Chapter 3

Epidemiology of Healthcare - Associated Infections

Akeau Unahalekhaka

Key Points
• Patients risk acquiring pathogens while receiving care in healthcare facilities, especially when they undergo invasive diagnostic procedures or treatments. • Healthcare-associated infections (HAI) impact patients, their family, healthcare personnel, healthcare facilities, and national public health. • Healthcare personnel need to understand the epidemiology of HAIs, which include the occurrence, magnitude, severity, and distribution in their facilities. • Understanding the epidemiology of HAIs can assist both administrators and personnel in prioritising problems and determine the most appropriate and effective prevention and control strategies. • Understanding the chain of infection, especially the modes of transmission of infectious diseases and pathogens, can help prevent HAIs.

Background

Healthcare-associated infections (HAI) affect patients' morbidity and mortality. Healthcare personnel need to know the magnitude and severity of HAIs in their facilities to be aware of its serious impact to patient outcomes and suffering. Information from the epidemiology of HAIs is very useful in strengthening collaboration, implementation, monitoring, and evaluation of HAI prevention.

Epidemiology [1-3]

Epidemiology is the study of the dynamic occurrence, distribution, and determinants of health problems in populations. Epidemiology can explain the relationship of a health problem among the population at risk and related factors by determining the characteristic of the disease or health problem and its occurrence, determinants, and risk factors.

The epidemiology of HAIs provide information on the magnitude of infections among patients, both outpatient and inpatient. It explains the occurrence and distribution of HAIs, what happens to whom, and where and when it happens. Information on the distribution of HAIs by patient characteristics, site of infections, causative pathogens, unit of treatments, and date of onset can help healthcare personnel in determining appropriate prevention strategies and support effective planning and implementation of HAI prevention programs.

Healthcare-associated Infections[3]

HAI (previously called nosocomial infection) refers to infections associated with health care delivery in any setting (e.g., hospitals, long-term care facilities, and community/ ambulatory settings). A HAI is defined as a localised or systemic infection that results from an adverse reaction to the presence of an infectious agent(s) or its toxin(s) for which there is no evidence of infection on admission. An infection is frequently considered a HAI if it appears ≥48 hours after admission.

Magnitude and Impact

HAIs occur in healthcare facilities worldwide. At any given time, 7 patients in developed and 10 in developing countries out of every 100 hospitalised patients will acquire at least one HAI. The European Centre for Disease Prevention and Control estimated that 4,131,000 patients are affected by HAIs every year in Europe and cause 16 million extra-days of hospital stay and 37,000 attributable deaths. Annual financial losses, including only direct costs, are estimated at approximately €7 billion.[4]

A multistate point-prevalence survey in acute care hospitals in the United States (USA) estimated that there were 648,000 patients with HAIs and on any given day about 1 in 25 hospitalised patients has at least one HAI. About 75,000 patients with HAIs died during their hospitalisation. More than half of all HAIs occurred outside of the intensive care unit (ICU).[5]

In Canada, more than 200,000 patients acquire HAIs every year while receiving health care. More than 8,000 patients die as a result of their infection. More than 50% of HAIs are caused by bacteria that are resistant to at least one type of antibiotic.[6]

Hospital-wide prevalence of HAIs in limited resource countries varied from 5.7% to 19.1% with a pooled prevalence of 10.1%.[7] The International Nosocomial Infection Control Consortium conducted a surveillance study in 503 ICUs in Latin America, Asia, Africa, and Europe from January 2007-December 2012. Among 605,310 hospitalised patients, the pooled rate of central line associated blood stream infection was 4.9 per 1,000 central line days. The overall rate of ventilator-associated pneumonia was 16.8 per 1,000 ventilator days, and the rate of catheter-associated urinary tract infection was 5.5 per 1,000 catheter days.[8]

Systematic review and meta-analysis of electronic databases and relevant articles in developing countries published during 1995–2008 showed that the pooled prevalence of HAIs was 15.5 per 100 patients,

much higher than in Europe and the USA. Pooled overall HAI density in adult ICUs was 47.9 per 1,000 patient-days, at least three times as high as reported from the USA. Surgical-site infection was the leading infection in hospitals (pooled cumulative incidence, 5.6 per 100 surgical procedures), higher than in developed countries. Gram-negative bacilli represented the most common pathogen isolated.[9]

Major types of HAI

There are four major types of HAIs, all of them related to invasive or surgical procedures. They include:

1. Catheter-associated urinary tract infection (CAUTI)
2. Ventilator-associated pneumonia (VAP)
3. Surgical site infection (SSI)
4. Catheter related bloodstream infection (CR-BSI)

Epidemiologic Factors

There are three main related factors for HAIs: host factors, agent factors and environmental factors (See Figure 3.1).

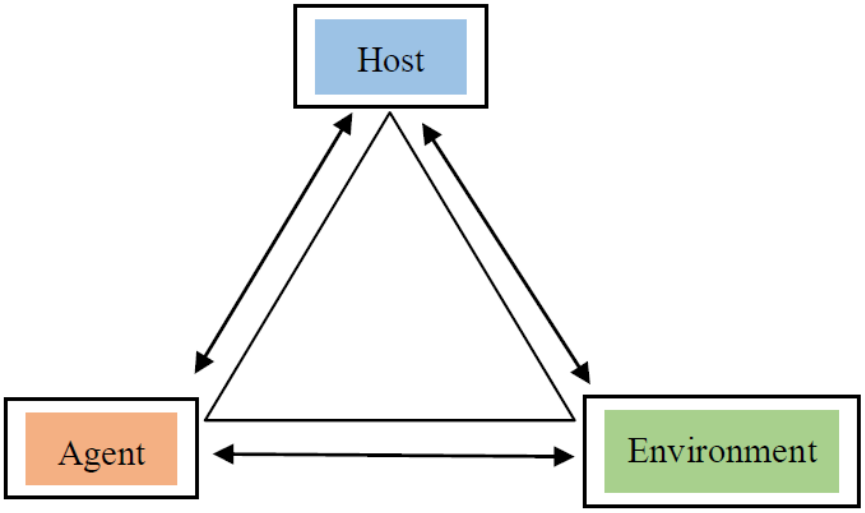

Figure 3.1. Relationship of factors in healthcare-associated infections

Host factors

Host factors affect a person's risk of exposure and resistance to infection. Patients admitted to healthcare facilities are usually in a poor state of health, with weakened defences against bacteria and other infectious agents. Advanced age, premature birth, or immunodeficiency (due to drugs, illness, or irradiation) present a general risk, while some diseases present specific risks. For instance, chronic obstructive pulmonary disease (COPD) increases the chances of respiratory tract infection. Additional host factors associated with an increased risk of HAIs include malignancies, infection with human immunodeficiency virus, severe burns and certain skin diseases, severe malnutrition, coma, diabetes mellitus, bronchopulmonary disease, circulatory impairment, open wound, and trauma.

Agent factors

An infectious agent can be a bacterium, virus, fungus, or parasite. The majority of HAIs are caused by bacteria; viruses and fungi are occasionally involved, while parasites rarely cause HAIs. There are two major types of bacteria that cause HAIs, Gram positive (e.g., s*taphylococci, streptococci, C. diffile*) and Gram negative (e.g., *Acinetobacter, Pseudomonas, Enterobacter, Klebsiella*). Many of these pathogens can survive on surfaces for a long period of time.

Environment factors

Environmental factors are extrinsic factors that can affect both the infectious agent and patients. Environmental factors related to HAIs include both the animate and inanimate environment of patients. The animate environment refers to healthcare personnel, other patients in the same unit, families, and visitors. The inanimate environment refers to medical instruments and equipment, diagnostic and therapeutic manoeuvres, and environmental surfaces. Other factors related to the healthcare environment include sanitation and cleanliness of the unit, temperature, and humidity.

Diagnostic and therapeutic procedures can increase the risk of acquiring HAIs, particularly 1) those transecting contaminated/infected tissues or involving insertion of a foreign body; 2) indwelling catheters, especially intravenous and urinary catheters; 3) tracheostomy or endotracheal intubation, mechanically respiratory ventilation, and anaesthesia; 4) dialysis; 5) transfusion; 6) immunosuppressive drugs, antimicrobials, hyperalimentation; and 7) radiation therapy. All invasive procedures can by-pass the patient's natural defence mechanisms and provide an easy route for infection. The longer a device is left in place, the greater the risk of infection.

A patient's treatment can also leave them vulnerable to infection - immunosuppression and antacid treatment undermine the body's defences, while antimicrobial therapy (removing competitive flora and only leaving resistant microorganisms) and recurrent blood transfusions have also been identified as risk factors. (See Table 3.1)

Table 3.1 Risk factors of important healthcare-associated infections*

Site of Infection	Risk factors
Urinary tract infection[10]	Extremes of age Severity of underlying disease Diabetes mellitus Duration of catheterisation Breaks in closed systems
Pneumonia[11]	Extremes of age Underlying disease (COPD, Adult Respiratory Distress Syndrome) Head trauma Use of antacids Re-intubation Receipt of enteral nutrition Failed subglottic aspiration
Primary bloodstream[12]	Extremes of age Underlying disease, immunosuppression, burns Femoral catheter Density of skin flora at catheter insertion site
Surgical site infection[13]	Extremes of age Obesity Smoking Diabetes mellitus Existing infection Trauma Shock Prolonged procedure

* Adapted from reference 3, pages 10-13.

Information on key determinants of HAIs is very useful in identifying preventive strategies and measures. In limited resource countries, there were many determinants related to HAI occurrence identified, e.g., inadequate environmental hygiene and waste disposal; poor infrastructure; insufficient equipment; understaffing; overcrowding; lack of knowledge of infection prevention and control (IPC); and absence of local and national guidelines and policies.[7]

Chain of Infection

Infection results from an interaction between an infectious agent and a susceptible host. This interaction occurs by means of contact between the agent and the host and is affected by the environment (See Figure 3.1). Breaking the chain of infection by interrupting transmission is generally the best way to prevent HAIs. The chain of infection consists of the following components: infectious agent, reservoir, portal of exit, mode of transmission, portal of entry, and susceptible host. (See Figure 3.2)

Infectious agent is a pathogen that causes a HAI. The ability of a pathogen to cause an infection depends on its virulence, pathogenicity, infectious dose, and infectivity.

Reservoir is a place in which an infectious agent can survive (it may or may not multiply). Common reservoirs in healthcare facilities are persons with infectious diseases and contaminated medical devices or equipment (usually called vehicles). There are three types of human reservoirs:

1. Persons who are ill (have signs and symptoms of disease)
2. Colonised persons (harbour an infectious agent but do not have an infection)
3. Carriers (infected but do not show any signs or symptoms; they can transmit the infection to others)

Portal of exit is the path by which an infectious agent leaves the reservoir. Portal of exit can be the respiratory tract, genitourinary tract, gastrointestinal tract, skin/mucous membrane, blood, or transmission from a mother to her child during pregnancy (transplacental).

Mode of transmission is the movement of pathogens from the reservoir to the host.

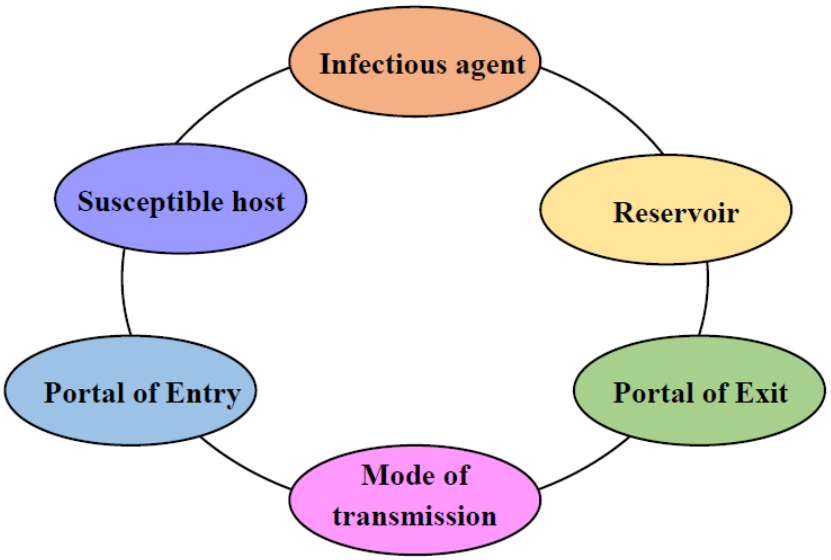

Figure 3.2 Chain of Infection

Portal of entry is the path by which an infectious agent enters the host; can be via the respiratory tract, genitourinary tract, gastrointestinal tract, skin/mucous membrane, parenteral, or transplacental.

Susceptible host is a person lacking effective resistance to a particular pathogen. In healthcare facilities, many patients are susceptible to infections since they are already seriously ill.

Modes of Transmission

A pathogen can spread by a single or several routes. The modes of HAI transmission are as follows:

Contact Transmission

Contact is the most important and frequent mode of HAI transmission; it is divided into three subgroups: direct-contact, indirect-contact, and droplet transmission.

Direct-contact transmission involves a direct surface-to-body contact and physical transfer of microorganisms between a susceptible host and an infected or colonised person. For instance, direct contact occurs when a nurse turns a patient, gives a patient a bath, or performs other patient-care activities that require direct personal contact.

Indirect-contact transmission involves contact of a susceptible host with an intermediate object, usually inanimate, such as contaminated instruments, needles, or dressings, or contaminated gloves that are not changed between patients.

Droplet transmission occurs when droplets are generated from a human reservoir, mainly during coughing, sneezing, or talking, or during the performance of certain procedures, such as bronchoscopy. Transmission occurs when droplets containing pathogens from the infected person are propelled a short distance (< 1 metre) through the air and deposited on the host.

Airborne Transmission

Airborne transmission occurs by dissemination of airborne droplet nuclei (small-particles, ≤5 µm in size of evaporated droplets containing microorganisms) that remain suspended in the air for long periods of time or dust particles containing an infectious agent. Droplet nuclei, dust particles, or skin squamae containing microorganisms are transmitted by air currents; they may become inhaled by a susceptible patient within the same room or over a longer distance from the source patient, depending on environmental factors. Special ventilation is required to prevent airborne transmission. Microorganisms transmitted in this manner include *Mycobacterium tuberculosis* and rubeola (measles) and varicella (chickenpox) viruses.

Vehicle Transmission

Vehicle transmission applies to microorganisms transmitted through contaminated items, such as food, water, medications, medical devices and equipment, toys, and biological products, such as blood, tissues or organs.

Vector-borne Transmission

Vector-borne transmission occurs when vectors, such as mosquitoes, flies, rats, and other vermin, transmit microorganisms. Transmission occurs through simple contamination by animal or arthropod vectors or their actual penetration of skin or mucous membranes. This mode of transmission plays a minor role in spread of HAIs.

Basic Principles of Epidemiology

Use of surveillance data to drive changes[14-15]

One of the most useful epidemiological methods is surveillance. Results from the USA Centers for Disease Control and Prevention's Study on the Efficacy of Nosocomial Infection Control[14] supported four important recommendations for effective HAI prevention: surveillance, control measures, an infection control professional/nurse, and a hospital epidemiologist.

Surveillance is the systematic, active, ongoing observation of the occurrence and distribution of HAIs and of the events or conditions that increase the risk of HAI occurrence. Surveillance data can be used to provide baseline endemic infection rates, identify epidemics, provide information on the occurrence of HAIs, evaluate efficacy of preventive measures, reinforce appropriate infection prevention and patient-care practices, defend against malpractice suits, provide data for comparisons, problem solving and/or research, and plan and measure the impact of implementing recommendations. The surveillance information allows healthcare facilities to direct their efforts toward the most serious HAI problems and risks, to obtain support from administrators and healthcare personnel, and to provide feedback on the results of preventive changes.

Surveillance information can be combined with process indicators to improve practices. Process indicators are activities that affect the development of HAIs. Care bundles are groupings of best practice process indicators that individually improve care; when applied together they result in substantially greater improvement in outcomes.

Types of epidemiological studies[16]

An epidemiological study should be conducted to obtain increased knowledge and understanding of HAI occurrence and effective prevention and control measures. Conducting research is one of the important activities in HAI prevention. Epidemiological studies can be classified as either observational or experimental. The most commonly used types of epidemiological studies are listed in Table 3.2 together with their focus of study and their alternative names.

Observational studies include descriptive or analytical studies. A descriptive study describes the occurrence of a disease in a population and is often the first step in an epidemiological investigation.

A ***cross-sectional study***, often called a prevalence study, measures the prevalence of disease. The measurements of exposure and effect are made at the same time. Data from cross-sectional studies are helpful in assessing the health care needs of populations.

An ***analytical study*** analyses and tests relationships between a disease and its causes. Case-control studies are used to investigate causes of disease, especially rare diseases. The possible cause is compared between cases (people with a disease) and controls (people without a disease). This is a *retrospective study*, since the design looks backward from outcome to possible exposure or causative factors. Case-control studies often are performed when investigating an outbreak.

In a ***cohort study***, a group of people (a cohort) is evaluated, none of whom has experienced the outcome of interest. On entry to the study, people in the cohort are classified according to characteristics or exposures that might be related to the outcome. Groups with and without certain exposures or characteristics are then observed over time to compare outcomes.

An ***experimental or intervention study*** involves an active attempt to change a disease determinant, such as an exposure or behaviour, or the progress of a disease, through treatment, usually involving a randomised controlled trial with patients as subjects. Field trials and community trials are other experimental designs, in which the participants are healthy people and communities, respectively.

The effects of an intervention are measured by comparing the outcome in the experimental group with that in a control group. Since the interventions are strictly determined by the protocol, ethical considerations are of paramount importance in the design of experimental studies.

Summary

HAIs are infections that occur among patients who receive care in healthcare facilities. Healthcare personnel need to understand the chain of infection and epidemiology of HAIs in order to effectively prevent and control infections.

Table 3.2 Type of epidemiological studies

Type of study	Alternative name	Unit of study
Observational studies		
Descriptive studies		
Analytical studies		
Ecological	Correlational	Population
Cross-sectional	Prevalence	Individuals
Case-control	Case-reference	Individuals
Cohort	Follow-up	Individuals
Experimental studies	Intervention studies	Patients
Randomised controlled trials Field trials	Clinical trials	Patients Healthy people
Community trials	Community intervention studies	Communities

References

1. Friis RH, Sellers TA. *Epidemiology for public health practice*. London: Jones and Bartlett Publishers, Inc., 2004.
2. Gordis L. Epidemiology. (3rd ed). Philadelphia: W.B. Saunders Company, 2009.
3. Jarvis WR. Bennett & Brachman's Hospital Infections. (6th ed.) Philadelphia: Walters Kluwer, Lippincott Williams & Wilkins, 2014.
4. WHO. Health Care-Associated Infections Fact Sheet. http://www.who.int/gpsc/country_work/burden_hcai/en/. [Accessed 8 July 2015]
5. Magill SS, Edwards JR, Bamberg W, et al. Multistate Point-Prevalence Survey of Health Care–Associated Infections. N Engl J Med 2014; 370:1198-208.
6. Public Health Agency of Canada. The Chief Public Health Officer's Report on the State of Public Health in Canada, 2013 Infectious *Disease - The Never-Ending Threat*. http://www.phac-aspc.gc.ca/cphorsphc-respcacsp/2013/infections-eng.php [Accessed 14 July 2015].
7. WHO. *Report on the burden of endemic healthcare-associated infection worldwide*. 2011. Geneva, Switzerland. http://whqlibdoc.who.int/publications/2011/9789241501507_eng.pdf [Accessed 14 July 2015]
8. Rosenthal VD, Maki DG, Mehta Y, et al. International Nosocomial Infection Control Consortium (INICC) report, data summary of 43 countries for 2007-2012. Device-associated module. *Am J Infect Control* 2014; 42: 942-56.
9. Allegranzi B, Nejad SB, Combescure C, et al. Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. *Lancet* 2011; 377:228-241. http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(10)61458-4/abstract [Accessed 14 July 2015]

10. Chenoweth C, Saint S. Preventing Catheter-Associated Urinary Tract Infections in the Intensive Care Unit. *Crit Care Clin* 2013; 29:19-32.
11. Bonten MJM, Kollef MH, Hall JB. Risk Factors for Ventilator-Associated Pneumonia: From Epidemiology to Patient Management. *Clin Infect Dis* 2004; 38:1141–9.
12. O' Grady NP, Alexander M, Burns LA, et al. Guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis* 2011; 52(9):e162-93.
13. Cheadle WG. Risk Factors for Surgical Site Infection. *Surg Infect* 2006; 7 (Supp 1): S7-S11.
14. Haley RW, Culver DH, White JW, et al. The efficacy of infection surveillance and control programs in preventing nosocomial infections in U.S. hospitals. *Am J Epidemiol* 1985; 21: 182-205.
15. Lynch P, Pittet D, Borg MA, Mehtar S. Infection control in countries with limited resources. *J Hosp Infect* 2007; 65 (Suppl. 2):148-150.
16. Pittet D. Health care-associated infection: moving behind headlines to clinical solutions. *J Hosp Infect* 2009; 73: 293- 295.

Key Web Links

- Centers for Disease Control and Prevention (CDC) www.cdc.gov
- European Centre for Disease Prevention and Control (ECDC) www.ecdc.europa.eu
- Institute for Health Care Improvement (IHI) www.ihi.org
- The International Federation of Infection Control (IFIC) www.theific.org
- Public Health Agency of Canada www.publichealth.gc.ca
- U. K. National Patient Safety Agency (NPSA) www.npsa.nhs.uk
- World Health Organization (WHO) www.who.int

Published by the International Federation Of Infection Control
47 Wentworth Green
Portadown, BT62 3WG, N Ireland, UK
www.theific.org