Chapter 3
Epidemiology of Health care-Associated Infections

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Key points

- Patients are exposed to infectious risks when they receive care in health care facilities, especially when they undergo invasive treatments and procedures.
- Healthcare-associated infections impact patients, their family members, health care personnel, and health care facilities.
- Epidemiology can help health care personnel understand the occurrence, magnitude, distribution, and severity of healthcare-associated infections in their settings.
- Understanding the epidemiology of healthcare-associated infections can help prioritise problems and effectively determine prevention and control strategies.
- Understanding the chain of infection, especially the modes of transmission, can greatly help health care personnel prevent healthcare-associated infections.
- Information on the occurrence of healthcare-associated infections by host, agent and environment, and their distribution by time and place is very useful for planning prevention strategies and evaluating the success of preventive interventions.

Background

Healthcare-associated infections (HAI) are a significant cause of patient morbidity and mortality. Healthcare personnel should be actively involved in the diagnosis, surveillance, and early management of HAIs with the goal of reducing the risk of preventable complications associated with health care.

Epidemiology[1-2]

Epidemiology is the study of the dynamic occurrence, distribution, and determinants of health-related events in specified populations. Epidemiology defines the relation of a disease to the population at risk and involves the determination, analysis, and interpretation of rates. The epidemiology of HAIs explains the occurrence of HAIs among patients cared for in a health care facility and the magnitude of the problem in these settings. It includes the distribution of HAIs by patient type, causative pathogen, unit of treatment, and period of time. This information can help healthcare personnel understand HAI problems in their facility and is very useful for determining preventive strategies.

Healthcare-associated Infections

HAI (previously called nosocomial infection) refers to infections associated with health care delivery in any setting (e.g., hospitals, long-term care facilities, community/ambulatory settings, and home/community care). An 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 to a health care facility. An infection is frequently considered an HAI if it appears ≥48 hours after admission.

Magnitude and Impact[2-6]

HAIs occur in both developed and developing countries; approximately 1.4 million patients acquire HAIs each day. In the United States, the Centers for Disease Control and Prevention (CDC) estimated that 1.7 million HAIs contribute to 99,000 deaths each year; they are among the top ten leading causes of death. The highest morbidity was among patients in intensive care units (ICU). The number of deaths associated with HAIs was greatest for pneumonia and bloodstream infections. The infection rate per 1,000 patient-days was highest in ICUs, followed by high-risk nurseries, and well-baby nurseries.

The prevalence of HAIs among patients in France was 5.0% in 2006. The most common HAIs were urinary tract infections (30.3%) followed by pneumonia (14.7%), surgical site infection (14.2%), and infections of the skin and mucous membrane (10.2%). HAIs caused patients to stay in the hospital 4-5 additional days. During 2004-2005, about 9,000 patients died each year with an HAI.

In Italy, 6.7% of patients developed HAIs, between 450,000 and 700,000 patients since the year 2000. Approximately 4,500 - 7,000 patients with HAIs died.

In 2006 in the United Kingdom, the estimated HAI rate was 8.2%. In Switzerland, a national survey showed an infection rate of 7.2% in 2004. In Finland, 8.5% of patients developed HAIs in 2005.

A surveillance study of HAIs in developing countries was conducted in 173 ICUs in Latin America, Asia, Africa, and Europe from January 2003 through December 2008 by the International Nosocomial Infection Control Consortium. There were a total of 155,358 hospitalised patients in the study. The pooled rate of central venous catheter (CVC) - associated bloodstream infections (BSI) was 7.6 CVC-BSIs per 1,000 CVC-days. This rate is nearly 3 times higher than comparable U.S. ICUs. The overall rate of ventilator-associated pneumonia (VAP) was also far higher; 13.6 VAPs versus 3.3 per 1,000 ventilator-days, respectively. The rates of catheter-associated urinary tract infections (CA-UTI) were 6.3 versus 3.3 per 1,000 catheter-days, respectively. The crude unadjusted excess mortalities of device-related infections ranged from 23.6% (CVC-BSIs) to 29.3% (VAP).

Major types of HAI

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

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

Epidemiologic Factors related to HAI

There are three main risk factor groups for HAIs: host factors, agent factors and environmental factors. The detail of each risk factor is as follows:

Host factors

Host factors affect a person's risk of exposure and resistance to infection. Patients admitted to health care facilities are usually in a poor state of health, with weakened defences against bacteria and other infectious agents. Advanced age or premature birth and immunodeficiency (due to drugs, illness, or irradiation) present a general risk, while some diseases present specific risks. For instance, chronic obstructive pulmonary disease 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 and viruses; fungi occasionally and parasites rarely cause HAIs. There are 2 major types of bacteria that cause HAIs, Gram positive cocci (e.g., staphylococci and streptococci) and Gram negative bacilli (e.g., *Acinetobacter, Pseudomonas, Enterobacter, Klebsiella*)

Environmental factors

Environmental factors are extrinsic factors that affect either the infectious agent or a person's risk of exposure to that agent. Environmental factors related to HAIs include both the animate and inanimate environment of patients. The animate environment refers to health care personnel, other patients in the same unit, families, and visitors. The inanimate environment refers to medical instruments and equipment and environmental surfaces. Other risk factors associated with the health care environment include sanitation, cleanliness of the unit, temperature and humidity, and diagnostic and therapeutic manoeuvres.

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 tracheal intubation, assisted respiratory ventilation, anaesthesia;

4. dialysis;
5. transfusion;
6. immunosuppressive drugs, antimicrobials, hyperalimentation; and
7. radiation therapy. Invasive devices, for instance intubation tubes, catheters, surgical drains, and tracheostomy tubes, all 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

Table 3.1 Risk factors of important healthcare-associated infections

Site of infection	Risk factors
Urinary tract infection	Female sex Severity of illness Urinary tract catheterisation Breaks in closed system Advanced age
Pneumonia	Underlying disease (altered mental status, diabetes, alcoholism) Malnutrition Severity of illness Histamine II blockers, antacid Intubation, mechanical ventilation, respiratory therapy equipment, tracheostomy
Primary bloodstream	Extremes of age Severity of illness Underlying disease, immunosuppression, burns Intravascular devices
Surgical site	Advanced age Malnutrition Severity of illness Preoperative shaving Wound classification Type of procedure Prosthesis

defences, while antimicrobial therapy (removing competitive flora and only leaving resistant microorganisms) and recurrent blood transfusions have also been identified as risk factors. Table 3.1 outlines risk factors for some specific HAIs.

Chain of Infection

Infection results from an interaction between an infectious agent and susceptible host. This interaction occurs by means of contact between the agent and the host and is affected by the environment. 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 3.1)

The infectious agent is a pathogen that causes an 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 but may or may not multiply. Common reservoirs in health care 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 (are 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 of disease from a mother to her child during pregnancy (transplacental).

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

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

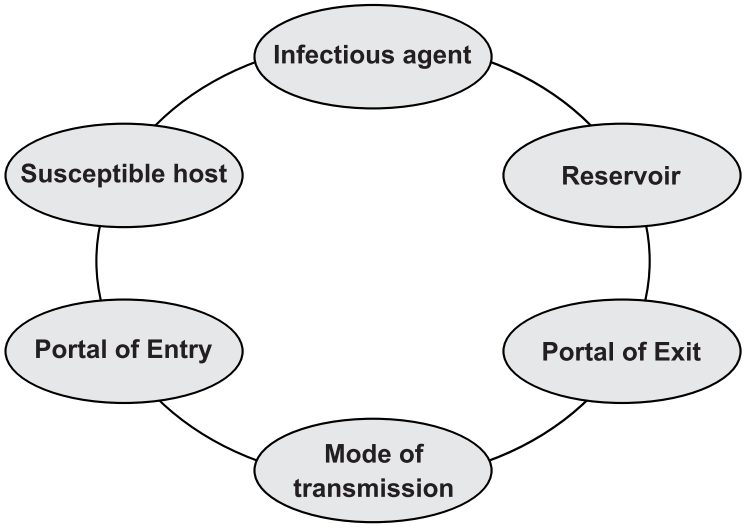

Figure 3.1 Chain of Infection

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

Modes of transmission of HAI

A pathogen may be transmitted by a single route or it can be transmitted in several ways. The modes of transmission of HAIs 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 body surface-to-body surface 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. Direct-contact transmission also can occur between two patients.

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, and 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 meter) through the air and deposited on the host's body.

Airborne Transmission

Airborne transmission occurs by dissemination of either 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 the infectious agent. Droplet nuclei, dust particles, or skin squames containing microorganisms are transmitted by air currents and 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*, 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 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 the skin or mucous membranes. This mode of transmission plays a minor role in transmission of HAIs.

Basic principles of epidemiology

Use of surveillance data to make improvements [8-9]

One of the most useful epidemiological methods is surveillance. The results from the CDC's Study on the Efficacy of Nosocomial Infection Control (SENIC Study)[7] supported four important recommendations for effective

prevention of HAIs: surveillance, control measures, an infection control professional/nurse, and a hospital epidemiologist.

HAI 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. The information allows health care organisations to direct their efforts toward the most serious HAI problems and risks, to obtain support of personnel, and to provide feedback on the results of preventive changes.

Surveillance data can be used to provide baseline endemic infection rates, identify epidemics, provide information on the occurrence of HAIs, evaluate efficacy of control 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.

Surveillance data can enhance a health care organisation's performance and reduce the risk of adverse outcomes. These data can be combined with process indicators to improve practices. Process indicators are activities that affect the development of HAIs.

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	Clinical trials	Patients
Field trials		Healthy people
Community trials	Community intervention studies	Communities

Care bundles are groupings of these best practice process indicators with respect to a disease process that individually improve care. However, when applied together they result in substantially greater improvement. The Institute for Health Care Improvement outlines care bundles for the most common HAIs.

Types of epidemiological studies[10]

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 the outcome.

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 (RCT) 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 these studies.

Statistics

Some basic use of statistics is helpful in infection prevention and control activities. Proper statistical methods must be used if correct interpretation of the data is expected.

Mean - Measure of Central Tendency

The most commonly used parameter is the arithmetic mean. The formula to calculate the sample mean is: $x = \sum x/n$ - where $\sum$ (sigma) is the symbol for "the sum of," x is the value of each observation, and n is the number of observations.

Standard Deviation - Measure of Variability

Standard deviation is a measure of dispersion that reflects the variability in values around the mean. The standard deviation (σ) of a distribution is defined as the square root of the variance, $\sigma = \sqrt{(x2)-(x)\ 2}$

Pictures

Pictorial statistics present the numerical data that have been collected in graphs or charts, creating a picture of the data. Types include bar and line graphs and pie charts.

Summary

Healthcare-associated infections are those that occur among patients who receive care in hospitals or other health care facilities. HAIs can cause serious complications and greatly impact patients, their families, and health care personnel. Health care personnel need to understand the epidemiology of HAIs to prevent them in their own settings. Understanding the chain of infection and epidemiology of HAIs can lead to effective prevention and control intervention.

The epidemiology of HAIs can explain what happens to whom, and where and when it happens, (i.e., the occurrence and distribution of HAIs). Using evidence-based recommendations can reduce infection rates. This information supports effective planning and implementation of programs to prevent HAIs.

Acknowledgement

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Key Web Links

The Association for Professionals in Infection Control and Epidemiology (APIC) www.apic.org
U.S. Centers for Disease Control and Prevention (CDC)
www.cdc.gov
Institute for Health care Improvement (IHI)
www.ihi.org
U. K. National Patient Safety Agency (NPSA)
www.npsa.nhs.uk
The Society for Health care Epidemiology of America (SHEA)
www.shea-online.org
World Health Organization (WHO)
www.who.int
Statistics
http://easycalculation.com/statistics/standard-deviation.php

Web Resource

Centers for Disease Control and Prevention Self-Study Course: Principles of Epidemiology in Public Health Practice, Third Edition

The introductory self-study course, Principles of Epidemiology in Public Health Practice, Third Edition, is available online. The course provides an introduction to applied epidemiology and biostatistics; it consists of six lessons: Introduction to Epidemiology, Summarizing Data, Measures of Risk, Displaying Public Health Data, Public Health Surveillance, and Investigating an Outbreak. Continuing education credits are offered to physicians, nurses, veterinarians, pharmacists, certified public health educators, and other professionals. The textbook is available at no charge at http://www.cdc.gov/training/products/ss1000/ss1000-ol.pdf and the self-study course (SS1000) is available at no charge at http://www2a.cdc.gov/tceonline/registration/detailpage.asp?res_id=1394. [Accessed July 8, 2011]