in many institutions.[12,13] The surveillance methodology should rely on metrics that are objective, standardized and risk adjusted. Case validation by the practitioners of the procedural area under evaluation should be avoided; in this setting the process may be prone to bias and lose objectivity, especially if financial incentives are involved. On the other hand, periodic review of the case definitions and feedback on the surveillance should include members of the practice team in order to provide insights not necessarily within the skill set of the infection control team and to devise corrective quality improvement actions adapted to that specific practice.
3. Whatever the system of surveillance is, both numerator and denominator data must be available for review. For instance, central line-associated bloodstream infections (CLABSI) are generally expressed as number of CLABSI/number of central line days × 1000. This allows the surveillance to be expressed as a rate such that trends can be tracked and compared within and between institutions.[14]
4. Appropriate benchmarking should be sought. Increasingly, health-care systems are being asked to compare their rates of events to other institutions. In the USA between 1992 and 2004 the National Nosocomial Infections Surveillance (NNIS) System collected data regarding targeted infections from participating tertiary care hospitals; this system was reorganized in 2005 under the National Health and Safety Network (NHSN). Data provided from this network can be used for benchmarking infections between hospitals. However, although standardized data may be useful for identifying areas deserving more intensive interventions within a given institution, differences in hospital size, patient mix and risk adjustment introduce complexity when comparing rates across the spectrum from smaller community hospitals to tertiary care and specialty hospitals.[15,16]
5. Reports describing the surveillance activities and findings should be prepared (using appropriate statistical analysis) and distributed to the appropriate groups, which should include the services associated with the monitoring process and the administrative liaison affiliated with the service.
6. After feedback to the particular service is provided, that service (generally in conjunction with the IPCP) should develop an action plan for process improvement, if needed. This plan, after approval by all relevant parties, should be implemented. If possible, the next surveillance cycle should be used to evaluate if improvements occurred associated with the action plan.

Develop and implement policies and procedures to prevent or minimize infection risk (e.g. isolation precaution policies, etc.)

Another critical role for the infection control unit within a health-care facility is to develop and implement evidence-based policies and procedures that are aimed at preventing HAIs. These policies need to be practicable and available as a written or online resource to users. In general, these policies will be adapted to institutional needs using resources available from the following:

- relevant published literature;
- Healthcare Infection Control Practices Advisory Committee (HICPAC), Society for Healthcare Epidemiology of America (SHEA) and Association for Professionals in Infection Control and Epidemiology (APIC) guidelines;
- professional practice guidelines;
- state and federal regulatory bodies;
- Occupational Safety and Health Administration (OSHA);
- Environmental Protection Agency (EPA), etc.

Institutional policies and procedures should be regularly reviewed and updated.

Intervene to prevent disease transmission

Outbreak investigation and control

An outbreak can be defined as an increase in the incidence of a disease/infection above the background rate in a given population. In a health-care setting, the 'background' rate may be provided by ongoing surveillance activities as described above. In the health-care setting, prompt identification of an outbreak and intervention on the part of the IPCP is critical in preventing adverse outcomes and accruing costs. Whether the outbreak under investigation is SARS or methicillin-resistant *Staphylococcus aureus* (MRSA), or an increase in the baseline rate of hip prosthesis infection, the same basic components of outbreak investigation are followed, as outlined in Table 6.2.[17,18] An example of a functional surveillance program laying the groundwork for an outbreak investigation would be as follows:

> *Hospital X performs a large number of hip joint replacements, and this is a procedure monitored by IPCP (Fig. 6.1). Standardized NHSN criteria are used to define surgical site infections (SSIs) for hip prosthesis. Hospital X's surveillance for hip prosthesis involves review of all microbiology data for all hip replacements done at the institution plus readmission data after hip replacement, as well as antibiotic utilization data for patients with hip replacement. Charts are then reviewed to evaluate if a hip infection occurred and at what level (superficial, deep or organ space, by NHSN criteria).*
>
> *It is noted that in July, there was a large increase in the rate of hip infections that was two standard deviations above the institutional mean and over the 75th percentile for NHSN hip infection rate. Charts are reviewed to confirm, and an epidemic curve is generated suggesting that the increase in infection started in mid July. This information is reported back to Orthopedics as well as Hospital Administration. Patient data review indicates that the infections are with multiple different organisms, with procedures performed with multiple different surgeries in different ORs.*
>
> *It is noted by one of the health-care workers interviewed that a new surgical scrub was put into place in late June in the orthopedic ORs, and the concern is raised that the increased infection rate may be associated with this. A review reveals that the new scrub is not being used per recommendations. A plan to develop and implement an educational module regarding surgical scrub is enacted, and by September infection rates in this procedure are back to baseline.*

The role of the microbiology laboratory

The microbiology laboratory plays a critical role in both surveillance and outbreak investigation. Traditional roles have included detection, identification and susceptibility testing of microbes causing hospital infection. Rapid detection and reporting of key organisms with high potential to cause outbreaks such as *Clostridium difficile* or *Mycobacterium tuberculosis* are critical components of infection prevention, leading to appropriate implementation of control measures and reducing the risk of secondary spread.[19] For instance, at our institution, when a *C. difficile* toxin is identified in the microbiology laboratory, a report goes out simultaneously to the ward where the patient resides, so that the appropriate isolation can be ensured, including signage; to the infection control group to ensure that the isolation is logged in centrally; and to environmental services to ensure use of bleach cleaning for that room.

The development of an institutional antibiogram is a critical function that often results from collaboration between different groups, as will be discussed below.

Understanding pathogen distribution and relatedness in the hospital is an important component of both surveillance and outbreak investigation. Typing of microbial pathogens can help determine if isolates that appear to be epidemiologically linked are in fact genetically related and thus likely to have originated from the same strain. Typing can help distinguish extent and pattern of spread of 'epidemic' clones; it can also help assess the source of an outbreak (environmental, personnel, etc.). The incorporation of molecular typing methodologies along with traditional epidemiologic surveillance has been shown in a number of studies to reduce the number of HAIs and to be cost-effective.[20] Typing can be done using phenotypic methods (such as biotyping and serotyping) or genotypic/molecular methods, such as pulsed field gel electrophoresis, plasmid analysis, southern blotting or various forms of polymerase chain reaction (PCR). Newer modalities, such as sequence-based molecular epidemiologic analysis (SLST or MLST), have been used for the evaluation and typing of some pathogens.

Table 6.2 Steps in the investigation and control of a potential outbreak

1. Establish case definition(s).
2. Confirm that the cases are 'real' (case confirmation).
3. Establish the background rate of disease (in order to confirm the outbreak and determine the scope of the outbreak geographically and temporally).
4. Case finding.
5. Examine the descriptive epidemiology of the cases (e.g. define the age, sex, home/overseas travel, occupation, attendance at events) and plot an 'epidemic curve' of time of onset of disease.
6. Generate a hypothesis regarding the source and route of exposure.
7. Test the hypothesis by case control, cohort or intervention studies and by epidemiologic typing of representative samples if indicated and if possible.
8. Collect and test potential sources of infection such as environmental surfaces, patients, personnel, iv fluids, etc. as indicated; consider epidemiologic typing to establish an epidemiologic link to cases.
9. Devise and implement control measures.
10. Review results of investigation or report on ongoing investigations to administration and staff; consider consultation with local public health officials.
11. Follow-up surveillance to evaluate efficacy of control measures; generate reports for administration and staff.

Education and training

One of the most critical functions of the IPCP is to provide education and training. Education for health-care providers includes instruction on isolation precautions, aseptic practice, prevention of blood and body fluid exposures, and appropriate usage of personal protective equipment and safety devices. Teaching of policies and procedures should be simple, reproducible and, if possible, innovative (e.g. combinations of computer technology and live) in order to make an impact and reach the greatest number of health-care workers.

An important component of teaching involves the measurement and subsequent feedback of infection control data to the staff. As an example, performance and infection rate feedback in a neonatal unit has been effective in sustaining hand hygiene compliance improvement and in reducing infection risk in neonates.[21]

Collaboration with other programs to achieve common goals

Occupational and employee health

An active employee health service and IPCP collaboration is critical in the protection of health-care workers and the control of hospital-acquired infections. Joint objectives generally include:

- education of personnel about the principles and importance of infection control;
- prompt diagnosis and appropriate management of transmissible diseases in health-care workers, such as respiratory syncytial virus or pertussis;
- assessing and investigating potential exposures and outbreaks among personnel;

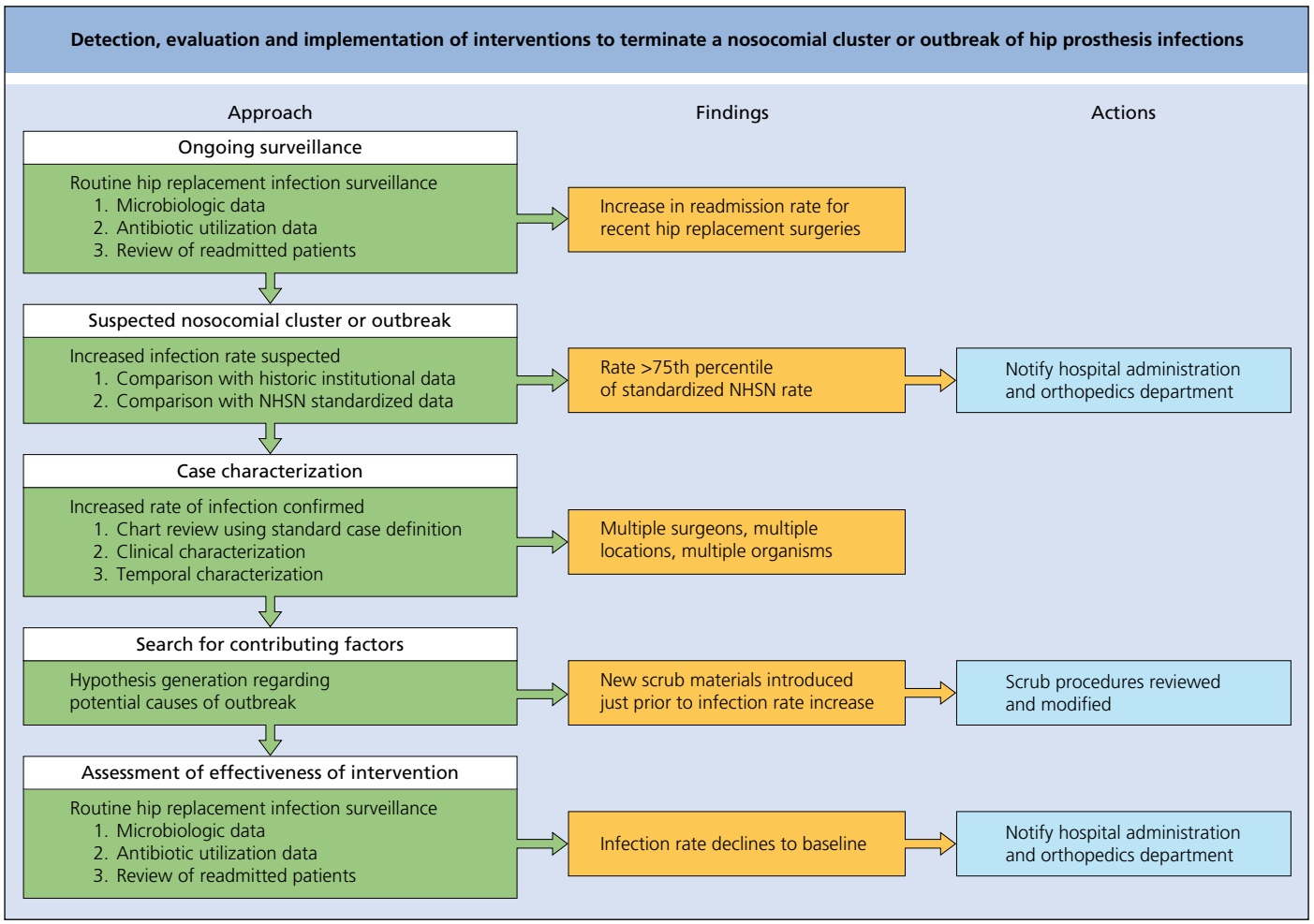

Fig. 6.1 Flow diagram of the detection, evaluation and implementation of interventions to terminate a nosocomial cluster or outbreak of hip prosthesis infections.

- identification and vaccination of workers susceptible to vaccine-preventable diseases;
- identifying work-related infection risks and instituting preventive measures; and
- surveillance of health-care workers for diseases such as tuberculosis.[22]

Detailed discussion of the role of employee health services is beyond the scope of this chapter. The CDC has published extensive guidelines and recommendations on immunization of health-care workers, occupational health guidelines and protection of health-care workers from blood-borne pathogens, including postexposure prophylaxis guidelines.[23–25] These are updated on a regular basis at http://www.cdc.gov.

Environmental health and safety and environmental services

The health-care facility environment is not commonly associated with disease transmission in competent hosts. Environmental Health and Safety and IPCP work together to ensure environmental safety and prevent exposure of patients and staff to environmental and airborne pathogens. The combination of infection control and environmental engineering strategies can help prevent such occurrences. These control measures include:

- adherence to ventilation standards for specialized care environments (e.g. airborne infection isolation rooms, protective environments or operating rooms) and to water-quality standards, including for hemodialysis;
- appropriate infectious waste management;
- appropriate use of cleaners and disinfectants; and
- appropriate use of precautions during construction.

Environmental Safety is often responsible, with Employee Health, for monitoring of pressure-negative airborne isolation rooms and N95 respirator fit testing.[26]

In this era of antibiotic resistant pathogens, the importance of environmental cleaning cannot be overstated. Environmental contamination of floors, beds, tables, faucets, doorknobs, blood pressure cuffs, thermometers, gowns, stethoscopes and computer terminals has all been well documented.[26,27] Among other factors associated with transmission, acquisition of drug-resistant organisms such as vancomycin-resistant *Enterococcus* (VRE) and MRSA may depend on room contamination, and the odds of acquiring antibiotic-resistant bacteria are increased by patient admission to a room previously occupied by a patient harboring the resistant organism.[27]

The cleaning and disinfection of all patient-care areas is important for frequently touched surfaces, especially those closest to the patient. Increased frequency of cleaning may be needed for compromised patients in a protective environment to minimize dust accumulation or in situations where environmental contamination is more likely (e.g. incontinent patients). During a suspected or proven outbreak where an environmental reservoir is suspected, cleaning procedures should be assessed and adherence should be monitored and reinforced.

In general, use of a US Environmental Protection Agency (EPA)-registered detergent/disinfectant (used according to the manufacturer's recommendations for amount, dilution and contact time) is sufficient

to remove pathogens from surfaces of rooms of colonized or infected individuals. Certain pathogens (e.g. rotavirus, noroviruses, *C. difficile*) may be resistant to some routinely used hospital disinfectants. Since levels of spore production for *C. difficile* may be increased when exposed to nonchlorine-based cleaning agents, and the spores are quite resistant to commonly used surface disinfectants, many investigators have recommended the use of a 1:10 dilution of 5.25% sodium hypochlorite (household bleach) and water for routine environmental disinfection of rooms of patients with *C. difficile*. Many institutions also recommend bleach cleaning when faced with outbreaks of norovirus or rotavirus as well.

General and specific recommendations for disinfection and sterilization may be found in the CDC's *Guidelines for Environmental Infection Control in Health-Care Facilities*.[26]

Disinfection and sterilization

Numerous reports detailing infection outbreaks secondary to faulty or inadequately disinfected medical instruments highlights the critical importance of sterilization and disinfection of such items.[28] IPCP collaborates with sterile processing to help prevent such problems.

Medical equipment and instruments/devices must be cleaned and maintained according to the manufacturers' instructions to prevent patient-to-patient transmission of infectious agents. Cleaning to remove organic material must always precede high-level disinfection (a process that eliminates many or all pathogenic organisms except bacterial spores) and sterilization (complete elimination or destruction of all microbial life). Disinfection may be accomplished using physical, chemical or physiochemical strategies to denature proteins. Sterilization is most commonly performed by steam/heat sterilization; ethylene oxide or hydrogen peroxide gas or prolonged liquid sterilization is also sometimes used.

Noncritical equipment, such as commodes, intravenous pumps and ventilators, computers used in patient care, etc., must be thoroughly cleaned and low-level disinfected before use on another patient. Providing patients who are on transmission-based precautions with dedicated noncritical medical equipment (e.g. stethoscope, blood pressure cuff, electronic thermometer) may prevent pathogen transmission. If this is not possible, disinfection after use is recommended. Semicritical items come in contact with mucous membranes and intact skin. This includes respiratory therapy and anesthesia equipment. High-level disinfection after cleaning is an appropriate standard of treatment for heat-sensitive, semicritical medical instruments (e.g. flexible, fiberoptic endoscopes).[28] This process inactivates all vegetative bacteria, mycobacteria, viruses, fungi and some bacterial spores. Critical items are objects that enter sterile tissue or the vascular system and pose a high risk of infection if contaminated with micro-organisms. This includes surgical instruments, various catheters, implants, etc. These items should either be purchased sterile or undergo heat-based sterilization after cleaning prior to patient use.

Information detailing the specific agents and processing used in disinfection and sterilization of equipment has been extensively reviewed elsewhere[26,29] and is beyond the scope of this chapter.

Pharmacy and therapeutics

Infection with antibiotic-resistant bacteria has been associated with increased morbidity, mortality and costs of health care. The goals of an effective antimicrobial stewardship program (ASP) include optimizing clinical outcomes while minimizing both toxicity associated with antibiotic use and the emergence of resistance, and reduction of health-care costs while maintaining or improving quality of care. The Infectious Diseases Society of America recommends a multidisciplinary approach to an ASP, with an infectious disease physician and a clinical pharmacist with infectious diseases training as core members of the team. Collaboration with a clinical microbiologist, an information systems specialist, an infection control professional and hospital epidemiologist is critical. Because such ASPs are important patient safety initiatives, they should function under the umbrella of quality assurance and patient safety and receive hospital administrative and fiscal support.[30–32] The ASP may also work with microbiology, pharmacy and the IPCP to create an institutional and unit-specific antibiogram, which can be accessible to all antibiotic prescribers in the health-care system.

Safety, quality and public reporting

Health-care-associated infections are one of the most common complications affecting hospitalized patients and are considered to be one of the more accurate indicators of the quality of patient care. Thus, the process and outcome data generated by infection control and other practitioners is relevant to patient safety and quality of care at the level of the institution, across institutions and extending to credentialing and governmental regulatory boards such as the Joint Commission (formerly JCAHO) and OSHA.[33] Ensuring the quality of care requires input from many groups, including infection control, quality improvement, risk safety and other committees.

Since 2002, seven states in the USA have enacted legislation that requires health-care organizations to publicly disclose HAI rates, and many others have submitted similar legislation for review. In the UK, mandatory health-care organization-based surveillance and public reporting of MRSA bloodstream infections have been in place since 2001.[34] Despite this movement toward public reporting of HAIs, little is known about its effectiveness in improving health-care performance. The CDC published consensus recommendations for public reporting in 2005,[35] which emphasize choosing standardized epidemiologic methodologies, promoting thoughtful choices of process and outcome measures depending on the nature of the institution, ensuring feedback to health-care providers and providing adequate infrastructure support. They recommended consideration of several process measures to evaluate, such as central line insertion practices, surgical antibiotic prophylaxis and influenza vaccination coverage of health-care workers and patients. The two outcome measures considered most appropriate for some hospitals to consider were rates of central line infections and surgical site infections for selected operations.

Disaster and bioterrorism preparedness

The anthrax letters in 2001, the SARS outbreak in 2002 and the continued concern about an avian influenza pandemic have all heightened awareness of the importance of disaster (natural or bioterrorism related) preparedness. Infection control plays an integral role in such a committee, in order to develop plans to minimize exposure of staff and the potential for nosocomial transmission (see isolation guidelines).

ISOLATION PRECAUTIONS

Standard and transmission-based precautions

Standard precautions

Standard precautions constitute a system of barrier precautions designed to be used by all health-care personnel on all patients, regardless of diagnosis, to reduce the risk of transmission of microorganisms from both recognized and unrecognized sources. These sources include blood, all body fluids, secretions, excretions, intact and non-intact skin, mucous membranes, equipment and environmental surfaces. Standard precautions are part of the standard of care for all patients.

The use of barriers is determined by the care provider's 'interaction' with the patient and the level of potential contact with body substances. It is the responsibility of the individual to comply with

all isolation precautions. Ongoing education concerning standard precaution principles will be given to newly hired employees involved directly or indirectly in patient care and as needed for dissemination of new information or for reinforcement of consistent practices.

Elements of standard precautions include hand hygiene and the banning of artificial nails. This is because most infections in the health-care environment are transmitted through contact with contaminated hands of the health-care workers. In 2002, the CDC published guidelines for hand hygiene.[36] These guidelines were adopted by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) in 2004 as part of the new National Patient Safety Goal 7A.[37]

Whenever possible and available, alcohol-based products will be the primary method used for decontaminating hands. Alcohol-based products are more effective for reducing microbes on the skin than soap or antimicrobial soaps and water, and should be the routine method for decontaminating hands if hands are not visibly soiled. Visibly soiled hands should be washed with soap or antimicrobial soap and water for 15 seconds.

Artificial nails are not permissible for personnel with any direct patient contact or with patient supplies, equipment or food. Studies have shown that long fingernails, both artificial and natural, are more likely than short natural nails to harbor bacteria that cause health-care acquired infections. The natural nails of health-care workers must be kept neatly manicured and should not extend 5 mm past the fingertips. Besides artificial nails, other nail enhancements must not be worn. This includes but is not limited to tips, wraps, appliqués, acrylics, gels and any additional items applied to the nail surface. Nail polish, provided it is not chipped, is the only enhancement that should be permitted on short natural nails.

Hand washing and hand antisepsis must occur before any direct patient contact and between patients, between tasks/procedures on the same patient to prevent cross-contamination of body sites, before donning gloves and performing an invasive procedure, after contact with patient's intact skin (e.g. taking a pulse, blood pressure or lifting a patient), after removing gloves or other personal protective equipment (PPE), after contact with body substances or articles/surfaces contaminated with body substances, and before preparing or eating food. Hands should be washed with soap and water after 7–10 applications of an alcohol-based product.

In the presence of *Clostridium* spores alcohol hand products should not be used because they are not killed by alcohol. In these situations, hands should be washed with soap and water. In addition, hands should be washed with soap and water after covering a sneeze, nose blowing or using the bathroom, all of which may contaminate and soil hands.

Gloves, masks, eye protection and face shields, aprons, gowns and other protective body equipment

Disposable gloves must be worn for anticipated contact with moist body substances, mucous membranes, tissue and non-intact skin of all patients, for contact with surfaces and articles visibly soiled or contaminated by body substances, during venous blood draws or other vascular access procedures (starting a venous line or blood draws) – in other words, in any situation where contamination of hands is anticipated. If the use of gloves is needed, gloves should be donned immediately prior to the task. Torn, punctured or otherwise damaged gloves must be replaced immediately. Gloves should be removed and disposed of after every task involving body substance contact and before leaving the bedside. Gloves should not be worn away from the bedside or laboratory bench, at the nursing station, to handle charts, when touching clean linen, clean equipment or patient care supplies, or in hallways or elevators. Hands have to be washed as soon as possible after glove removal or removal of other protective equipment. Gloves are not to be washed or decontaminated for reuse. An exception to this rule are utility gloves (not for direct patient care) used by house keepers, plumbers, etc. In this situation, gloves may be decontaminated and reused provided the integrity of the glove is not compromised.

Masks, in combination with eye protection devices (goggles or glasses with side shields) or chin-length face shields, should be worn during procedures or other close contact that are likely to generate droplets, spray or splash of body substances to prevent exposure to mucous membranes of the mouth, nose and eyes. This is particularly relevant in situations known to increase the risk of splash or splatter. Nonexhaustive examples are surgery, trauma care, newborn delivery, intubation and extubation, and suctioning, bronchoscopy and endoscopy, emptying bedpans and suction canisters into hopper or a toilet. Masks and eye protection devices should be used if caring for a coughing patient with suspected infection.

Plastic aprons or gowns and other protective body clothing are used during patient care procedures to prevent contamination of clothing and protect the skin of personnel from blood or body fluid exposure. In laboratory settings, laboratory coats should be used.

Additional protective equipment, including surgical caps, hoods and shoe covers or boots, may be used in surgical or autopsy areas. All protective body clothing should be removed immediately before leaving the work area.[26,36]

Transmission-based precautions

Transmission-based precautions are to be used in addition to standard precautions, in patients with documented or suspected infection or who are colonized with an organism that is transmissible and/or that is of epidemiologic significance. There are three types of transmission-based precautions: contact, droplet and airborne. A sign with the type of transmission-based precautions should be placed outside the room of the patient. In the USA, to comply with the Health Insurance Portability and Accountability Act (HIPAA), enacted by the US Congress in 1996, the name of the infecting organisms may *not* be written on the sign.

Waste disposal, spill management, linen and food trays should be handled in the same way for all patients, regardless of precaution category. Isolation trays are not required. After patient use, both linen and food trays are sent directly for cleaning and disinfection.[26,38,39]

Contact precautions

Contact precautions are initiated and maintained to interrupt the transmission of epidemiologically significant micro-organisms known to be spread by contact. These precautions are intended to reduce the colony count of bacteria on horizontal surfaces and in the immediate vicinity of the patient.

Contact precautions are to be instituted on a case-by-case basis at the discretion of the IPCP staff, infectious disease staff and/or medical or nursing staff. Examples of situations in which contact precautions are to be initiated are:

- when a patient is colonized and/or infected with multidrug-resistant organisms or organisms that are not treatable with the usual antibiotics, i.e. multidrug resistant Gram-negative rods, MRSA and VRE; and
- when a particular organism is identified as being potentially hazardous because of its pathogenicity, virulence or epidemiologic characteristics, e.g. rotavirus, *C. difficile*, *Salmonella* spp. and *Shigella* spp.

After hand hygiene, the key element of contact precautions is personal protective equipment (PPE). Upon entering the room of a patient placed in contact precautions, gown and gloves should be worn at a minimum. All PPE must be removed before leaving the room and hand hygiene must be done. Disposable gowns should be used at all times when entering the patient's room. Gowns may be worn one time only, and then should be disposed of in the regular (nonbiohazardous) waste before leaving the room.

The patient should be placed in a private room whenever possible. When a private room is not available, cohorting of patients with the same confirmed micro-organism (but with no other infection) is acceptable but IPCP should be notified. Because a negative air pressure room is not required, the door may remain open. When neither a private room is available nor cohorting is achievable, a space

separation of at least 3 feet should be present between the infected patient and other patients or visitors.

To minimize contamination, equipment should not be shared (unless it is disinfected properly) between patients. Examples of dedicated equipment include, but are not limited to, electronic thermometer, blood pressure cuff, manometer, stethoscope, intravenous pole, wheelchair or gurney. For pediatric patients with fecal pathogens such as VRE or rotavirus and who require weighing, a dedicated scale should be placed in the room.

In the USA, hospital staff should use an EPA-approved detergent/disinfectant to wipe down high-touch (e.g. door knobs, bed rails) and horizontal surfaces (e.g. over bed table, night stand) as needed and at a minimum once a day. This cleaning should also include the surfaces of electronic equipment, respiratory therapy equipment and other items that come in physical contact with the patient.

In critical care units or units where there is a high endemic rate of the organism the wipe down should be repeated as needed and at minimum each shift. Cleaning cloths used in the room should not be used to clean other patients' rooms and equipment.

Traffic into the patient's room should be limited only to essential staff/visitors. All visitors shall be instructed in proper hand hygiene technique. Visitors that participate in direct patient care shall be instructed in gowning and gloving, if the patient is incontinent, diapered or has diarrhea or a draining wound. Visitors may be referred to infection control or given written educational material.

Droplet precautions

Droplet precautions are required when a patient is suspected or known to have a serious illness transmitted by large particle droplets or direct contact with respiratory secretions. Droplets are often 30–50 microns in size compared to aerosolized droplet nuclei which are less than 5 microns in size. They are often generated by a patient coughing, sneezing or talking, or during suctioning while in close contact with the patient. Droplet precautions include the use of barriers to prevent contact between infectious droplets and the mucous membrane of health-care providers and visitors. Organisms and diseases that require droplet precautions are listed in Table 6.3. After hand hygiene, the key element of droplet precautions is the use of a surgical mask with face shield or 'surgical masks with eye protection' for face to face contact within three feet of a symptomatic patient to prevent self-inoculation. A surgical mask should be donned upon entering the room. All PPE must be removed before leaving the room and hand hygiene must be done.

The patient should be placed in a private room whenever possible. Because a negative air pressure room is not required, the door may remain open. When neither a private room is available nor cohorting is achievable, a space separation of at least 3 feet should be present between the infected patient and other patients or visitors.

Patient movement should be limited to essential needs outside of room. Patients must wear a surgical mask while outside of room.

Visitors should be limited. If visitors are susceptible, they must wear a surgical mask with face shield. Visitors with upper respiratory symptoms should not visit, but special consideration may be given to close family members. Nursing staff must instruct family and visitors to wash hands after contact with patient secretions or contact with the immediate patient environment.

Airborne precautions

Airborne precautions are required when a patient is suspected or known to have a disease transmitted by airborne droplet nuclei. The evaporated droplets contain micro-organisms that remain suspended in the air and can be widely dispersed by air currents within a room or over a long distance. The diseases or infections requiring airborne precautions are listed in Table 6.4.

Strict hand hygiene after contact with patient or items contaminated with respiratory secretions is required. An OSHA-approved mask for tuberculosis, such as the N95 respirator that has been fit-tested or a powered air purifying respirator (PAPR), should be worn by health-care personnel.

In the USA, the patient should be placed in a designated private room with monitored negative air pressure in relation to surrounding areas, with a minimum of 12 air exchanges per hour for new construction and renovation and six air exchanges per hour for existing facilities. Air from the room must be discharged directly outdoors or recirculated through high-efficiency particulate air (HEPA) filters before being circulated to other areas in the hospital. The windows and the door to the patient's room must remain closed except for entry/exit. The patient is confined to the room unless a procedure outside the room is necessary. The patient must wear a tight-fitting surgical mask outside of the room when transported to another department and personnel accompanying the patient should wear an N95 respirator or a PAPR during transport. Patients who are discharged from the hospital but are still considered contagious must be instructed about the need to wear a surgical mask. Visitors should be limited to strictly necessary at all times. Visitors must wear a surgical mask that is secured and snugly fitted. Symptomatic household or other contacts of the patient should not visit until medically cleared. If a symptomatic contact must visit, a mask must be donned before entering the hospital and worn continuously while in the facility.

Table 6.4 Organisms and conditions requiring airborne transmission-based precautions

- Hemorrhagic fevers
- Lassa fever
- Marburg virus disease
- Mycobacteria, tuberculous
- Pneumonia
- SARS (coronavirus)
- Smallpox (variola)
- Smallpox vaccine (vaccinia) from UCSF
- Tuberculosis (TB) including multidrug-resistant tuberculosis (MDR-TB)
- Vaccinia

Table 6.3 Organisms requiring droplet transmission-based precautions

- Adenovirus infection
- Anthrax pneumonia
- Coronavirus infection, respiratory
- Croup (laryngotracheobronchitis)
- Diphtheria
- Ebola virus infection
- German measles (rubella)
- Herpes simplex
- Influenza
- Meningitis
- Meningococcal pneumonia
- Meningococcemia
- Mumps (infectious parotitis)
- *Mycoplasma* infections
- Parainfluenza
- Parvovirus B19
- Pertussis (whooping cough)
- Plague
- Rabies
- Respiratory infectious disease, acute (if not covered elsewhere)
- Respiratory syncytial virus (RSV) infection
- Rhinovirus infection, respiratory
- Rubella (German measles)
- Scarlet fever
- Streptococcus: Group A
- Whooping cough (pertussis)

Table 6.5 Organisms requiring airborne non-acid-fast bacillus transmission-based precautions

- Chickenpox (varicella)
- Herpes zoster (disseminated)
- Herpes zoster (shingles in immunocompromised)
- Measles (rubeola)
- Rubeola (measles)
- Varicella (chickenpox)

Vacating an airborne precautions patient room

If the patient is being ruled out for TB or diagnosed with TB and was in a room without negative pressure, the room must not be used for 1 hour after the patient has been discharged. If the patient is being ruled out for TB or is diagnosed with TB and was in a negative-pressure room, the room must not be used for 30 minutes after the patient has been discharged.

Airborne precautions are also required for patients with diseases that are highly communicable by the airborne route. Examples of diseases that fall into this category of precaution are listed in Table 6.5. Nonimmune staff or visitors are not allowed to enter the patient's room or provide care. Non immunity means either no history of the specific disease or no vaccination against that disease. Respiratory protection is not needed for immune healthcare workers.

HEALTH-CARE AND DEVICE-ASSOCIATED INFECTIONS

Health-care-associated infections (HAIs) are infections occurring as a result of treatment and after exposure to the health-care environment. Infections can be acquired in all health-care settings – ambulatory, inpatient or during emergency room visits. Duration and frequency of exposure appear to increase the risk of infection as does decreased immunity due to co-morbidities or treatments. Infections are considered health-care associated if they manifest 48 hours or more after admission to a hospital, within 30 days of discharge from a health-care facility or if a patient visited an outpatient medical facility within the past 6–12 months.[40,41]

Health-care-associated infections include those with hospital onset, which are diagnosed 48 hours or more after admission to the facility and those diagnosed with community onset in patients with previous health-care encounters. In contrast, community-associated infections are defined as infections manifesting and diagnosed within 48 hours of admission in patients without any previous encounter with health care. In this section, we will address HAIs.

A recent CDC report updated previous estimates of HAIs and related deaths in US hospitals.[42] This report was based on HAI surveillance outcome data submitted to the NNIS System. The NNIS was a voluntary collaborative network of 283 US hospitals with 100 or more beds performing HAI surveillance using standardized CDC definitions and methodologies.[43]

This report estimated that, in 2002, HAI accounted for 1.7 million infections and that 98 987 deaths were either associated or were caused by HAI. While the majority (1 195 142) of HAIs in adults and children occurred outside of an intensive care unit (ICU), 394 288 (23%) were among patients in an ICU, which were also associated with the highest rates of associated deaths, and 52 328 infections were in newborns residing in either a high risk or a well baby nursery. The calculated rates were 9.3 infections per 1000 patient days or 4.5 infections per 100 admissions in 2002.

In addition to the deaths, the morbidity associated with HAI is significant. Studies have demonstrated that HAI results in excess length of stay (LOS) and costs.[6] For example, the mean attributable cost of a catheter-associated bloodstream infection was $18 432 with a mean excess LOS of 12 days.[6] The cumulative excess cost of HAI based on the 2002 CDC data was recently estimated at $4.5–6.5 billion.[44]

Table 6.6 Hospital-acquired infection (HAI) groups

- Device-related infections
  - Central line-associated bloodstream infection (CLABSI)
  - Ventilator-associated pneumonia (VAP)
  - Foley catheter urinary tract infection (UTI)
  - Infection of a prosthetic device
- Nondevice-related infections
  - Health-care-associated pneumonia (HAP) other than VAP
  - Infections due to multidrug-resistant organisms (MDRO)
    - *Clostridium difficile* colitis
    - Methicillin-resistant *Staphylococcus aureus* (MRSA)
    - Vancomycin-resistant *Enterococcus* (VRE)
    - Gram-negative rods with MDRO pattern or extended spectrum β-lactamase (ESBL) producing
- Procedure-related infections
  - Transplant-associated infections
  - Surgical site infections (SSI)
  - Bloodstream infections
  - Septicemia

Of all HAIs with an identifiable source, urinary tract infections (UTI) were the most frequent at 32%, followed by surgical site infections (SSI) at 22% (2% of all surgeries performed), pneumonias (PNA) at 15%, followed by bloodstream infections (BSI) at 14%. In the ICUs, 20–25% of all infections were caused by a UTI, PNA or a BSI. Outside the ICUs, 35% of HAIs were UTI, 11% were either BSI or PNA and 20% SSI. Thirty-six percent of deaths were attributed to PNA, 31% to BSI, 13% to UTI and 8% to SSI.[44]

Since the SENIC study,[45,46] HAI rates have decreased following implementation of infection prevention initiatives, but the proportion of truly preventable infections remains unclear. Based on a meta-analysis of infection control intervention studies, Harbarth and colleagues estimated this proportion to be between 10% and 70%, depending on preintervention HAI rate, hospital setting, study design, types of intervention and infection.[47] Interventions associated with the greatest reduction in a particular HAI have consistently been those aimed at prevention of central line-associated bloodstream infections (CLABSI).

HAIs can be divided into three broad, sometimes overlapping groups: device related, nondevice related and procedure related (Table 6.6).

Device-related HAI

Central line-associated bloodstream infections

Of all device-related HAIs, central line-associated bloodstream infections (CLABSI) are among the best studied. Vascular access is an essential part of care of patients and often extends beyond the inpatient stay into ambulatory care. Colonization of the device around the insertion site by bacteria or fungi on the skin are thought to constitute the most frequent first step of a central line infection. However, for invasion into the bloodstream to occur, bacteria have to adhere and incorporate into the biofilm,[48] multiply and then invade. Infection of the catheter hub and invasion of the lumen by coagulase-negative staphylococci is a known independent major risk factor for a central line infection that has been extensively researched.[49,50]

Bacteremia and septicemia secondary to contamination of the infusate occur much less frequently but are a recognized source of clusters or outbreaks of bloodstream infections with Gram-negative organisms.[51–53]

Risk factors for CLABSI include host factors (severity of illness, lack of skin integrity, type of immunosuppression), factors related to

the device (catheter insertion and maintenance processes, type and size of catheter, number of lumens, insertion site) and finally factors related to the purpose of the catheter (function of catheter, duration of placement).[54,55]

CLABSI prevention initiatives and surveillance have been standardized internationally, have well-established definitions and methodologies and therefore can be easily linked to measurable process and outcome measures. Unlike other quality and safety measures, surveillance of CLABSI has proven very helpful in the objective evaluation of the efficacy of performance improvement initiatives.[4,36,56–59]

The significant reductions in CLABSI following adherence to simple infection control principles and surveillance observed in the SENIC study in the late 1970s have continued, with median CLABSI rates in adult critical care units now ranging from 0.6 to 4.0 CLABSI per 1000 line days.[4,60]

In 2002, a working group published guidelines for the prevention of intravascular device-related bloodstream infections. Among the key evidence-based recommendations were education and standardization of insertion and maintenance processes, the use of maximal sterile barrier precautions upon insertion, chlorhexidine skin preparation, antiseptic/antibiotic-impregnated central venous catheters for short-term use only when rates of infection are high, avoiding routine replacement of the line for the purpose of line-infection prevention and using standardized process metrics to measure compliance with these guidelines. However, it was not until the Institute for Healthcare Improvement (IHI) launched the '100 Thousand Lives' central line-associated bloodstream infection prevention initiative that these recommendations were widely adopted by health-care facilities in the USA in the ICU setting (http://www.ihi.org/IHI/Programs/Campaign). Following implementation of the IHI campaign, CLABSI rates have seen substantial and sustained drops not only in the ICU setting but also on acute care wards.[4]

Ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) develops in 9–27% of ICU patients who require mechanical ventilation.[61–63] To meet the criteria for VAP, the pneumonia has to manifest more than 48 hours after intubation.

Ventilator-associated pneumonia significantly increases the time on ventilator, the overall costs of care ($23 000–40 000) and length of stay in and after discharge from the ICU. The average length of stay is increased by 9.6 days in a patient who develops VAP.[6,64,65]

Moreover, VAP is the leading cause of death among HAIs and is associated with a doubling of mortality compared to ventilated patients with similar characteristics who do not develop VAP.[42,64,66–70]

Infection control/infectious diseases and critical care specialists have not come to full agreement on the definitions and methodology to be used for the diagnosis of VAP.[71,72] Diagnosis of VAP is challenging because patients requiring mechanical ventilation have underlying complex diseases and co-morbidities with similar and confounding symptoms and signs.[19,73]

Despite the lack of an uncontested gold standard for the diagnosis of VAP, the American Thoracic Society and the Infectious Diseases Society of America published guidelines in 2005 recommending that clinical signs and quantitative cultures of the bronchoalveolar lavage (BAL) fluid be used to diagnose and treat VAP.[74] In 2006, a large randomized trial of 740 patients on mechanical ventilation in 28 ICUs across the USA and Canada did not demonstrate any difference in outcomes and in antibiotic use between quantitative cultures of BAL and nonquantitative cultures of the endotracheal aspirate.[72] The development of institution-specific collaborative guidelines for the diagnosis and management of VAP have led to shorter antibiotic duration and improved antibiotic choice without affecting overall mortality.[75]

VAP prevention process measures are now better established and many are supported by randomized controlled trials. Preventive strategies are aimed at avoiding unnecessary intubation, decreasing the duration of ventilation, preventing aspiration, and minimizing inoculation and colonization of the lower respiratory tract with mouth, gastrointestinal and upper respiratory tract flora. When implemented fully, these measures have resulted in better patient outcomes and are cost-effective.[76,77]

Multidrug-resistant organisms

Many organisms can be potentially acquired in the health-care setting (Table 6.7).

As care has evolved and become more complex, new antimicrobials have increased antibiotic pressure and thus selection of drug-resistant mutants. As a result, organisms resistant to multiple classes of drugs have emerged worldwide.[65] Infections due to multidrug-resistant organisms (MDRO) represent a significant proportion of the both the HAI burden and the day-to-day work of the IPCP. A nonexhaustive list of MDRO associated with HAI is shown in Table 6.8.

Guidelines for metrics to be used to monitor, and processes to prevent, MDRO in health-care settings have just been published.[78–80]

While resistance definitions for Gram-positive organisms are well established, there is no standard definition for most Gram-negative

Table 6.7 Organisms that may be acquired in the health-care setting

- *Acinetobacter* species
- Blood-borne pathogens
- *Burkholderia cepacia*
- Chickenpox (varicella)
- *Clostridium difficile*
- *Clostridium sordellii*
- Creutzfeldt–Jakob disease (CJD)
- Ebola (viral hemorrhagic fever)
- Gastrointestinal infections
- HIV/AIDs
- Influenza
- Methicillin-resistant *Staphylococcus aureus* (MRSA)
- Mumps
- Norovirus
- Parvovirus
- Poliovirus
- Rubella
- Severe acute respiratory syndrome (SARS)
- *Streptococcus pneumoniae* (drug resistant)
- Tuberculosis
- Vancomycin-intermediate *Staphylococcus aureus* (VISA)
- Vancomycin-resistant *Enterococcus* (VRE)

Table 6.8 Multidrug-resistant organisms acquired in the health-care setting

- Drug-resistant *Staphylococcus aureus*
  - Methicillin-resistant *Staphylococcus aureus* (MRSA)
    - Healthcare-associated: acquired in hospital or outpatient health-care facilities
    - Community-associated: acquired in the community
  - Vancomycin-intermediate/resistant *Staphylococcus aureus* (VISA/VRSA)
- Other drug-resistant organisms
  - Vancomycin-resistant *Enterococcus* (VRE)
  - Gram-negative organisms with multidrug resistance (MDR) or extended spectrum β-lactamase (ESBL) producing
  - MDR *Acinetobacter* spp.
  - Penicillin-resistant *Streptococcus pneumoniae*
  - MDR *Pseudomonas* spp.
  - MDR *Mycobacterium tuberculosis*
- *Clostridium difficile*-associated disease (CDAD)

MDRO.[81,82] For the purpose of this chapter, Gram-negative MDRO are defined as organisms resistant to one or more classes of antimicrobial agent.[83]

Infections caused by MDRO are particularly prevalent in intensive care, transplant and human immunodeficiency virus units, where patients are most susceptible to invasion by colonizing organisms because of the acuity of the primary disease and the comorbidities with multiple potential portals of entry and high exposure to broad-spectrum antibiotics. In this setting, the inability to perform personal hygiene to decrease the bioburden and the forced immobilization exponentially increase the potential for acquiring pathogens from the contaminated environment or the health-care worker's hands.

New guidelines for the prevention of MDRO in the health-care setting underscore the importance of well-described evidenced-based infection prevention measures and coordinated antimicrobial stewardship programs.[78]

REFERENCES

References for this chapter can be found online at http://www.expertconsult.com