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THE TRANSMISSION OF INFECTION depends on the presence of three interconnected elements: an etiologic agent, a source, and a mode of transmission (Fig. 50-1). Understanding the characteristics of each element provides the practicing anesthesiologist with a methodologic aid to protect susceptible patients and health care workers and to avoid spreading infection.

There has always been concern about the transmission of infectious agents both to the patient from the anesthesiologist as well as from the anesthesiologist to the patient. In addition, there are many sites within the hospital environment where moist or desiccated organic material with the ability to host potentially pathogenic microbes may survive for extended periods of time (Table 50-1); some may even resist the usual cleaning and disinfection techniques. Their transmission from the source to the host may occur via indirect nonapparent mechanisms (e.g., most commonly through the hands).

Etiologic Agent

The infectious vector may be any microorganism capable of causing infection. The pathogenicity is the ability to induce disease, which is characterized by its virulence (infection severity, determined by the germ morbidity and mortality rates) and the level of invasiveness (capacity to invade tissues). No microorganism is completely avirulent. An organism may have a very low level of virulence, but if the host (patient or health care provider) is highly susceptible, infection by the organism may cause disease. The risk of infection increases with the infecting dose (i.e., the number of organisms available to induce disease), the reservoir (i.e., the site where the organisms reside and multiply), and the infection source (i.e., the site from where it is transmitted to a susceptible host either directly or indirectly through an intermediary object). The infection source may be a human (e.g., health care providers, children, visitors, housekeeping personnel) with a symptomatic or an asymptomatic infection during the incubation period. The source may also be temporarily or permanently colonized (the most frequently colonized tissues are the skin and digestive and respiratory tracts).

Host

The presence of a susceptible host is an increasingly important element in the chain of infection that paradoxically results from advances in current medical therapies and technology (e.g., children undergoing organ transplantation, chemotherapy, or extremely premature neonates) and the presence of children with diseases that compromise their immune systems (e.g., acquired immunodeficiency syndrome [AIDS], tuberculosis, malnutrition, burns). The organism may enter the host through the skin, mucous membranes, lungs, gastrointestinal tract, genitourinary tract, or the bloodstream via intravenous solutions, following laryngoscopy, or from surgical wounds. Organisms may also infect the individual as a result of work accidents with cutting or piercing devices. The development of infection is influenced by the host defense mechanisms that may be classified as either nonspecific or specific:

- **Nonspecific defense mechanisms** include the skin, mucous membranes, secretions, excretions, enzymes, inflammatory responses, genetic factors, hormonal responses, nutritional status, behavior patterns, and the presence of other diseases.
- **Specific defense mechanisms or immunity** may occur as a result of exposure to an infectious agent (antibody formation) or through placental transfer of antibodies; artificial defense may be acquired through vaccines, toxoids, or exogenously administered immunoglobulins.
Methods of Transmission

Microorganisms are transmitted in the hospital environment through a number of different routes; the same microorganism may also be transmitted via more than one route. In the operating room, three main routes of transmission are possible: air, direct contact, and indirect contact.

Air Transmission
Airborne infections that may infect susceptible hosts are transmitted via two mechanisms: droplets and droplet nuclei.

Droplets
Droplet contamination is considered a direct transmission of organisms because there is a direct transfer of microorganisms from the colonized or infected person to the host. This generally occurs with particles whose diameters are greater than 5 μm that are expelled from an individual’s mouth or nose, mainly during sneezing, coughing, or talking or during procedures such as suction, laryngoscopy, and bronchoscopy (Fig. 50-2). Transmission occurs when the microorganism-containing droplets, expelled or shed by the infected person (source), are propelled a short distance (usually not exceeding 60 cm or about 3 feet through the air) and deposited on the host’s conjunctivae or oral or nasal mucous membranes. When a person coughs, the exhaled air may reach a speed of up to 965 km/hr (600 mph). However, because the droplets are relatively large they tend to

Table 50-1. Nosocomial Pathogens and Environmental Contamination

Rights were not granted to include this table in electronic media. Please refer to the printed publication.

Modified from Hota B: Contamination, disinfection, and cross-colonization: are hospital surfaces reservoirs for nosocomial infection? Clin Infect Dis 2004; 39:1182-1189.
descend quickly and remain suspended in the air for a very brief period, thus obviating the need for special handling procedures for the operating room air. Examples of droplet-borne diseases include influenza, respiratory syncytial virus, severe acute respiratory syndrome (SARS), and others commonly found in droplets from the respiratory tract.

**Droplet Nuclei**

Droplet nuclei result from the evaporation of droplets while suspended in the air. Unlike droplets, the nuclei have an outer layer of desiccated organic material and a very small diameter (1 to 5 μm) and remain suspended in air indefinitely. The microorganisms contained within these nuclei may be spread by air drafts over great distances, depending on the environmental conditions (dry and cold atmosphere, with limited or nonexistent exposure to sunlight favor the spreading). In contrast to droplets, which are deposited on mucous membranes, the droplet nuclei may enter the susceptible host by inhalation; examples of droplet nuclei-borne diseases include tuberculosis, varicella, and measles.

**Contact Transmission**

Direct and indirect contacts are the most significant and frequent methods of hospital infection transmission.

**Direct Contact**

This type of disease transmission involves direct physical contact between two individuals. The physical transfer of microorganisms from an infected or colonized person to a susceptible host may occur from child to health care provider or from health care provider to the child during professional practice (e.g., venous cannulation, laryngoscopy, burn care, suction of secretions). Health care providers working in the operating room may be exposed to skin contamination by body fluids. This is an issue of grave concern because of the potential exposure of health care providers to patients with unrecognized infections, especially hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV). Hepatitis B is a highly infectious virus that requires a small amount of blood (10⁻⁷ to 10⁻⁵ mL) to transmit the disease. The incidence of skin contamination of anesthesiologists and related personnel by blood and saliva is quite high. One study examined 270 anesthetic procedures during 7 consecutive days. The blood of 35 patients (14%) contaminated the skin of 65 anesthesiologists in 46 incidents. Twenty-eight contamination events (61%) occurred during venous cannulation. Five of 65 anesthesiologists who had been contaminated by blood (8%) had cuts in the skin of their hands. The importance of this observation is that seroconversion of health care providers has been reported after skin contamination by infected blood from HIV carriers and HBV infection after blood splashing into health care workers’ eyes. Scabies, pediculosis, and herpes simplex are among the diseases most frequently transmitted by direct contact. These studies explain why meticulous hand washing and routine use of barriers such as gloves and eye protection are such an important part of protecting ourselves from such exposures even during routine procedures such as starting an intravenous line or performing laryngoscopy.

**Indirect Contact**

Indirect contact involves the transmission of microorganisms from a source (animate or inanimate) to a susceptible host by means of a vehicle (e.g., an intermediary object) contaminated by body fluids. Tables 50-2 and 50-3 provide examples of diseases associated with bodily fluids to which health care workers may be exposed. The vehicle for transmission may be the hands of a health care provider who is not wearing gloves or a provider who fails to wash his or her hands between children. This type of contact can also come from health care providers who touch (with or without gloves) contaminated monitoring or other patient care devices (e.g., blood pressure cuffs, stethoscopes, electrocardiographic cables, ventilation systems [respirators, corrugated tubes, Y pieces, valves]), which are used with several children without proper cleaning or disinfection in between each use.

Although no definitive studies have demonstrated a cause-and-effect relationship in the transmission of infections by anesthesiologists or anesthetic staff, there are reports of elements, fomites, and drugs (mainly propofol) that have resulted in hospital-acquired infections. However, many of the following situations could potentially cause an infection:

- Up to 40% of the anesthetic equipment in the operating room that was in direct or indirect contact with the child (blood pressure cuffs, cables, oximeters, laryngoscopes, monitors, respirator settings and horizontal and vertical surfaces) may be contaminated with blood because of inadequate cleansing procedures between children.
- In some institutions, up to 8% of the Bain circuits that were reused without previous sterilization were contaminated.
- Contamination of syringe contents has occurred with glass particles during ampule opening, which in turn may compromise the sterility of the contents, presumably due to the passage of bacteria contained on glass particles into the solution.
- Intravenous tubing has a significant blood contamination rate as well as contamination by blood from syringes used to inject drugs. This can occur with the absence of visible blood reflux in the tubing or syringe. Changing a fresh needle to a syringe that will be reused is useless to prevent cross infection, thus emphasizing the importance of not using the same syringe on multiple patients.

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**Table 50-2. Body Fluids and Diseases They May Transmit**

| Body Fluid            | Diseased Transmitted |
|-----------------------|----------------------|
| Blood                 | HBV, HIV, HCV, CMV, EBV, NANBH |
| Seminal fluid         | HIV, HBV, CMV         |
| Vaginal discharge      | HIV, HBV, CMV         |
| Saliva and sputum      | HSV, TB, CMV, respiratory diseases |
| Cerebrospinal fluid    | Encephalopathic organisms (see Table 50-5), HIV |
| Breast milk            | HIV, HBV, CMV         |
| Urine                 | CMV, EBV, HBV         |
| Feces and intestinal fluid | HAV, gastrointestinal diseases (see Table 50-5) |

HBV, hepatitis B virus; HIV, human immunodeficiency virus; HCV, hepatitis C virus; CMV, cytomegalovirus; EBV, Epstein-Barr virus; NANBH, non-A non-B hepatitis; TB, tuberculosis; HAV, hepatitis A virus; HSV, herpes simplex types I and II.

Modified with permission from Browne RA, Chenesky MA: Infectious diseases and the anaesthetist. Can J Anesth 1988; 35:655-665.
Refilling both glass and plastic syringes several times has been shown to result in contamination of the contents.45,46

Some drug formulations, especially propofol, can sustain bacterial growth under certain conditions. Thus, great care should be given to aseptic technique when transferring drugs from the vial to a syringe and not allowing the syringe to remain unused for more than 4 hours.47-51

Needles that had been used for spinal or epidural anesthesia were found to be contaminated with coagulase-negative staphylococci (15.7%), yeasts (1.5%), enterococcus (0.8%), pneumococcus (0.8%), and micrococcus (0.8%), suggesting that despite standard skin preparation and cleansing there is a significant rate of needle contamination.52 It is unclear whether these organisms produce an inoculation that could lead to an infection during neuraxial blockade.

There is a high incidence of skin contamination by blood and saliva of anesthetic personnel that occurs during routine anesthetic practice.

Violations of contemporary guidelines for preventing infections (hand washing, wearing gloves, surgical masks, ocular protection, scrubs, syringe reutilization) by anesthesiologists are frequent. Anesthesia staff are aware of the potentially infectious working environment, but to a great extent (11%-99%) they do not implement protection measures for themselves or their patients.18,53-55

**Accidents with Cutting or Piercing Devices**

Percutaneous contamination as a result of a cutting or piercing accident is the most effective means to transmit blood-borne pathogens. Evidence suggests that this is the main route of HIV, HBV, and HCV infection, especially if injuries are caused by hollow-bore needles that were used to draw blood or introduce an intravenous line.48,49 Over 20 other blood-borne pathogens have been transmitted by this means, including those causing herpes, malaria, and tuberculosis.60 The infectious risk after a percutaneous exposure to blood or body fluids from an HIV-positive person is 0.3%. Among health care providers lacking protective antibodies, the risk of HBV infection after an injury with a cutting or piercing device infected with hepatitis B antigen is approximately 37%; in the case of HCV it is 1.8% (0%-7%). Anesthesia staff lacking HBV protective antibodies are at high risk for acquiring the disease.61,62 These infection rates underscore the need for the use of “safe” needles and the need to advocate the use of “needleless” systems even though they are significantly more expensive. This also emphasizes the need for meticulous handling and disposal of needles and other sharp instruments as well as the use of special “sharps boxes” designed to minimize accidental needlesticks (e.g. “mail box” type boxes that do not allow the hand to enter the disposal area).63-78 The U.S. Centers for Disease Control and Prevention (CDC) has estimated that in the United States there are approximately 385,000 cutting and piercing accidents annually among health care providers in hospitals; 25% of these occur in the operating room.60 However, the actual prevalence is believed to be much greater because many of these events are unreported. The distribution of these accidents among anesthesiologists is shown in Figure 50-3A; the distribution of the elements most frequently associated with cutting and piercing injuries in health care providers is shown in Figure 50-3B. Should such an accident occur (needle puncture, exposure to nonintact skin, mucous membrane exposure) there are now specific recommendations.
regarding immediate assessment of risk, assessment of the exposure source (chart review, inform the patient that an accident has occurred and ask permission to determine HBV, HCV, and HIV serologic tests) and initiation of appropriate treatment of the health care worker. It is advised to obtain as much information regarding the patient as possible if the patient is known, to obtain a sample of blood from the patient for determination of potential carrier state (Table 50-4), and to report to the health service for immediate institution of prophylaxis and follow-up (Table 50-5), especially for HIV exposure (Tables 50-6 and 50-7).

**Table 50-4. Recommendations for the Contents of the Occupational Exposure Report**

- Date and time of exposure
- Details of the procedure being performed, including where and how the exposure occurred; if related to a sharp device, the type and brand of device; and how and when in the course of handling the device the exposure occurred
- Details of the exposure, including the type and amount of fluid or material and the severity of the exposure; for example, for a percutaneous exposure, depth of injury and whether fluid was injected and for a skin or mucous membrane exposure, the estimated volume of material and the condition of the skin (e.g., chapped, abraded, intact)
- Details about the exposure source (e.g., whether the source material contained hepatitis B virus, hepatitis C virus, or human immunodeficiency virus; if the source is infected with human immunodeficiency virus, the stage of disease, history of antiretroviral therapy, viral load, and antiretroviral resistance information, if known)
- Details about the exposed person (e.g., hepatitis B vaccination and vaccine-response status)
- Details about counseling, postexposure management, and follow-up

http://www.cdc.gov/mmwr/PDF/rr/rr5011.pdf
Modified with permission from Updated U.S. Public Health Service guidelines for the management of occupational exposures to HBV, HCV, and HIV and recommendations for postexposure prophylaxis. MMWR Recomm Rep 2001; 50:1-52.

**Table 50-5. Factors to Consider in Assessing the Need for Follow-up of Occupational Exposures**

**Type of Exposure**
- Percutaneous injury
- Mucous membrane exposure
- Nonintact skin exposure
- Bites resulting in blood exposure to either person involved

**Type and Amount of Fluid/Tissue**
- Blood
- Fluids containing blood
- Potentially infectious fluid or tissue (semen; vaginal secretions; and cerebrospinal, synovial, pleural, peritoneal, pericardial, and amniotic fluids)
- Direct contact with concentrated virus

**Infectious Status of Source**
- Presence of HBsAg
- Presence of HCV antibody
- Presence of HIV antibody

**Susceptibility of Exposed Person**
- Hepatitis B vaccine and vaccine response status
- HBV, HCV, and HIV immune status

http://www.cdc.gov/mmwr/PDF/rr/rr5011.pdf
Updated U.S. Public Health Service guidelines for the management of occupational exposures to HBV, HCV, and HIV and recommendations for postexposure prophylaxis. MMWR Recomm Rep 2001; 50:1-52.
### Table 50-6. Recommended HIV Postexposure Prophylaxis (PEP) for Percutaneous Injuries

| Exposure Type | Infection Status of Source | Source of Unknown HIV Status | Unknown Source | HIV-Negative |
|---------------|-----------------------------|-----------------------------|----------------|--------------|
| Less severe³  | Recommend basic 2-drug PEP  | Recommend expanded ≥3-drug PEP | Generally, no PEP warranted; however, consider basic 2-drug PEP³ for source with HIV risk factors⁴ | Generally, no PEP warranted; however, consider basic 2-drug PEP³ in settings in which exposure to HIV-infected persons is likely | No PEP warranted |
| More severe** | Recommend expanded 3-drug PEP | Recommend expanded ≥3-drug PEP | Generally, no PEP warranted; however, consider basic 2-drug PEP³ for source with HIV risk factors⁴ | Generally, no PEP warranted; however, consider basic 2-drug PEP³ in settings in which exposure to HIV-infected persons is likely | No PEP warranted |

³HIV-positive class 1: asymptomatic HIV infection or known low viral load (e.g., <1500 ribonucleic acid copies/mL). HIV-positive class 2: symptomatic HIV infection, acquired immunodeficiency syndrome, acute seroconversion, or known high viral load. If drug resistance is a concern, obtain expert consultation. Initiation of PEP should be delayed pending expert consultation, and because expert consultation alone cannot substitute for face-to-face counseling, resources should be available to provide immediate evaluation and follow-up care for all exposures.

¶The recommendation “consider PEP” indicates that PEP is optional; a decision to initiate PEP should be based on a discussion between the exposed person and the treating clinician regarding the risks versus benefits of PEP.

**If PEP is offered and administered and the source is later determined to be HIV-negative, PEP should be discontinued.

**For example, a major blood splash.

### Table 50-7. Recommended HIV Postexposure Prophylaxis (PEP) for Mucous Membrane Exposures and Nonintact Skin* Exposures

| Exposure Type | Infection Status of Source | Source of Unknown HIV Status | Unknown Source | HIV-Negative |
|---------------|-----------------------------|-----------------------------|----------------|--------------|
| Small volume⁷ | Consider basic 2-drug PEP⁶  | Recommend basic 2-drug PEP  | Generally, no PEP warranted** | Generally, no PEP warranted | No PEP warranted |
| Large volume²⁷ | Recommend basic 2-drug PEP  | Recommend expanded ≥3-drug PEP | Generally, no PEP warranted; however, consider basic 2-drug PEP³ for source with HIV risk factors** | Generally, no PEP warranted; however, consider basic 2-drug PEP³ in settings in which exposure to HIV-infected persons is likely | No PEP warranted |

*For skin exposures, follow-up is indicated only if evidence exists of compromised skin integrity (e.g., dermatitis, abrasion, or open wound).

³HIV-positive class 1: asymptomatic HIV infection or known low viral load (e.g., <1500 ribonucleic acid copies/mL). HIV-positive class 2: symptomatic HIV infection, acquired immunodeficiency syndrome, acute seroconversion, or known high viral load. If drug resistance is a concern, obtain expert consultation. Initiation of PEP should be delayed pending expert consultation, and because expert consultation alone cannot substitute for face-to-face counseling, resources should be available to provide immediate evaluation and follow-up care for all exposures.

²⁷For example, a major blood splash.

Updated U.S. Public Health Service guidelines for the management of occupational exposures to HBV, HCV, and HIV and recommendations for postexposure prophylaxis. MMWR Recomm Rep 2001; 50:1-52. Available at http://www.cdc.gov/mmwr/PDF/rr/rr5011.pdf
Strategy for Preventing Infection Transmission in Health Care Institutions

Institutional administrative measures aimed at developing, implementing, and monitoring specifically designed accident prevention policies and procedures are key factors in reducing and preventing transmission of infectious agents in health care centers. To this end, the center must take the following actions.  

- Include infection control as a major goal in the organizational mission statement and implement safety programs both for patients and health care workers.  
- Provide sufficient administrative and financial support to carry out this mission.  
- Provide sufficient administrative and financial support for the microbiology laboratory and implement an infection surveillance plan, especially for postsurgical infections.  
- Establish a multidisciplinary cross-functional team (e.g., a team manager, an epidemiologist, a representative from industrial health, a person trained in quality control) to identify health and safety issues within the institution, analyze trends, implement interventions, assess outcomes, and make recommendations to other members of the organization.  
- Provide sufficient administrative and financial support to develop and implement education programs for health care providers, patients, and their families. One positive example of such education is that anesthesiologists who have read the CDC’s Universal Precaution Guidelines for the Prevention of Occupational Transmission of HIV and HBV develop better hygienic practices.  
- Provide health care workers with hepatitis B vaccine and document that an appropriate immunologic response was achieved. Provide hepatitis B immune globulin (HBIG) for those exposed who do not have established immunity.  
- Provide a health care service for employees for counseling and post-exposure prophylaxis should an exposure to HIV occur.  
- Provide regular surveillance of health care workers to determine established immunity to infectious diseases such as tuberculosis, measles, mumps, rubella, and chickenpox. Lack of immunity may require immunization; several studies have demonstrated the cost-effectiveness of immunization (for prevention of disease) versus the cost of replacement of health care workers who have become infected.

Measures for Prevention of Infection Transmission in the Operating Room

Prevention of Air-borne Pathogen Transmission

Air-borne pathogens may be transmitted through the operating room heating, ventilation, and air conditioning systems. Thus, it is vital to have in place proper systems to (1) remove contaminated air, (2) facilitate air management requirements to protect susceptible health care providers and children against hospital-related air-borne pathogens, and (3) minimize the risk of air-borne pathogens being transmitted by children. Table 50-8 shows the 2003 HICPAC’s (Healthcare Infection Control Practices Advisory Committee) and CDC’s general recommendations for ventilation system specifications for the operating room. Children with tuberculosis require special consideration because of the high risk of occupational transmission of Mycobacterium tuberculosis, especially after the emergence of multidrug-resistant strains of M. tuberculosis (MDR-TB) (Table 50-9). An easy preventive measure is to screen all

Table 50-8. Ventilation System Specifications for the Operating Room

| Item                                      | Specification                                                   |
|-------------------------------------------|-----------------------------------------------------------------|
| Minimize the circulation of people during surgeries. | It has been proved that the level of microbes in the operating room air is directly proportional to the number of people moving inside the room. |
| Maintain humidity under 68% and temperature control to prevent environmental conditions that favor the development of germs. | Maintain positive pressure compared with corridors and surrounding areas to prevent microorganisms from entering the operating room. |
| Maintain positive pressure compared with corridors and surrounding areas to prevent microorganisms from entering the operating room. | Provide at least 15 air changes per hour in the operating room, 20% of which should be fresh air. Air should be recirculated through a high-efficiency particulate air (HEPA) filter. |
| Air should be introduced at ceiling level and disposed of at ground level. | Provide at least 15 air changes per hour in the operating room, 20% of which should be fresh air. Air should be recirculated through a high-efficiency particulate air (HEPA) filter. |

Guidelines for environmental infection control in health-care facilities: recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). 2003. www.cdc.gov/ncidod/dhqp/gl_environinfection.html

Table 50-9. Summary of Recommended Tuberculosis Control Guidelines

| Item                                      | Specification                                                   |
|-------------------------------------------|-----------------------------------------------------------------|
| Early diagnosis                           | Availability and access to diagnostic tests                      |
| Improved tests and reporting of results   | Source controls                                                  |
| Containment of infectious nuclei from coughs and sneezes | Personal respirators                                               |
| Patient isolation                         | Engineering controls                                             |
| Negative-pressure patient environments*   | Ultraviolet light sources                                        |
| Minimum of 6 air changes per hour         | High-efficiency particulate air (HEPA) filters                   |
| Ultraviolet light sources                 | Personal respirators                                             |
| Decontamination                           | Sterilization and disinfection of equipment                      |
| Screening/treatment                       | Annual tuberculin testing                                       |
| Availability and compliance with chemoprophylaxis | Annual tuberculin testing                                       |
| Bacille Calmette-Guérin (BCG) vaccination | *Negative-pressure rooms are to prevent the escape of contaminated air to the outside. |

From Tait A: Occupational transmission of tuberculosis: implications for anesthesiologists. Anest Analg 1997; 85:444-451.
Standard Precautions

Standard Precautions\textsuperscript{57} assume that any person or patient is potentially infected or colonized by microorganisms that could be transmitted and cause an infectious process. Standard Precautions must be implemented with all patients and include:

- Universal Precautions—Blood and Body Fluid Precautions, developed to reduce blood-borne pathogen transmission
- Body Substance Isolation, designed to reduce the risk of pathogen transmission by moist body substances

Standard Precautions are used to reduce the transmission of all infectious agents from one person to another, thus protecting health care providers and children against exposure to the most common microorganisms. Standard Precautions are implemented for any contact with blood and body fluids, secretions, and excretions (except sweat), whether or not they contain visible blood, as well as for any contact with non-intact skin, mucous membranes, and intact skin that is visibly soiled with blood and/or body fluids. Summaries of Standard Precautions, Droplet Precautions, Air-borne Precautions, and Contact Precautions are available online.\textsuperscript{35-36}

### Hand Washing

Hand washing is considered the most important and cost-effective individual intervention in the prevention of hospital-acquired infections in children and health care providers.\textsuperscript{37} Its significance in medical practice had not been universally accepted despite the pioneering work by Oliver Wendell Holmes\textsuperscript{38} (1843) and Ignaz Semmelweis\textsuperscript{39} (1846), who separately recognized the role of the contaminated hands of physicians performing autopsies in the spread of puerperal fever due to \textit{Streptococcus} sepsis and how by washing their hands before delivering a baby they could reduce maternal mortality by 90%!

Unfortunately, the scientific basis for hand washing was not established until the introduction of the germ theory of disease by Louis Pasteur\textsuperscript{100} and the discovery of the microorganism that caused anthrax (\textit{Bacillus anthracis}) by Robert Koch\textsuperscript{101} in the late 19th century. More than one and a half centuries later, and with strong evidence that health care providers are one of the most frequent sources of infection transmission among patients,\textsuperscript{102} health care providers’ compliance with hand hygiene protocols in the hospital environment is generally small (5%-48%) and difficult to change,\textsuperscript{103-106} especially in intensive care areas, operating rooms, and postanesthesia care units. The risk of pathogen transmission through the hands is proportional to the power of the number of times a child is touched.\textsuperscript{118} Table 50-10 presents a summary of the indications for hand washing and antisepsis.

| Table 50-10. Indications for Hand Washing and Antisepsis |
|---------------------------------------------------------|
| Hand washing is defined as a process for removal of soil and transient microorganisms from the hands. Hands should be washed with soap and water or disinfected. |
| 1. When hands are visibly dirty or contaminated with proteinaceous material or are visibly soiled with blood or other body fluids, wash hands with either a non-antimicrobial soap and water or an antimicrobial soap and water. |
| 2. If hands are not visibly soiled, use an alcohol-based hand rub for routinely decontaminating hands in all other clinical situations described in items 3 to 10. Alternatively, wash hands with an antimicrobial soap and water in all clinical situations described in items 3 to 10. |
| 3. Decontaminate hands before having direct contact with patients. |
| 4. Decontaminate hands before donning sterile gloves when inserting a central intravascular catheter. |
| 5. Decontaminate hands before inserting indwelling urinary catheters, peripheral vascular catheters, or other invasive devices that do not require a surgical procedure. |
| 6. Decontaminate hands after contact with a patient’s intact skin (e.g., when taking a pulse or blood pressure and lifting a patient). |
| 7. Decontaminate hands after contact with body fluids or excretions, mucous membranes, non-intact skin, and wound dressings if hands are not visibly soiled. |
| 8. Decontaminate hands if moving from a contaminated body site to a clean body site during patient care. Decontaminate hands after contact with inanimate objects (including medical equipment) in the immediate vicinity of the patient. |
| 9. Decontaminate hands after removing gloves. |
| 10. Before eating and after using a rest room, wash hands with a non-antimicrobial soap and water or with an antimicrobial soap and water. |
| 11. Antimicrobial-impregnated wipes (i.e., towelettes) may be considered as an alternative to washing hands with non-antimicrobial soap and water. Because they are not as effective as alcohol-based hand rubs or washing hands with an antimicrobial soap and water for reducing bacterial counts on the hands of health care workers, they are not a substitute for using an alcohol-based hand rub or antimicrobial soap. |
| 12. Wash hands with non-antimicrobial soap and water or with antimicrobial soap and water if exposure to \textit{Bacillus anthracis} is suspected or proven. The physical action of washing and rinsing hands under such circumstances is recommended because alcohols, chlorhexidine, iodophors, and other antiseptic agents have poor activity against spores. |

Modified from Boyce JM, Pittet D: Guideline for Hand Hygiene in Health-Care Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HIPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Am J Infect Control 2002; 30:S1-S46.
An important addition to the 2002 CDC Hand Washing Guide is to use alcohol-based hand rubs, because they work more rapidly (10-20 seconds compared with 90-120 for hand washing) and can be used while amputating. These advantages preclude the usual objections of health care workers to hand washing that include a lack of time, absence of sinks, and skin damage. Furthermore, the scarcity of water in developing countries would no longer be a constraint against hand hygiene.

After hand washing, it is very important to dry them properly with appropriate paper towels, hot air flow, or both, because the level of pathogen transmission from a health care worker’s hands to a patient is greatly increased if the hands are wet. Transmission may also occur from patients’ wet sites, such as groins or armpits, or when a health care worker gets his or her hands wet when opening parenteral solutions. It is critical for health institutions to establish written procedures and protocols to support adherence to the recommended hand hygiene practices.

Gloves

Wearing clean or sterile gloves while caring for children is an effective means of reducing hospital-acquired infections. Gloves remain a supplementary barrier to infection that should not replace proper hand hygiene. Gloves protect patients by reducing health care provider hand contamination and the subsequent transmission of pathogens to other children, provided the gloves are changed between patients. Additionally, when the use of gloves is combined with CDC Standard Precautions, they protect the health care provider against exposure to blood-borne infections or infections transmitted by any other body fluids, such as excretions, secretions (except sweat), mucous membranes, and non-intact skin.

Recommendation for the use of gloves include:

- Wear gloves in case of contact with blood or any other potentially infecting body fluid such as excretions, secretions (except sweat), mucous membranes, and non-intact skin.
- Remove the gloves immediately after providing care to a child. Staff should not wear the same pair of gloves to take care of more than one child, nor should they touch the surfaces of any equipment, monitoring devices, or even light switches. Contaminated gloves can pass blood or other body fluids to working areas and have proved to be a vector for hepatitis transmission.
- Change gloves when taking care of a child if you must move from a contaminated to a clean body site.
- Apply hand hygiene measures immediately after removing the gloves because, despite the use of gloves, hands may get contaminated through small holes in the gloves.
- Remove the gloves by using an appropriate technique (so as not to contaminate your hands with the contaminated surface of the gloves).
- Alcohol-based hand rub dispensers and clean glove boxes (at least two sizes) should be in place near every patient care site.
- Disposable gloves should not be washed, resterilized, or disinfected. If gloves are reused, appropriate reprocessing methods should be in place to ensure the physical integrity of the gloves and their full decontamination.
- Sterile gloves are much more expensive than clean, disposable gloves and should be used only for certain procedures, such as when hands are in contact with normally sterile body areas or when inserting intravascular or urinary catheters. Clean gloves should be used during any other procedure, including wound dressing.
- Latex free gloves should be worn when caring for children at risk for latex allergy.

Antimicrobial Prophylaxis

Surgical antimicrobial prophylaxis is an essential tool to reduce the risk of postoperative infections, and the anesthesia team plays a central role in ensuring the proper timing of drug administration. The aim of the perioperative administration of antibiotics is to obtain plasma and tissue drug levels exceeding the minimal inhibitory concentration of those organisms most likely to cause an infection. This will reduce the microbial load of the intraoperative contamination to a level not exceeding the host defenses; it is not the intent to cover all possible pathogens, because this can lead to the selection of drug-resistant bacteria.

Selection of the Antimicrobial Agent

Several antimicrobial prophylaxis guidelines have been published (Table 50-11). For most surgical procedures that do not involve chronically colonized organs, the most common pathogens are the skin flora, Strepococcus and Staphylococcus. A first-generation cephalosporin (i.e., cefazolin) can provide cost-effective coverage for these organisms. Surgical procedures that involve contamination from the bowel require antibiotic treatment against gram-negative and anaerobic pathogens. For these procedures, cefoxitin, cefotetan, or a second-generation cephalosporin is appropriate. The selection of antibiotics requires consideration of resistance patterns as determined by local microbiology or health center infectious disease departments. The newer-generation broad-spectrum antibiotics should not be used for routine antibiotic prophylaxis but should be reserved for the treatment of resistant organisms. Moreover, the dose of antibiotic selected should be based on the child’s weight or body mass index; administration should be repeated intraoperatively if surgery exceeds more than two half-lives after the first antibiotic administration (see Table 50-11), if the duration of surgery exceeds 4 to 8 hours, if blood loss is extreme, or if the drug has a particularly short half-life (e.g., penicillin or cefoxitin) to ensure appropriate tissue concentrations of antibiotic until wound closure.

The Timing of Antibiotic Prophylaxis

A key element in the prevention of surgical site infection is the timely administration of prophylactic antibiotics. For most surgical procedures, a single prophylactic dose of antibiotics should be administered 30 to 60 minutes before the skin incision. This should provide appropriate plasma concentrations of the antibiotic. However, in the case of children, intravenous access is often established after induction of anesthesia. With a brief time interval between establishing intravenous access and skin
### Table 50-11. Suggested Initial Dose and Time to Redosing for Antimicrobials Commonly Used for Surgical Prophylaxis

| Antimicrobial | Half-Life Normal Renal Function (hr) | Half-Life End-Stage Renal Disease (hr) | Recommended Infusion Time (min) | Standard Intravenous Dose (g) | Weight-Based Dose Recommendation* (mg) | Recommended Dosing Interval† (hr) |
|---------------|--------------------------------------|---------------------------------------|--------------------------------|----------------------------|----------------------------------------|-------------------------------|
| Aztreonam     | 1.5-2                                | 6                                     | 3-5†                           | 1-2                        | Max 2 g (adults)                      | 3-5                           |
| Ciprofloxacin | 3.5-5                                | 5-9                                   | 1-2                            | 20-30 mg/kg                | 1 g < 80 kg                          | 2-5                           |
| Cefazolin     | 1.2-2.5                               | 40-70                                 | 3-5†                           | 1-2                        | 50 mg/kg                              |                              |
| Cefuroxime    | 1-2                                   | 15-22                                 | 3-5†                           | 1-2                        | 50 mg/kg                              |                              |
| Cefamandole   | 0.5-2.1                               | 12.3-18†                              | 3-5†                           | 1-2                        | 50 mg/kg                              |                              |
| Cefotetan     | 2.8-4.6                               | 13-25                                 | 3-5†                           | 1-2                        | 20-40 mg/kg                           | 3-6                           |
| Clindamycin   | 2-5.1                                 | 3.5-5.0†                              | 10-60                          | 600-900                    | <10 kg: at least 37.5 mg              | 3-6                           |
| Erythromycin  | 0.8-3                                 | 5-6                                   | NA                             | 9-13 mg/kg                 | NA                                    |                              |
| Gentamicin    | 2-3                                   | 50-70                                 | 1.5 mg/kg**                    | See footnote**              | 3-6                                   |
| Neomycin      | 2-3 hours (3% absorbed under normal Gl conditions) | 12-24 NA | 1 g orally 19, 18, 9 hr before surgery | NA | 20 mg/kg | NA |
| Metronidazole | 6-14                                  | 7-21 no change                        | 30-60                          | 15 mg/kg (adult)           | 7.5 mg/kg on subsequent doses         | 6-8                           |
| Vancomycin    | 4-6                                   | 44.1-406.4 (Clcr <10 mL/min)          | 1 g ≥ 60 min (use longer infusion time if dose < 1 g) | 1.0 | 10-15 mg/kg (adult) | 6-12 |

*Weight-based doses are primarily from published pediatric recommendations.  
†For procedures of long duration, antimicrobials should be redosed at intervals of 1 to 2 times the half-life of the drug. The intervals in the table were calculated for patients with normal renal function.  
‡Dose injected directly into vein or running intravenous fluids.  
§Intermittent intravenous infusion.  
||In patients with a serum creatinine value of 5 to 9 mg/dL.  
¶The half-life of clindamycin is the same or slightly increased in patients with end-stage renal disease compared with patients with normal renal function.  
**If the patient's weight is 30% above the ideal body weight, dosing weight can be determined as follows: DW = IBW + 0.4 (total body weight – IBW). DW, dosing weight; IBW, ideal body weight; NA, not applicable.

incision, it is important to administer the antibiotics as soon as possible after intravenous access is established. If vancomycin must be used for prophylaxis, it should be infused slowly over 60 minutes (to minimize the risk of severe hypotension) beginning within 2 hours of skin incision. If a tourniquet is required, the full antibiotic dose should be administered before the tourniquet is pressurized.126 Postsurgical prophylactic antibiotics are not necessary for most procedures and should generally be stopped within 24 hours after the surgical procedure.126

### Allergy to β-Lactams

Several studies have shown that the true incidence of allergy is less than that reflected in medical charts.127 For surgical procedures where cephalosporins are the prophylaxis of choice, alternative antibiotics should be administered to those children at high risk for serious adverse reactions or allergy, based on their history or diagnostic tests (e.g., skin testing). However, the incidence of adverse reactions to cephalosporins in children with reported allergy to penicillin is rare; furthermore, skin testing does not reliably predict the likelihood of adverse reactions to cephalosporins in those with reported allergy to penicillin.128-130 For the most part, “allergies” to oral antibiotics that appear on children’s charts (rash, vomiting, gastrointestinal disturbances) are reactions to the additives in the antibiotic formulation including food dyes, fillers, and other compounds. Intravenous administration of small test doses of the pure
antibiotics in a fully monitored (and anesthetized) child with a so-called allergy may be used to establish the child’s susceptibility to an allergic reaction to the antibiotic.

In the case of surgical procedures where antibiotic prophylaxis is mainly directed at gram-positive cocci, children who are truly allergic to β-lactams (cephalosporins) should receive either vancomycin or clindamycin.122

**Indications for Prophylactic Antibiotics**

Surgical wounds are classified in four categories (Table 50-12). The use of antibiotic prophylaxis for postoperative infections is well established for clean-contaminated procedures. Within the clean category, prophylaxis has been traditionally reserved for surgical procedures involving a foreign body implantation or for any surgical procedure where a surgical site infection would be catastrophic (e.g., cardiac surgery or neurosurgical procedures). However, there is evidence to demonstrate that postoperative infections resulting from procedures not involving prosthetic elements are underreported; estimates show that over 50% of all complications occur after the patient is discharged from hospital and are unrecognized by the surgical team. Therefore, antibiotic prophylaxis is also recommended for certain procedures such as herniorrhaphy.131,132 The direct and indirect costs of these complications will not affect the hospital budget; however, they represent a high cost for the community at large. In the case of contaminated or dirty procedures, bacterial contamination or infection is established before the procedure begins. Accordingly, the perioperative administration of antibiotics is a therapeutic, not a prophylactic, measure. The use of antibiotics in children has implications not only for the response to the current treatment but also to future treatments. Thus, all medical professionals are jointly responsible for the rational use of antibiotics.

Protocols, although effective, require continuous feedback on their acceptance and surgical site infection results. No surgical protocol can replace the judgment of the medical professional; clinical reasoning must be tailored to the individual circumstances. Finally, children with congenital heart disease and many of those with repaired congenital heart disease will require subacute bacterial endocarditis prophylaxis (see also Tables 14-1 and 14-2).131

### Table 50-12. Wound Classification System

| Wound Category     | Description                                                                 |
|--------------------|-----------------------------------------------------------------------------|
| Class I/clean      | Uninfected wound with no inflammation and the respiratory, alimentary, genital, or uninfected urinary tract is not entered. Clean wounds primarily are closed and drained, when necessary, with closed drainage. Operative wounds after blunt trauma may be included in this category if they meet criteria. |
| Class II/clean contaminated | Operative wound in which the respiratory, alimentary, genital, or urinary tract is entered under controlled conditions and without unusual contamination. Specifically, operations involving the biliary tract, appendix, vagina, and oropharynx are included in the category, provided no evidence of infection or major break in technique is encountered. |
| Class III/contaminated | Open, fresh, accidental wounds; operations with major breaks in sterile technique (e.g., open cardiac massage) or gross spillage from the gastrointestinal tract; and incisions in which acute, nonpurulent inflammation is encountered. |
| Class IV/dirty-infected | Old traumatic wounds with retained devitalized tissue and those that involve existing clinical infection or perforated viscera, suggesting that the organisms causing postoperative infection were present in the operative field before operation. |

From Neville HL, Lally KP: Pediatric surgical wound infections. Semin Pediatr Infect Dis 2001; 12:124-129.