7 Infection Prevention and Control: Applying Common Sense to Everyday Practice

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Background

The concept of infection control stemmed from observations that Dr. Ignaz Semmelweis made about 200 years ago in 1847 [1]. As the house staff officer in one of two obstetric clinics at the University of Vienna Allgemeines Krankenhaus (General Hospital), Semmelweis observed that patients in one clinic suffered much higher maternal mortality rates than the other, mostly attributed to puerperal fever. He noticed that doctors and medical students often went directly to the delivery suite after performing autopsies and had an odor on their hands despite handwashing with soap and water before entering the clinic. As a result, Semmelweis recommended that hands be scrubbed in a chlorinated lime solution before every patient contact and after leaving autopsies. Following the implementation of this measure, the mortality rate fell by 80% and remained low. Semmelweis is

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viewed as the founding father of hand hygiene; his intervention is also a model of how to use epidemiologically-driven strategies to prevent infection [1–3].

In the hundred years following Semmelweis' breakthrough, medicine and public health have significantly advanced to meet the needs of human beings. With the development of bacteriology, European discoveries such as Pasteur's rabies treatment, diphtheria antitoxin, and typhoid vaccination were quickly introduced into the United States. By World War II, emerging new drugs, especially penicillin, took modern medicine to a new level. The introduction of the polio vaccine in the 1950s, following a massive research effort, was a thrilling public and scientific event. Recent decades have also witnessed substantial progress in immunization and vaccination against influenza, measles, allergies, and other diseases.

These remarkable excitements have been mixed with sobering experiences. The epidemic of penicillin-resistant *Staphylococcus aureus* infections that occurred during the 1950s ravaged hospital nurseries. It captured the public's attention and highlighted the importance of implementing techniques to prevent infections in healthcare settings [4]. In the mid-twentieth century, some surgeons, microbiologists, and infectious disease physicians began to focus their studies on the epidemiology and control of infections in hospital settings. By the 1960s, hospital-based infection control efforts had been established in scattered hospitals throughout the United States. The number of hospitals with infection control programs increased substantially during the 1970s, and infection control programs were present in almost every US hospital by the early 1990s.

To date, although healthcare facilities and infection control experts have made significant progress in preventing some types of infections, there is still significant work that needs to occur. Each year in the United States, at least 2.8 million people contract an antibiotic-resistant infection, and more than 35,000 people die. It's important that each healthcare worker understands proper infection control procedures, for patient health and their own health.

The role of infection control and public health cannot be understated. We are currently the midst of a once-in-a-lifetime crisis. The COVID-19 pandemic has turned the lives of millions of people upside down and will likely have implications on our society as a whole in the coming years. The healthcare industry is no exception; COVID-19's infectivity and severity have increasingly brought infectious control measures under scrutiny and rocketed infection control practices into the public's eye. As infection control specialists, it is our duty now more than ever to ensure everyone, both inside and outside hospitals, correctly follows infection control measures.

Purpose of Infection Control

The purpose of an infection control program in a hospital is to prevent or stop the spread of infections among patients.

People often think that because hospitals cure illnesses and make people feel better, they are safe places. It's quite the opposite: hospitals are very dangerous *because* they cure illnesses and make people feel better. When a person feels ill and walks into a hospital seeking medical care, they do not know what disease they have nor its infectivity. Unless hospitals put infection control and other safety measures in place, being in a hospital can place one at risk for infectious disease. Besides this, hospitals are busy places, and many people, processes, supplies, devices, and spaces are involved in a patient's care. When one of these components fails to comply with infection control measures, patients can be at risk of acquiring an infection that is unwanted, unnecessary, and often avoidable.

These infections, whether they are acquired in a hospital or developed as a result of seeking medical care, are known as healthcare-associated infections (HAIs). HAIs are a type of medical error and are harmful to patients, hospitals, and society at large. They are associated with both extra care and additional costs for care. Despite treatment, many lives are still lost to HAIs, jeopardizing hospitals' reputations and placing them at risk for lawsuits.

History did not record who first understood or recognized HAIs, but by the 1960s, hospital-based clinicians and Centers for Disease Control and Prevention (CDC) epidemiologists were beginning to tackle HAIs. Common public health strategies were applied to build an HAI prevention system that focused on systematic surveillance to identify HAIs. This system implemented ongoing analysis of surveillance data to recognize potential problems, application of epidemic investigation techniques to epidemics and endemic HAIs, and implementation of hospital-wide interventions to protect patients, staff, and visitors.

Everyday, approximately one in every thirty-one patients in the United States contracts at least one infection associated with his or her hospital care, underscoring the need for improvements in patient care practices in US healthcare facilities. While great progress has been made, more still needs to be done to prevent healthcare-associated infections in a variety of settings. Today, hospitals are expected to implement "zero-tolerance" policies toward HAIs into the culture and care of their patients and are incentivized to reduce HAIs and improve patient outcomes. Hospitals are required to support a well-organized infection control program to develop, institute, and advance infection control practices in a hospital routine process – the result being markedly improved care and outcomes for patients.

Scope of Infection Control Practice

Infection control practice is patient-first; it includes every individual visiting or working in a hospital and anything that interacts with a patient.

Such a broad scope of service is defined by the chain of infection, the basic principle behind infection transmission, and the foundation on which infection prevention is built (Fig. 7.1). The chain of infection has six components: an *infectious agent*, a *reservoir* that hosts the agent, a *portal of exit* from the reservoir to the environment, a *mode of transmission* through the environment, and a *portal of entry* into the *susceptible host*. For infection to spread, all six links must work together unbroken. As such,

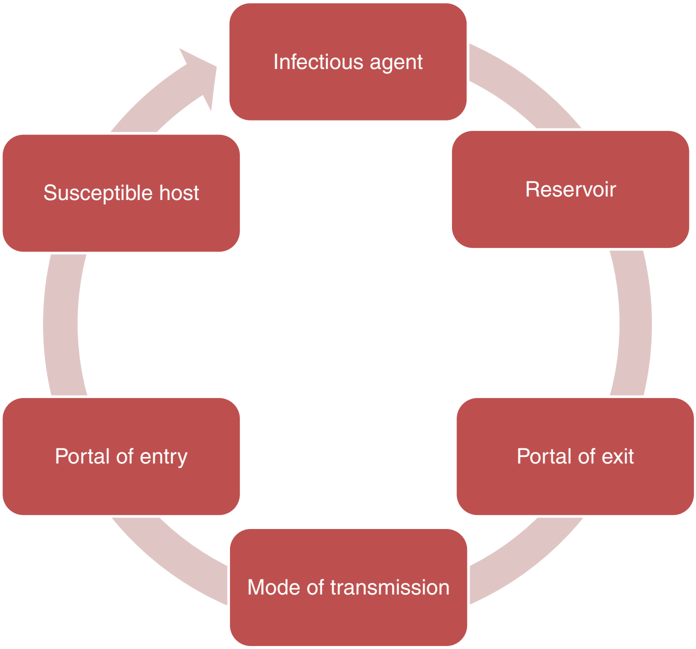

Fig. 7.1 The chain of infection

infection control is about the prevention of these components and the breaking of one or more links in the chain.

Infectious Agent

Infectious agents come in many different shapes and sizes. There are five major types of agents – bacteria, viruses, fungi, protozoa, and helminths. Bacteria, viruses, and fungi account for nearly all hospital-acquired infections and healthcare-setting outbreaks. When considering infectious disease, the infectious agent is often the first component of the chain of transmission that comes to mind. Generally, for an infection to occur, the agent must be present in the susceptible host; however, the efficacy of the agent in causing disease is influenced by other factors such as pathogenicity and infectivity [5].

Reservoir

The reservoir is the location in which an agent can grow, reproduce, and proliferate. The three most common types of reservoirs include human, environmental, and animal reservoirs. Each poses its own unique challenges in controlling and stopping the incidence of disease; it is the role of infection control specialists to be aware of the reservoirs existing in a hospital at any given time. In HAIs, reservoirs can include contaminated equipment, poorly-cleaned rooms, and visitors and family members.

As mentioned before, awareness and control of the reservoirs of disease is critical in undermining the spread of disease in a population and healthcare. Part of this control is reliant on personal accountability; initiatives, such as frequent handwashing, equipment maintenance, and mask-wearing, are entirely dependent on the compliance of the users. However, considering the importance of regulating reservoirs in maintaining patient health, it is prudent that reservoir-targeted infection control measures are implemented. In delivering quality improvement, infection control specialists must recognize clinical variation and work to capitalize on their hospital's strengths and work on their weaknesses.

Portal of Exit

The portal of exit is any method by which an agent exits its reservoir. In the case of human reservoirs, an infectious agent can exit through open wounds, aerosols, and splatter of body fluids including coughing, sneezing, and saliva.

Mode of Transmission

The mode of transmission is the method with which an agent leaves its reservoir until it reaches the next susceptible host. Mode of transmission can be broadly classified into direct and indirect transmission. Direct transmission includes direct contact and droplet spread, whereas indirect transmission includes airborne, vehicleborne, and vectorborne diseases.

Contact transmission occurs when there is direct skin-on-skin exposure. While droplet spread may sound similar to airborne transmission, droplets typically have a lower range and shorter infectious lifespan than airborne agents. Airborne agents can remain suspended in the air on droplet nuclei or dust or as an aerosol for much longer times. Vehicleborne illnesses are borne by inanimate media, such as surfaces, food, and bodily fluids. In contrast, vectors are animate carriers of disease; vectors may transmit disease solely through mechanical means or they may harbor growth and proliferation.

Portal of Entry

The portal of entry is how an agent enters a susceptible host. Modern healthcare employs many types of invasive devices and procedures to treat patients. When a central line, tube, or drain is inserted in a patient to either inject life-saving medication or to drain unwanted fluids out of the body, the procedure creates a potential portal of entry. Portals of entry are also created at surgery sites when the skin is deliberately opened. An infection can occur at any moment in a patient's care when an infectious agent enters through any one of these portals.

Susceptible Host

The final link in the chain of transmission is the host. The susceptibility of a host to infection is dependent on multiple factors, including genetics, environment, and physical health. Patients whose condition requires medical attention are often more predisposed to infection. HAIs pose a high risk to patients of all ages and demographics. As such, it is important that the previous five links in the chain are broken before it reaches the susceptible host.

Strategies to Break the Chain of Infectionz

A hierarchy of controls is shown in Fig. 7.2 based upon the effectiveness of various strategies that have been developed to break the chain of infection. These strategies include elimination, substitution, engineering controls, administrative controls, and personal protective equipment. Elimination refers to physically removing hazards, including infectious agents, harmful behaviors, and others. If a hazard is unable to be removed, replacing it with less harmful agents (substitution) and physically separating hazards from people (engineering control) are also options. Sometimes, simply changing the way that people work reduces hazard risk (administrative control). The least effective means of handling hazards is to use personal protective equipment (PPE), used when people must work in environments with uncontrollable hazards. Despite its low efficacy, PPE is also the most intuitive

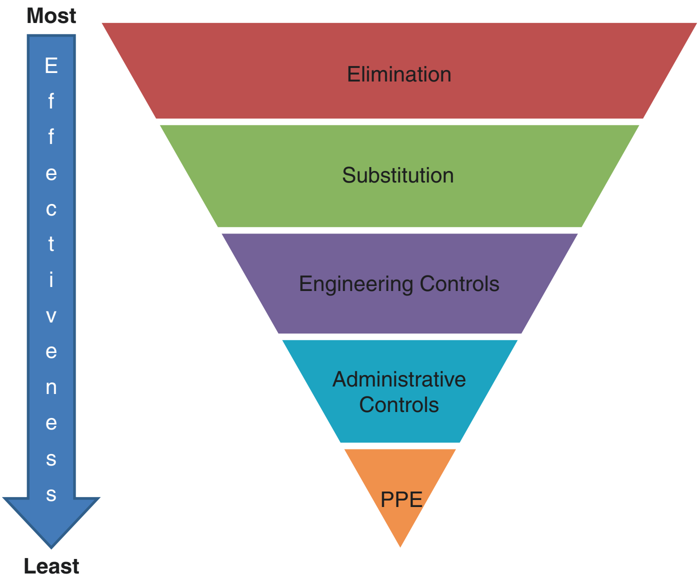

Fig. 7.2 The hierarchy of controls

way to make people feel safe: placing a physical barrier between a user and their environment.

Elimination

Hand hygiene may be the best example of using elimination strategies to prevent infections. As Semmelweis demonstrated hundreds of years ago, clean hands save lives. Hands are a natural reservoir of millions of microorganisms; some of these are commensal microbes that are beneficial to humans. For example, *Staphylococcus epidermidis*, the most common commensal skin flora, typically lives harmlessly on the skin. However, *Staphylococcus epidermidis* is also the number one cause of bloodstream infections in patients with a central venous catheter (CVC) [6]. CVC insertion creates a portal of entry that opens directly into a patient's bloodstream. When improperly sanitized hands handle catheters, microorganisms on the hands can inadvertently migrate into a patient's blood, causing life-threatening bloodstream infections.

Furthermore, when staff members touch medical devices or environments, their hands can be contaminated with environmental microbes. Hands that are not sufficiently cleaned between patients and between environments can become dangerous mediums, transmitting infectious agents from one patient to the other or from nonviable environments to humans. Besides the hands of healthcare providers, those of patients and visitors can become contaminated with microorganisms as well. When patients fail to wash their hands before eating or drinking, they can contract infections such as gastroenteritis or *Clostridium difficile*. Even when healthcare workers uphold the highest standards of infection control, the many other moving gears in the hospital machine may still fail.

Another example of when elimination works is the process of cleaning, disinfection, and sterilization. Microbes are ubiquitous elements of environments and human life. However, when microbes enter bodily sites that are meant to be sterile, like the blood or the heart, infections may occur. Hence, during many surgical and nonsurgical procedures, instruments that contact patients are expected to be microbe-free, to minimize infection risk. The elimination of microbial elements from these instruments is achieved through sterilization, a process that has been embraced in modern medicine. However, surgery predated sterilization by a full 600 years. The principles of asepsis and anesthesia were introduced in the mid-1800s by Joseph Lister, who invented the basic tenets of antisepsis and prevention of wound infection by eliminating germs on instruments, dressings, hands, and everything else in contact with wounds [7]. These principles of asepsis remain in use to this day. Failure to eliminate microbes from instruments almost certainly causes infection, as evidenced by many outbreaks reported in hospitals [8]. An analysis of nosocomial outbreaks between 1980 and 1990 found contaminated medical products and devices to be the number one cause of infection outbreaks! The analysis also demonstrated an ominous trend: in just 5 years, outbreaks caused by these devices and products increased by 50%. Decades later, hospitals continue to struggle with meeting safety standards on reprocessing used instruments and improving from HAI clusters and outbreaks [9–11].

Aside from large equipment, standard medical supplies, such as saline water, antiseptic agent, heparin flush, and more, have all been implicated in infection outbreaks [12–15]. Every incident sounds the alarm, reminding people of the importance of sterility throughout the entire patient care delivery process. This delivery process begins outside of the healthcare facility when a product is manufactured in a factory, continues when a product is stored and handled inside a healthcare facility, and ends when a product reaches a patient. Every person, every product, and every step in this process count toward safe care.

Substitution

When one stays in a hospital for medical treatment, coming into contact with tap water is unavoidable. From showering, brushing one's teeth, to taking an ice cube – tap water is everywhere in our daily routines. The notion of water as a vehicle for disease was not considered by hospitals until evidence began to surface of outbreaks linked to waterborne illnesses [16–19]. In our own experience at Children's National, T-cell-deficient patients experience a greater risk of developing nontuberculous mycobacterial infection after exposure to tap water during bathing and daily activities [20]. Strategies to mitigate these opportunistic infections include substituting tap water with distilled or sterile water for daily use and by maintaining a clean water system throughout the institution.

The CDC has estimated that four in five problems leading to US healthcare-associated outbreaks could be prevented with effective water management. When a water disinfection system in a building fails, such as by water not flowing properly, substandard disinfectant levels, or the presence of "deadlegs" (stagnant water), microbes that can be naturally found in bodies of water proliferate rapidly [21]. The higher the bacterial load in the water, the higher the likelihood that bacteria enter and infect a patient during contact. When a patient lacks a full immune system to defend the body, infections such as Legionnaires' disease can occur. Legionnaires' disease is a serious and deadly lung infection that kills 25% of those who contract the disease in a healthcare facility. Legionnaires' is caused by breathing in or aspirating small water droplets containing a pathogenic type of *Legionella* bacteria [22]. Among people who reported a site of exposure to Legionnaires' disease, 76% identified a healthcare facility as their exposure location [23]. To help building owners reduce the risk of *Legionella* growth and transmission, guidelines and standards have been developed by several agencies and professional groups [21]. *Legionella* water management programs are now an industry standard for large buildings in the United States (ASHRAE 188: Legionellosis: Risk Management for Building Water Systems June 26, 2015. ASHRAE: Atlanta) [23]. Hospitals are obligated to comply with the standard and to maintain a healthy water delivery system in the institution.

Engineering Control and Administrative Control

During infectious disease pandemics, such as influenza, COVID-19, and the Ebola virus, elimination (physically removing the hazard) and substitution (replacing the hazard) are not typically options. In these instances, engineering (isolating people from hazard) and administrative (changing the way people work) controls must be enforced to reduce and avoid exposure to these contagious illnesses. Prompt detection and effective triage and isolation of potentially infectious patients are essential to prevent unnecessary exposures among patients, healthcare providers, and visitors at the facility.

Beginning in late 2019, humans have confronted unprecedented challenges raised by the novel coronavirus – the SARS-COV-2 pandemic, more commonly known as COVID-19. The virus has all of the traits needed to cause a pandemic. It can spread quickly through respiratory droplets or aerosol among humans, and, as a novel disease, there is no natural immunity or vaccine to prevent infection and no effective therapy to treat infected patients. Hospitals must stay in operation and be ready to care for patients infected with COVID-19, while effective infection prevention and control strategies must be deployed to prevent the transmission of this virus from patients to staff and vice versa. Failure to control the spread of an infectious disease like COVID-19 in a hospital is reflected by hospital-onset infection among patient and occupational acquisition of the disease among staff.

In the context of engineering control, combating COVID-19 in the hospital starts with early identification and early isolation. Staff members actively reach out to families and patients before their scheduled visit to identify patients with signs and symptoms consistent with COVID-19 infection and proactively coordinate patients' visits, so that potential patients can be promptly isolated upon entering the hospital. With knowledge of a patient's infectious status, staff can take precautions during their patient interactions. When these preventive measures work in concert, safe care can be delivered to a patient without jeopardizing staff safety and the safety of other individuals.

When an infectious disease circulates in communities, healthcare workers are not immune to being infected and can even become a source of spread to patients and other coworkers. Thus, altering the way that staff work is prudent to reduce risks of spread. Taking advantage of our interconnectedness with the Internet, society, including the healthcare industry, has quickly adopted telemedicine, teleworking, virtual meetings, and other innovative communication methods and mitigated virus transmission risk associated with crowded spaces and contact with the sick. With employer commitment and employee buy-in, the consistent use of administrative control can effectively interrupt disease transmission in workplaces.

Personal Protective Equipment (PPE)

The duties of healthcare workers call on them to provide hands-on care to patients with known and unknown infectious diseases. Without knowing a patient's infectious disease status, PPE offers instant protection and must be included in the suite of strategies to protect personnel.

PPE, as defined by the Occupational Safety and Health Administration (OSHA) (an American governmental body that issues regulations for workplace health and safety) is any "specialized clothing or equipment worn by an employee for protection against infectious materials." The use of PPE in healthcare settings is required by the OSHA to protect healthcare personnel from exposure to bloodborne pathogens and other potentially infectious diseases. Hospitals, as employers, must provide appropriate PPE and ensure proper management and disposition of PPE after use. The CDC issues recommendations for when and what PPE should be used to prevent exposure to infectious diseases, and the Food and Drug Administration establishes standards that qualify a PPE to be used in healthcare settings and in special environments such as operating rooms.

All the types of PPE listed in Table 7.1 can be used individually or concurrently to protect healthcare workers from exposures to infectious diseases by creating a barrier between the worker and infectious material. When used appropriately, PPE reduces contamination of staff hands and clothing, therefore reducing the risk of transmitting infectious agents, including multidrug-resistant organisms.

The effectiveness of PPE is determined by three factors. Firstly, the selection of proper PPE should be based on anticipation of

Table 7.1 Types of PPE in healthcare settings

Gloves: protect hands
Gowns/aprons: protect skin and/or clothing
Masks and respirators: protect mouth/nose
Respirators – protect the respiratory tract from infectious agents
Goggles: protect eyes
Face shields: protect face, mouth, nose, and eyes

exposure and the type of exposure (i.e. blood, respiratory secretion, urine, etc.) and the durability and appropriateness of the PPE for the task and fit for the user. Correct PPE offers healthcare workers safety, durability, and comfort. Secondly, employees must obtain proper training in safely donning and, more importantly, doffing PPE to avoid the cross-contamination of hands, clothing, and surrounding objects. Thirdly, deciding the proper PPE for patient interactions should be based upon clinical interactions with a patient and the patient's status of infectivity [24]. Ultimately, while hospitals make PPE available to healthcare workers, for their own health, healthcare workers must take the matter into their own hands by knowing when to use what type of PPE and how to use it correctly every time.

The Importance of Connecting the Dots: A Case Study

Successful infection prevention and control in a hospital arises from the successful integration of infection control practices into every provider's practice with every patient. As described above, many strategies, techniques, and protective gear are available as options for healthcare providers to choose for patient interactions. This case study is to illustrate the importance of applying infection control principles and practices that are tailored to an individual's care.

The patient is a teenage male who was admitted for cancer remission during the COVID-19 pandemic. On the day of his admission, he was tested for COVID-19 to determine the status of his infectious disease. Because COVID-19 has a prolonged incubation period and the possibility of false negatives, a single test is unable to rule out the possibility of COVID-19 infection. Accordingly, staff members utilized universal precaution by wearing a surgical mask and eye protection when entering the patient's room to prevent exposure to COVID-19. A central line was placed on the patient for the rapid delivery of critical medication and for reducing pain and discomfort from repeat intravenous injections.

As the patient's condition deteriorated, the patient experienced skin breakdown at multiple body sites, intra-abdominal bleeding, diarrhea, and mucositis. The gross discomfort and the pain were so overwhelming that the patient was unwilling to carry on their daily routine, including basic personal hygiene. Eight days after admission, the patient developed a bloodstream infection caused by *Pseudomonas aeruginosa*. Although the patient recovered from the infection, his infection reveals that infection control principles, the chain of infection, and the hierarchy of control are imperative in an episode like this.

His medical condition and subsequent treatment marked the patient as a susceptible host for infection. The insertion of a central line, together with skin breakdowns, created multiple portals that facilitated the entry of *Pseudomonas aeruginosa* into the patient's bloodstream. This condition was worsened when he refused daily hygiene in the setting of diarrhea and further increased the risk of *Pseudomonas aeruginosa* transmission. Despite the concurrently raging COVID-19 pandemic, the staff understood that patient care must be provided. As such, all staff wore proper PPE, including surgical masks and face shields, for their own health and the health of others.

In this case, opportunities to break the chain of infection are limited, given the patient's overall condition and that an endogenous process might have contributed to the translocation of the infectious agent to the patient's bloodstream. Nonetheless, with the information available, this patient's infection meets the definition of a central line-associated bloodstream infection. Taking a closer view of this incident, the care team subsequently emphasized to all caregivers the need to escalate concerns promptly. In this case, the patient's poor personal hygiene and poor skin conditions merited concern and increased precaution.

Every staff member in a hospital plays a role in preventing HAIs. When infection control strategies are applied correctly in everyday practice, they can stop the spread of infection and protect the safety of both patients and staff members. Not every HAI is preventable, but every HAI should only occur after all prevention efforts have been exhausted. *Infection prevention and control is in everyone's hands.*

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