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Burden of Illness and Scope of the Problem

Children ill enough to require admission to a critical care unit are among the most vulnerable to infection in the hospital. Normal physical defenses such as skin integrity, the cough reflex, and gastric motility are interrupted in the critically ill child. Innate and adaptive immunity are compromised during high-acuity acute illness. Broad-spectrum antibiotics used as empiric therapy for suspected sepsis may disrupt normal protective flora and permit overgrowth by pathogenic bacteria and fungi. Younger children are more likely to require intensive care unit (ICU) admission than older children; this age group has a maturing immune system and may not have completed the full series of all routine childhood vaccines.

The most common health care–associated infections (HAIs) in the pediatric ICU (PICU) are primary bloodstream infections (BSIs) (28%), ventilator-associated pneumonia (21%), and catheter-associated urinary tract infections (15%). HAIs increase length of stay and morbidity and mortality rates for both adult and pediatric critically ill patients. This translates to an economic burden on the system as a whole.

There has been renewed emphasis in the last decade on systematic strategies for preventing HAIs, both from a patient safety perspective and in an effort to reduce the cost of health care. In a public health care system, it is often argued that money is not saved by improving efficiency because each patient discharged is replaced by a new patient with comparable overall costs. In this context, the incentive to reduce HAIs is perhaps more on the ability to help decrease ICU and hospital length of stay and therefore improve access to the system. Infection prevention and control, patient safety, patient advocates, and health care providers alike see the value of improved health outcomes associated with reduction in nosocomial infections.

This chapter reviews the epidemiologic principles underlying infection prevention and control measures and recommends interventions to prevent the most common HAIs in the PICU.
wards of an Austrian maternity hospital and subsequently observed a reduction in the rates of puerperal fever. In this instance, the initiation of hand hygiene after patient contact (cadavers) interrupted the spread of the infectious agent (group A Streptococcus) via the route of transmission (hands). Over time the epidemiologic roles of the susceptible host, the infected person, and the route of infection were more clearly elucidated and came to be known as the chain of infection. The interaction among these three components is dynamic, and infection may be favored when the host is more susceptible, the infectious agent is more virulent, and the route of transmission is more facilitating.

Children, long recognized as not just “little adults,” are unique hosts because of their continuing physical, neuro-development, and immunologic change and development from infancy through adolescence. Children, especially infants, lack immunity to many pathogens because they have not been exposed through infection or immunization. They are prone to multiple viral infections during any year and naturally share them. Young children are not developmentally capable of understanding or performing good self-hygiene.

The nature of a children’s hospital can also put children at risk of developing an HAI. Open design wards and critical care units rather than single-room design, shared toys, pet visiting, and communal play areas provide many opportunities for transmission of infection.

Once admitted to the ICU, children become more vulnerable to infection because of the interventions needed to provide life-sustaining care as well as the close contact of multiple care providers. An infectious agent that is a harmless or helpful commensal in a normal host can become a life-threatening pathogen in the ICU patient. Because of frequent antibiotic use, the spectrum of infecting microorganisms in the hospital, particularly the ICU, are usually more pathogenic that those acquired in the community setting. Finally, the route of transmission of infection in the ICU is facilitated through frequent patient contact by health care workers, use of mechanical devices and medical therapies that disrupt natural defenses, and inadequate attention to infection prevention and control measures that prevent spread of infection to and between patients (Box 97-1).

**Routes of Infectious Disease Transmission**

Infectious diseases, whether bacterial, viral, protozoal, fungal, or helminthic, are transmitted via one or more of three routes, usually categorized for infection control purposes as contact (direct or indirect), droplet, or airborne (Table 97-1).

Contact transmission includes direct contact and indirect contact. **Direct contact** transmission occurs when organisms are transferred through physical contact from an infected or colonized person to a susceptible host. **Indirect contact** transmission occurs when microorganisms are passively transferred to a susceptible host via an intermediate object, such as a contaminated medical device, inanimate objects in the patient’s physical environment, or contaminated hands.

Droplet transmission is the transfer of microorganisms through large droplets (≥5 μm in diameter) generated from the respiratory tract of an infected or colonized person (the source) that are propelled 1 to 2 meters from the source and land on the nasal or oral mucosa of the susceptible host or in the immediate environment. The droplets can be propelled from the respiratory tract in the course of coughing, sneezing, vomiting, or singing or during procedures such as suctioning. These large droplets are propelled a distance of less than 2 meters through the air but do not remain suspended in the air; that is, they do not become aerosolized.

Airborne transmission refers to the spread of microorganisms in particles that are very small (<5 μm) and can therefore remain suspended in the air and widely dispersed by currents to places far from the host. Airborne particles are created through the evaporation of large droplets or may exist in dust particles containing skin squames and other debris.

**Infection Prevention and Control Measures**

**The Infection Prevention and Control team**

Prevention of infection in patients receiving health care is the responsibility of all health care providers. Although Infection Prevention and Control Professionals (ICP) provide an essential expertise, it is important that the PICU team establish ongoing multidisciplinary processes to reduce infection risk. Among the activities the multidisciplinary team will address are the integration of surveillance data into formal plans for

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**Table 97-1**: Factors that Influence Risk of Infection in the PICU

| Factors that Influence Exposure |
|-------------------------------|
| Host Factors                  |
| Loss of skin integrity (e.g., intravascular devices) |
| Loss of respiratory defenses such as cough, cilia propulsion (e.g., intubation, sedation) |
| Loss of gastrointestinal defenses such as low pH, motility (e.g., use of H2 blockers, nasogastric tubes) |
| Anatomic defect (e.g., surgical site) |

| Environmental Features |
|------------------------|
| Crowding in the ICU |
| High patient/health care worker ratios (decreased time for infection prevention measures) |
| Use of prophylactic antibiotics (alters colonizing normal flora, allows overgrowth of pathogens) |
| Infection prevention and control practices of ICU health care workers |
| Immunization status of health care workers |
| Visitor policies |
| Reservoirs of infectious organisms in the ICU (e.g., health care workers who are carriers, environmental reservoirs) |

| Factors that Influence Likelihood of Infection if Exposed |
|--------------------------------------------------------|
| Host Factors |
| Age |
| Gender |
| Genetic makeup |
| Coexisting infection |
| Nutritional status |
| Use of immunosuppressive agents, including systemic steroids |
| Immunization status |
| Immune deficiency |

| Infectious Agent |
|------------------|
| Virulence |
| Antimicrobial resistance |
improvement of patient care at regular intervals and designing and implementing quality improvement initiatives. The collaborators in these initiatives can be infection control practitioners, the hospital epidemiologist or medical director of infection control, a clinical pharmacist, members of quality and patient safety departments, and representatives from nursing, ICU physicians, and respiratory therapy. Others may be needed depending on the issue at hand, such as housekeeping or information technology.

Isolation Practices: Standard Precautions and Additional (Transmission-Based) Precautions

Schema to classify infection prevention and control techniques have evolved over time from systems in which a microbiologic laboratory isolate was required (e.g., disease-specific *Salmonella* diarrhea isolation), to systems focused on preventing transmission of blood-borne diseases to health care workers (Universal Precautions), to the present system in which certain practices are followed continuously with all patients and supplemented based on syndromic presentation and/or specific laboratory diagnoses. In Canada and the United States, the procedures and practices that should be continuously practiced in health care settings are termed Standard Precautions and Routine Practices, respectively, and are briefly outlined in Table 97–1. The concept of Standard Precautions, in which the health care worker has a responsibility to practice certain behaviors (e.g., hand hygiene) or use certain interventions (e.g., wear a mask when face-to-face with a coughing patient) based on a recognition of the need to do so rather than because they were asked to do so, has not yet been universally adopted in health care settings. Training in these skills should be considered an essential component of health care worker competency.

Types of isolation practices (routine, additional) are based on the scientific understanding of how infectious diseases are transmitted from a host or inanimate reservoir to a susceptible host and aim to control or eliminate the reservoir or infectious agent, interrupt transmission, and protect susceptible persons.

If a patient has symptoms that could be caused by an infection (e.g., cough, diarrhea, rash) or diagnosis of a communicable infectious disease, then Additional Precautions may be required in addition to Standard Precautions.3 The three types of Additional Precautions are contact, droplet, and airborne. A full description of the rationale for these precautions and the specific information needed to apply them is beyond the scope of this chapter; readers are referred to comprehensive guidelines available from public health agencies such as the U.S. Centers for Disease Control and Prevention (CDC) or from the relevant agency in the jurisdiction in which they practice. A useful guide when deciding which type of precautions to use for an individual patient is the “Red Book” of the Infectious Diseases Committee of the American Academy of Pediatrics; each institution will also have its own infection control manual.

The basic components of Standard Precautions are hand hygiene, use of personal protective equipment (PPE) (e.g., gowns, gloves, masks, face shields) based on the nature of the health care worker-patient interaction and the extent of anticipated body fluid exposure, respiratory/cough etiquette, and safe injection practices. As previously emphasized, Standard Precautions are to be integrated into all patient care activities, regardless of the clinical status of the patient. Additional, or transmission-based, precautions are used when the route(s) of transmission are not completely interrupted by using Standard Precautions alone.3

### Table 97–1 Modes of Transmission of Microorganisms in the ICU

| Mode of Transmission | How Organisms Are Transmitted | Example |
|----------------------|-------------------------------|---------|
| Direct               | Direct physical contact between an infected or colonized individual and a susceptible host. | Visitor asymptatically shedding herpes simplex virus kisses postoperative transplant patient. |
| Indirect             | Passive transfer of microorganisms to a susceptible host via an intermediate object such as contaminated hands that are not washed between patients or contaminated instruments or other inanimate objects in the patient’s immediate environment. | Health care worker provides care to patient with *Clostridium difficile* diarrhea, does not perform adequate hand hygiene, then enters room of a noncolonized patient and handles bedding and bedrails, leaving *C. difficile* spores in susceptible patient’s environment. |
| Droplet              | Large droplets (≥5 μm in diameter) generated from the respiratory tract of the source (infected individual) during coughing or sneezing or during procedures such as suctioning or bronchoscopy. These droplets are propelled a distance of <1 m through the air and are deposited on the nasal or oral mucosa of the new host (newly infected individual) or in the immediate environment. These large droplets do not remain suspended in the air; therefore special ventilation is not required since true aerosolization (see below) does not occur. | Health care worker with influenza virus infection sheds respiratory secretions on the face of a PICU patient. |
| Airborne             | Dissemination of microorganisms by aerosolization. Organisms are contained in droplet nuclei, airborne particles <5 μm in size that result from evaporation of large droplets, or in dust particles containing skin squames and other debris that remain suspended in the air for long periods. Such microorganisms are widely dispersed by air currents and inhaled by susceptible hosts who may be some distance away from the source patients or individuals, even in different rooms or hospital wards. | Patient with measles is housed on an open ward in the emergency department; airborne virus particles are carried throughout the department and inhaled by susceptible hosts. |
Respiratory Etiquette/Cough Hygiene are measures to contain respiratory secretions and include covering one’s cough (e.g., coughing into a tissue or the elbow), promptly disposing of tissues, and performing hand hygiene after touching respiratory secretions.

Safe Injection Practices are basic principles of aseptic technique in the preparation and delivery of parenteral medication that limit the risk of infectious disease transmission for both the health care provider and the patient. They include preferential use of single-dose over multidose vials and use of sterile, single-use, disposable needles (needleless access devices) and syringes.

Infection Control Practices for special lumbar puncture procedures are the donning of a face mask and sterile gloves by the health care worker when placing a catheter or injecting material into the spinal space. These recommendations were made after a number of postmyelography meningitis cases occurred without such precautions.

Contact Precautions are intended to prevent transmission of infectious agents, including epidemiologically important microorganisms, that are spread by direct or indirect contact with the patient or the patient’s environment. In addition to Standard Precautions, for example, gloves are required for all entries to a patient’s room rather than just when patient interaction will occur.

Droplet Precautions are intended to prevent transmission of pathogens through close respiratory or mucous membrane contact with respiratory secretions. In addition to Standard Precautions, for example, health care workers and others coming within 3 to 6 feet of a patient on Droplet Precautions would be required to wear facial protection (mask, goggles, and/or face shield), a gown, and gloves. A child on Droplet Precautions would generally be placed in a room alone to avoid contact with other children. (Note: Some guidelines refer to a 3-foot perimeter of an infectious person on Droplet Precautions, and others refer to a 6-foot distance. The worldwide experience with the severe acute respiratory syndrome (SARS) virus, in which droplet transmission may have occurred up to 6 feet from the source, has led some jurisdictions to implement a 6-foot perimeter for droplet precautions.)

Airborne Precautions prevent transmission of infectious agents that remain infectious over long distances when suspended in the air. A patient on Airborne Precautions must be placed in a room alone with special air handling and ventilation capacity. PPE that should be donned by health care workers entering the room of a patient on Airborne Precautions includes a gown, gloves, and a surgical (procedure) mask or respirator depending on the disease encountered.

Patient placement is the determination of which physical setting is safest for the child while minimizing risk of transmission of infectious disease from a potentially or definitely infected patient. Within Additional Precautions recommendations include guidance about the need for a single room (e.g., whether shared rooms are acceptable) or whether a room with special air handling is required.

There are inherent safety risks associated with isolation practices. Isolation practices such as single rooms and PPE may limit the number and type of encounters health care workers have with patients because of the cumbersome nature of entering a room, breaking coverage, the discomfort of certain PPE, and the need to come and go to bring equipment, documentation, and other materials. Limited encounters may inhibit the critical care team’s ability to access and assess accurately the child and family. Adult studies have demonstrated a negative correlation between patient safety and infection isolation as well as increased HAI with lower nurse/patient ratios. Although no conclusions can be drawn regarding recommended staffing levels for isolated patients in the PICU, this evidence suggests that increased vigilance is warranted for these critically ill children.

**Hand Hygiene**

Contaminated hands of health care workers have been shown in many studies to transmit health care–associated pathogens. The World Health Organization Patient Safety initiative on hand hygiene emphasizes five moments for hand hygiene: before touching a patient, before clean/aseptic procedures, after body fluid exposure/risk, after touching a patient, and after touching patient surroundings.

The advent of waterless hand hygiene agents has been a particularly important development for the critical care setting because of superior antimicrobial killing, time saved compared with water-based handwashing, rapid action, no risk of antimicrobial resistance, and the ease with which waterless agents can be stationed close to the point of patient care. Alcohol-based hand rubs are in general the preferred hand hygiene product for all health care settings.

When hands have visible dirt or organic matter (e.g., blood) they must be cleaned with water and soap.

Although the benefits of proper hand hygiene far outweigh the risks, skin irritation and health care worker attitudes about hand hygiene products can be an impediment to compliance and satisfaction with hand hygiene agents and must be considered when choosing a particular product in a specific health care setting.

**Personal Protective Equipment**

PPE consists of clothing or devices donned by health care workers for their safety or protection while performing potentially hazardous patient care activity. To interrupt infectious disease transmission, eye protection (goggles or face shield), masks, gowns, and gloves may be worn as a part of Standard Precautions and Transmission-Based Precautions.

A surgical (procedure) mask provides adequate facial protection against droplets generated from the respiratory tract. Surgical masks are also used for source control (e.g., on a coughing patient) as a part of respiratory hygiene/cough etiquette. To protect against airborne particles, a particulate filtering face piece respirator is required because it is thought to filter at least 95% of the smaller airborne particles.

Airborne particles are known to be produced in certain infectious diseases (e.g., tuberculosis, varicella, measles) or may be produced during aerosol-generating procedures in the ICU (e.g., intubation) in patients with respiratory infections (e.g., influenza, SARS). The choice of mask type became a controversial topic during the influenza A H1N1 pandemic that began in 2009, with different jurisdictions recommending procedure masks for health care worker protection during non-aerosol-generating procedures in patients with suspected influenza and others recommending respirators. There is little evidence to suggest that influenza is transmitted through the airborne route; in a recent randomized controlled trial surgical masks
were not inferior to respirators in preventing influenza trans-
mission.12 Readers are referred to local public health and infec-
tion control authorities for jurisdiction-specific guidance.

Surveillance

Surveillance for HAIs in a PICU is a process in which infor-
mation about infections acquired after admission are sum-
marized and given back to the care team in a timely manner so that problems can be identified for action. Surveillance has been defined as “a systematic method of collecting, conso-
dating, and analyzing data concerning the distribution and
determinants of a given disease or event, followed by the dis-
semination of that information to those who can improve outcomes.”13

Although an HAI could occur in any body system to a
patient admitted anywhere in the hospital, historical systems of
total hospital surveillance are no longer seen as wise use of
scarce resources. Surveillance “by objective” was introduced in
the 1980s and has led to systems focused on “targets” that
cause the most morbidity or mortality, are frequent, or
are remediable.14 In the PICU, the most important are BSIs
and ventilator-associated pneumonia.15,16 Other important
surveillance targets in the PICU are urinary tract infec-
tion associated with catheterization, surgical site infections
such as mediastinitis, and acquisition of epidemiologically
important pathogens such as methicillin-resistant Staphylo-
coccus aureus (MRSA) or vancomycin-resistant enterococcus
(VRE).

The National Health Safety Network (NHSN) of the CDC
is a national surveillance system that collects data from a
sample of health care facilities that voluntarily submit data
on the occurrence of certain HAIs. Because standardized
methodology and definitions and risk-adjusted data are used in
the NHSN, the surveillance data permit recognition of
trends, identification of practices associated with prevention
of HAIs, and comparison of rates within and between facili-
ties.17 Relevant to the PICU setting, NHSN reports central
line–associated BSI (CLA-BSI) rates (number of infections
per central line days), central line utilization ratio (central line
days per patient days), urinary catheter–associated infection
(UTI) rate and utilization ratios, and ventilator-associated
pneumonia (VAP) rate (VAP days per ventilator days) and
utilization. It is important to note that these rates are device
specific and therefore incorporate the effect of exposure to an
important risk factor. Surveillance results from the NHSN are
updated periodically and published in medical journals and
on the CDC website.

Standard surveillance definitions have been developed by
the CDC (Table 97-2).18 The CDC definitions incorporate
subcategories for children younger than 1 year in recogni-
tion of the variable clinical presentation of infection by age.
However, CDC definitions may be difficult to apply in chil-
dren, and alternative approaches have been explored.19-23
Surveillance definitions fulfill a different purpose than inclu-
sion/exclusion criteria for clinical trial enrollment, or than
the diagnosis of illness by a clinician. Surveillance definitions
consistently identify indicators of HAI over time and between
settings.

Identification, synthesis, interpretation, and report gen-
eration of HAI surveillance data in the health care setting
are performed by infection control professionals.4 These
professionals have completed certification requirements, have
achieved competence in infection prevention and control
practice,24 and have been shown to perform HAI surveillance
more accurately than do quality assurance personnel.25

Screening

Patient Screening

Screening of patients for colonization with certain antibi-
otic-resistant organisms (AROs) such as MRSA has been
proposed as a method to contain spread of these organ-
isms in colonized or infected patients. Several types of ARO
screening programs have been described, including admis-
sion screening based on risk factors (e.g., hospitalization in
the last 6 months, patient from a long-term care facility),
universal screening on admission, and weekly point preva-
lence screening surveys. The pretest likelihood of coloniza-
tion, the cost of the test, the timeliness of test reporting, the
ability to isolate screened patients, and the degree to which
MRSA transmission is occurring are all factors that influ-
ence the feasibility and usability of the type of screening pro-
gram chosen.26 Although increased frequency of screening
will identify more colonized patients, it is not clear if this
practice reduces the frequency of transmission in the PICU
setting.27 An active MRSA surveillance testing program is
recommended when MRSA transmission continues to occur
despite the implementation of basic practices for prevention
and monitoring of transmission.28

Visitor Screening

The importance of family-centered care and visitation by
siblings as well as parents means that PICUs must establish
mechanisms to identify visitors who may have communicable
infections before they enter patient care areas. Education of
visitors regarding signs and symptoms of illness and recom-
 mendations to remain away are used in many PICUs. Visitor
self-screening was widely used during the 2009 H1N1 influ-
enza pandemic. Brochures, posters, telephone messages, and
videos may be used to communicate these messages.

Occupational Health

Occupational health programs play an essential role in the
protection of health care workers from infectious diseases
through prevention and management of unintended com-
municable disease exposures. These interventions reduce the
risk of infectious occupational hazards to health care work-
ers as well as opportunities for health care workers to spread
infectious diseases to patients. Occupational health programs
ensure health care workers are offered immunization against
vaccine-preventable infectious diseases of importance in the
health care setting, perform fitness-to-work assessments, assist
in educational programs so that health care workers can pro-
tect themselves and their families from acquiring infectious
diseases while at work (e.g., respiratory protection programs,
respirator fit testing), and provide postexposure counseling
and care (e.g., blood exposures during phlebotomy; unre-
protected intubation of a patient with meningococcemia or group
A Streptococcus toxic shock syndrome). Occupational health
programs collaborate closely with infection prevention and
control programs.29
| Condition | Laboratory confirmed (infections must be primary) | Regardless of age: |
|-----------|-------------------------------------------------|--------------------|
| Systemic infection | Disseminated infection | Infections, usually of viral origin, without an apparent single site of infection involving multiple organs and systems (e.g., varicella) |
| UTI | Symptomatic | \( \geq 10^5 \) Microorganisms/mL urine, not >2 species, and symptoms (at least one of the following: fever >38°C, urgency, frequency, dysuria, suprapubic tenderness) |
| Asymptomatic | Indwelling urinary catheter within 7 days before urine culture, and \( \geq 10^5 \) Microorganisms/mL urine, not >2 species, and Asymptomatic, or No indwelling urinary catheter within 7 days of urine culture, and \( \geq 10^5 \) Microorganisms/mL urine, not >2 species in two urine cultures with same organism(s) |
| Pneumonia (Alternate criteria are used for the diagnosis of pneumonia in adults.) | Clinically defined (infants and children) | Serial chest radiographs (one or more for patients without underlying disease and two or more for patient with underlying disease) with new or progressive and persistent infiltrate or consolidation or cavitation, or pneumatoceles (in ≤1 year old), and Clinical signs and symptoms (vary according to the patient age: ≤1 year or ≥1 year and ≤12 years) |
| Lower respiratory tract, not pneumonia | Bronchitis, tracheobronchitis, other lung infection | No clinical or radiographic evidence of pneumonia, and Two or more symptoms or signs (fever >38°C, cough, new or increased sputum production, rhonchi, wheezing), and One or more positive cultures from deep tracheal aspirate or bronchoscopy or positive antigen test on respiratory secretions, or Child ≤1 year with no clinical or radiographic evidence of pneumonia, and Two or more symptoms or signs (fever >38°C, cough, new or increased sputum production, rhonchi, wheezing, respiratory distress, apnea or bradycardia), and One or more of the following: positive culture from deep tracheal aspirate or bronchoscopy or positive antigen test on respiratory secretions, or serologic diagnosis |
| Ear, eye, nose, throat, mouth | Conjunctivitis | Pathogen cultured from purulent exudate from conjunctiva or contiguous tissues, or Patient has redness or swelling of conjunctiva or periorbital area and white blood cells and organisms on gram stain or purulent exudate, positive antigen test on exudate, or conjunctival scraping, positive viral culture, serologic diagnosis, or multinucleated giant cells on microscopic examination of conjunctival exudate |
| Sinusitis (Separate criteria exist for oral cavity, ear and mastoid infections, eye infections other than conjunctivitis, and pharyngitis, laryngitis, and epiglottitis.) | | At least one of the following: Organism cultured from purulent material from sinus cavity, or One or more of the following signs or symptoms with no other recognized cause: fever >38°C, pain or tenderness over the involved sinus, headache, purulent exudate, or nasal obstruction, and/or Positive transillumination or positive radiographic examination |
| Central nervous system | Intracranial infection | At least one of the following: Organisms cultured from brain tissue, or Abscess or intracranial infection seen during surgical operation, or Selected central nervous system symptoms without another cause and 1 of 4 laboratory criteria, or Patient ≤1 year with at least 1 of 5 selected symptoms and 1 of 5 laboratory criteria |
Table 97–2  Summary of CDC/NHSN Definitions for HIA (2008)—Cont’d

| Category | Definition |
|----------|------------|
| Meningitis or ventriculitis | • Organisms cultured from cerebrospinal fluid, or
• At least one of the following symptoms: fever, headache, stiff neck, meningeal signs, cranial nerve signs, irritability, and
• 1 of 5 laboratory criteria, or
• Patient ≤1 year with at least 1 of 5 selected symptoms and 1 of 5 laboratory criteria |
| Spinal abscess without meningitis | • Organisms cultured from abscess in the spinal epidural or subdural space, or
• Abscess in spinal epidural or subdural space seen during surgery, autopsy, or in histopathologic examination |
| SSI | Superficial incisional, primary or secondary | • Occurs within 30 days of operative procedure, and
• Involves only skin and subcutaneous tissue of the incision, and
• At least one of the following: purulent drainage from incision, organisms isolated from aseptically obtained incisional fluid or tissue, one sign or symptom (pain, tenderness, redness, swelling, heat), and
• Surgeon opens incision and incision is not cultured or is culture positive |
| Deep incisional, primary or secondary | • Occurs within 30 days of operative procedure or within 1 year if an implant is left in place, and
• Involves deep soft tissues of the incision, and
• At least one of the following: purulent drainage from the deep incision but not from the organ/space of the surgical site, spontaneous decapsulation of surgical site or symptomatic patient has site opened by surgeon and incision is not cultured or is culture positive, abscess found on direct examination (radiologic, histopathologic, or during operation), or surgeon diagnosis |
| Organ space, primary or secondary, indicated specific type (e.g., cardiac) | • Occurs within 30 days of operative procedure or within 1 year if an implant is left in place, and
• Infection involves any part of the body, excluding superficial or deep incisional areas, opened or manipulated during the operative procedure, and
• Patient has one of the following: purulent drainage via a drain placed into organ/space; organisms cultured from aseptically obtained specimen from organ/space; abscess found on direct examination, during reoperation, or by radiologic or histologic examination or surgeon diagnosis |
| Bone and joint infection (Separate criteria exist for joint or bursa infection and disc space infection.) | Bone (osteomyelitis) | At least one of the following:
• Organisms cultured from bone, diagnosis based on direct examination during surgery or on histopathologic examination, or
• Two or more symptoms (fever >38° C, localized swelling, tenderness, heat, or drainage at bone site), and
• One laboratory finding (positive blood culture or blood antigen test or radiographic evidence of infection) |
| Cardiovascular system | Mediastinitis (Separate criteria exist for endocarditis, myocarditis, pericarditis and vascular infection.) | At least one of the following:
• Organisms isolated from mediastinal tissue or fluid obtained by aspirate or during surgery, or
• Diagnosis during surgical procedure or by histopathologic examination, or
• Presence of one or more of the following signs or symptoms: fever >38° C, chest pain, or sternal instability, and
• One or more of the following: mediastinal widening on chest radiograph, purulent drainage, or organism cultured from drainage |
| Gastrointestinal (Separate criteria exist for hepatitis, gastrointestinal tract infections and intra-abdominal infection.) | Gastroenteritis | At least one of the following:
• Acute onset liquid stools for >12 hours with or without vomiting or fever and no likely noninfectious cause, or
• Two or more of following signs and symptoms: nausea, vomiting, abdominal pain, fever >38° C, or headache, and
• One or more of the following: enteric pathogen detected in stool or rectal swab (by culture, routine or electron microscopy, or cytopathic change in tissue culture), or enteric pathogen detected by antigen or antibody assay on blood or feces |
| Necrotizing enteritis | • In infants, two or more signs and symptoms (vomiting, abdominal distension, prefeeding residuals) and no other recognized cause, and
• Persistent microscopic or gross blood in stools, and
• More than one radiologic abnormality (e.g., pneumoperitoneum, pneumatosis intestinalis, unchanging rigid loops of small bowel) |

This summary of the CDC/NHSN surveillance definitions for HAI's and criteria is not comprehensive. The reader is referred to Horan TC, Andrus M, Dudeck MA, et al. CDC/NHSN surveillance definition of health care–associated infection and criteria for specific types of infections in the acute care setting. Am J Infect Control 36:309–332, 2008.  

Primary, First infection; secondary, infection as a result of another previous infection in the patient.  

*For infants ≤1 year of age, the symptoms and signs above are adapted to fever (>38° C rectal), hypothermia (<37° C rectal), apnea, bradycardia, or sternal instability.
Vaccine-preventable diseases of particular importance in the PICU setting are hepatitis B, pertussis, influenza, bacterial agents that cause meningitis and bacteremia (e.g., Neisseria meningitidis, Haemophilus influenzae), measles, mumps, rubella, and varicella. Critical care settings may present unique challenges because of the intensity and frequency of health care worker/patient contact and the likelihood of health care worker exposure to body fluids while manipulating invasive devices.

### Selected Topics in Policy, Procedure, and Program Development to Prevent Health Care–Associated Infection

#### Intervention Bundles

Care “bundles” are a group of evidence-based interventions that, when executed together, result in better patient care than when implemented individually and can reduce HAIs or colonization. Intervention bundles to prevent BSIs and VAP in the ICU setting have been included in national patient safety campaigns such as the United States’ Institute for Healthcare Improvement’s “Saving 100,000 Lives” and the Canadian Patient Safety Institute’s “Safer Healthcare Now.”

Characteristics of care bundles are their scientific grounding, all-or-none implementation (the process is not completed if one step is left out), goal of improved reliability of processes needed for effective care, and potential to contribute to improved teamwork and interprofessional communication in a care area. Strategies include team generation of ideas as to how to implement bundle components, development of educational approaches for acquisition of new knowledge and/or sharing of information, and creation of reliable processes and methods of measurement, such as a daily goals sheets incorporated into daily bedside rounds.

#### Antibiotic Stewardship

Judicious use of antimicrobials is now seen as an essential component of preventing the emergence of multidrug-resistant organisms. The overuse and inappropriate use of antibiotics is associated with the emergence of AROs. Principles of judicious antibiotic use include restriction of antibiotics (e.g., stop orders, restricted hospital formulary, requirement for infectious disease consultation for use of certain drugs), including antimicrobial susceptibility reporting and educational efforts aimed at changing physician prescribing practices.

Antibiotic stewardship begins with empiric treatment of the newly admitted patient. Although a suspected infection should initially be treated with broad-spectrum antibiotics, therapy should be changed to the most narrow spectrum agent once culture results are available or discontinued if there is no further evidence of bacterial infection. The clinical pharmacist is an integral member of PICU daily bedside rounds. They should participate in the one-on-one education of resident and nursing staff, be available for consultation, and assist in the development of evidence-based antibiotic prescribing guidelines for specific hospital acquired infections, updated regularly and combined with regular surveillance knowledge of local offending pathogens and their susceptibilities. Approval of certain antibiotics by an infectious disease consultant reduces antibiotic use, costs, and the emergence of AROs.

#### Antibiotic Prophylaxis

Some surgical procedures may be performed in the ICU rather than the operating room. Antibiotics given within 2 hours before certain surgical procedures (e.g., implantation of biomedical devices, central nervous system surgeries) and continued for less than 24 hours decrease the incidence of surgical site infection. There is no evidence that antibiotic prophylaxis before the placement of central venous catheters (CVCs) or external ventricular drains reduces infection rates. Antibiotic prophylaxis while these devices remain in place only leads to resistant colonizing organisms without reducing infection rates.

#### Antibiotic Cycling

Antibiotic cycling refers to a scheduled rotation of antibiotics with similar spectrums of bacterial coverage for a specified period, with the aim of limiting the emergence of resistance to any single agent. Although this strategy has been proposed as a potential method to decrease antimicrobial resistance, there is insufficient evidence to recommend its widespread application at this time.

#### Antibiotic Gastric Decontamination

Normal gut flora have an important role in nutrition, metabolism, and immune regulation. The normal balance of organisms is altered when a child becomes ill or receives antibiotics, leading to infection by endogenous flora. Selective decontamination of the digestive tract was first introduced in 1983 and extensively studied in adult ICU patients. Selective decontamination protocols involve a short course of intravenous antimicrobials (e.g., third-generation cephalosporin) and oropharyngeal and enteral nonabsorbable antimicrobials (e.g., colistin, amphotericin B, tobramycin) in addition to routine infection control practices. Variable effectiveness has been demonstrated in clinical studies. In a recent large randomized controlled trial of almost 6000 adults, oral decontamination and selective gut decontamination were associated with decreased mortality rate compared with standard care. There is insufficient data on selective decontamination in children to recommend its use at this time.

An alternate strategy to reduce the development of potential AROs is the oral administration of probiotics (nonpathogenic microorganisms) such as lactobacillus. Their main role appears to be the prevention of pediatric antibiotic-associated diarrhea, the prevention of necrotizing enterocolitis in premature infants, and the treatment of Clostridia difficile–associated diarrhea. Although apparently not associated with harm, the role of probiotics remains unclear in the critically ill child as an infection control strategy or therapy.

#### Specific Infection Syndromes in the Pediatric Intensive Care Unit

### Bloodstream Infections

BSIs are usually the most common HAI acquired in the PICU setting and are associated with morbidity, excess length of stay, and mortality, with an attributable cost of up to $46,000 per patient. Most BSIs are associated with intravascular catheter use and commensal skin flora that gain access to the bloodstream through the device. The scope of intravascular...
device–associated infections includes laboratory-confirmed bacteremia, infections of the skin and subcutaneous tissues around the device (exit site and tunnel infections), clinically defined sepsis, septic thrombophlebitis and thrombosis, and right-sided endocarditis.

**Epidemiology**

The median rate of CLA-BSIs in 71 pediatric medical/surgical ICUs, in the most recent report of the NHSN was 2.1 infections per 1000 central line days, with a 25th percentile of 0.0 and a 90th percentile of 6.0. The pooled mean in these medical/surgical ICUs was 2.9 infections per 1000 line days; in 10 medical PICUs the mean rate was 1.0. The median utilization ratio was 0.41 (central line days per patient days), which is comparable to adult ICUs. In 2007, the Canadian ICU Collaborative reported a cumulative rate of 2.8 CLA-BSIs for six PICUs, with rates ranging from 0 infections per 1000 line days to 10 over the 3-year surveillance period (Figure 97-1).

The most common infecting organism in CLA-BSI is the gram-positive bacteria coagulase-negative Staphylococcus (CONS), a group of about 20 species, including *Staphylococcus epidermidis*, that are normal flora of human skin. Gram-negative bacteria, including enterobacteriaeae, and nonfermenting gram-negative bacteria such as *Pseudomonas* spp., *Acinetobacter* spp., and *Stenotrophomonas* spp. account for about 25% of infections. *Candida* spp. infections are increasingly recognized.

There are many types of intravascular devices, including CVCs, arterial catheters, and peripherally inserted catheters. Catheters can also be classified according to the site of insertion, the expected duration of placement (e.g., long vs. short term), and the path to the vessel (e.g., tunneled or not). To date, surveillance for HAI associated with these devices has focused on central venous lines. For surveillance purposes, BSIs are categorized as primary (no other identifiable source of infection) or secondary (the BSI occurred as the result of an infection at another site). Surveillance definitions used for CLA-BSI can be found in Table 97–2.

Migration of skin flora along the catheter to the blood vessel is thought to be the pathogenesis of most CLA-BSIs. The reduction in rates of CLA-BSI studies using maximal sterile barrier precautions and careful antiseptics during catheter insertion and care support this hypothesis. Infection can also result from contamination of the catheter hub with endoluminal migration, be hematogenously seeded from another source, or occur because of contaminated infusate.

**Prevention**

Successful programs to reduce the incidence of CLA-BSIs have been reported in the last decade; all use multimodal team-based, systematic approaches in which combinations of effective preventive interventions are introduced into a care setting.

The central line bundle is a compilation of eight components broken into two separate bundles for insertion and maintenance. The bundle components described in the following sections are from the Canadian Safer Healthcare Now campaign and align with other improvement bundle packages for reduction of CLA-BSIs. The Canadian ICU Collaborative PICU teams reduced their collective CLA-BSI rate from 5.6 per 1000 line days to 2.8 per 1000 line days. Other PICUs that have implemented the central line bundle have seen dramatic reductions in CLA-BSI rates of up to 75%.

The insertion bundle components include hand hygiene, maximal barrier precautions, and skin antiseptics. Maximal sterile barrier precautions for the inserter mean strict compliance with hand hygiene, a cap that covers all hair, a mask that covers the mouth and nose securely, a sterile gown, and sterile gloves. The patient is covered from head to toe with a sterile drape except for a small opening for the insertion site. 

Figure 97–1. Canadian PICU Collaborative catheter-related bloodstream infection national rates. (From Northway T, Folz E, Gavin S, et al: Success of a national pediatric critical care collaborative in reducing central line blood stream infections: an update of our progress, Dynamics 19(2):40, 2008.)
fail to reduce a local institution’s infection rates below benchmark levels. They may be considered in specific patient populations such as the immunosuppressed requiring long-term CVC use, although their superiority over standard CVCs in this population has never been proven.

Ultrasound guidance for placement of CVCs to reduce insertion-related complications was identified by the Agency for Healthcare Research and Quality in 2001. In 2002, the National Institute for Clinical Excellence in the United Kingdom issued recommendations for the use of two-dimensional ultrasound guidance for insertion. The associated decrease in insertion-related complications might contribute to a reduction in CLA-BSIs through less-traumatic catheter placement, but this remains to be proven.

The maintenance bundle to prevent CLA-BSIs incorporates, in addition to hand hygiene, multimodal education and training programs, aseptic access to the lumens (scrubbing the hub), regular checks of the entry site for inflammation with each dressing change (at minimum), daily review of line necessity with removal if deemed unnecessary, and a dedicated total parenteral nutrition line.

Emerging trends in maintenance of CVCs include chlorhexidine-impregnated transparent dressings and bio-discs (which hug the catheter at the insertion site) and are intended to reduce the quantity of bacteria at the skin entry site. Evidence of the safety and efficacy of this intervention in children is lacking, and it is not routinely recommended.

Practitioners are urged to check for recent updates in CLA-BSI reduction quality improvement strategies from Safer Healthcare Now (www.saferhealthcarenow.ca) or the Institute for Healthcare Improvement (www.ihi.org) or their national or local equivalents because these strategies change over time based on evolving evidence.

Management

Clinical diagnosis of BSI in the ICU based on clinical signs and symptoms is insensitive and nonspecific. Laboratory confirmation should be sought and broad-spectrum antimicrobial therapy initiated early and targeted at likely pathogens until microbiologic results are available. If the device is suspected to be the source of infection or to have been secondarily infected, the clinician will need to decide if the infection can be eradicated with the device in place. The need for catheter removal will depend on the infecting organism and the availability of line necessity with removal if deemed unnecessary, and a dedicated total parenteral nutrition line.

Respiratory Infections and Ventilator-Associated Pneumonia

Respiratory Infections

Respiratory tract infections are the most common illness in children in the community as well as the most common reason for admission to hospital, with young healthy children having an average of 6 to 8 infections each year. Respiratory infections acquired during health care encompass a broad range of illness of the upper and lower respiratory tract (see Table 97-2). In the child with high-acuity illness requiring admission to the PICU, some respiratory infections are particularly associated with increased morbidity, mortality, and health care cost. The following section focuses on viral respiratory tract infections, VAP, and sinusitis.

Epidemiology

Respiratory syncytial virus (RSV) is the most common cause of lower respiratory tract infection in young children in the community and occurs in yearly outbreaks during the winter in temperate climates. Hospital-acquired RSV is associated with prolonged length of stay, increased morbidity and mortality rates and, if acquired around the time of cardiac surgery, worse postoperative outcomes. Outbreaks of various respiratory virus infections in the PICU have been reported with attack rates of up to 30%. Outbreaks of RSV and influenza provide useful information on the burden of illness associated with this HAI, but rates of HAI-associated respiratory virus infection determined by surveillance programs are infrequently reported.

Like RSV, influenza virus H1N1 occurs at the same time as the local winter community epidemic. Multiple other respiratory virus infections (e.g., rhinovirus, adenovirus, parainfluenza virus) also spread by large droplets from the respiratory tract, the contaminated hands of care providers, or contact with contaminated nonporous surfaces on which the virus may survive.

Respiratory viral illness can increase the risk of secondary bacterial infection because the normal defensive function of the mucociliary apparatus is impaired and colonizing bacteria in the respiratory tract can invade through the nasopharynx or descend to the lower respiratory tree.

In the past 10 years, three novel respiratory viruses exposed severe gaps in hospital infection control practices. The SARS epidemic in Canada and Asia demonstrated the ability of a novel coronavirus to infect health care workers providing care for critically ill patients. The avian influenza H5N1 virus and H1N1 influenza viruses spread predominately in community settings but forced health care centers to accelerate pandemic readiness and identified severe shortcomings in critical care capacity. Transmission of these agents is thought to be by large droplet, but evidence for optimal occupational health protection is lacking.

VAP is the second most common HAI in the PICU, estimated to occur in up to 10% of ventilated children. In the most recent NHSN report pooling data from 50 pediatric medical-surgical ICUs, the median incidence was 0.7 episodes of VAP per 1000 ventilator days, and the mean frequency was 2.1. Notably, the rate of VAP has decreased in the last decade from mean rates of 3.7 per 1000 ventilator days in 1998 in the Pediatric Prevention Network study and 5.7 per 1000 ventilator days (median, 4.2 days) in participating PICUs. VAP is a serious and life-threatening complication of PICU admission and is associated with prolonged ICU stay, need for ventilatory support and excess costs (more than $50,000 in one study). VAP is also associated with increased mortality; in a prospective PICU study, Bigham et al. observed a mortality rate of 19.1% in children with VAP compared with 7.2% in those without VAP (P = .01).
The preeminent risk factor for VAP in all age groups is the placement of an endotracheal tube, which provides a ready conduit to the lower respiratory tract and increases the risk of VAP 6-fold to 20-fold.\textsuperscript{70} VAP is usually due to endogenous bacteria, and less commonly fungi, from the patient’s oropharynx. VAP is often categorized into early (fewer than 5 days after intubation) and late (more than 5 days after intubation). Early VAP is usually caused by normal endogenous flora of the respiratory tract such as *H. influenzae*, *Moraxella* spp., *Streptococcus pneumoniae*, and alpha-hemolytic *Streptococcus* spp. These organisms are assumed to have gained entry around the time of intubation or to have been aspirated early in the course of treatment. During hospitalization, the normal endogenous flora of the nasopharynx are replaced within days by gram-negative bacteria such as *Pseudomonas* spp., *Escherichia coli*, *Acinetobacter*, and *Stenotrophomonas* spp., and various *Enterobacteriaceae* spp. *S. aureus* is also a cause of HAI lower respiratory tract infection. For practical reasons, many studies base their laboratory diagnosis on specimens obtained from the endotracheal tube rather than invasive sampling of the lower respiratory tract; hence isolated microorganisms could be present in the nasopharynx, colonizing the endotracheal tube, or actually be the cause of infection in the lung.

In addition to its role as a conduit, the endotracheal tube also serves as a foreign body. As with other biomedical devices, an endotracheal tube interferes with normal defense mechanisms (e.g., cough, mucociliary apparatus) and acts as a nidus for adherence of microorganisms, which create a biofilm. Tracheal suctioning can cause mucosal denudation and detachment and aspiration of adherent biofilm aggregates that become a pulmonary inoculum. Not surprisingly, the length of respiratory assistance and endotracheal intubation—and therefore the device-related risk—remain significant risk factors of nosocomial pneumonia.\textsuperscript{62,68,71,72}

Other risk factors for HAI pneumonia include immune deficiency, use of neuromuscular blocking agents, reintubation, transport outside the ICU, multiple organ dysfunction, shock, multiple-organ trauma, severe head trauma, and burns.\textsuperscript{66,73-75} More rarely, VAP is associated with inhalation of contaminated aerosolized fluids or medications or hematogenous seeding (e.g., right-sided bacterial endocarditis).

**Prevention**

**Respiratory Viruses.** Prevention of HAI respiratory virus infection in the PICU can be accomplished through a collaborative effort between the PICU and the organization’s infection prevention and control and occupational health programs. The goal of this effort is to avoid contact between persons with probable or definite respiratory infection (including family members) and PICU patients and prompt institution of isolation practices (Standard Precautions and Additional Precautions) in symptomatic patients, regardless of laboratory confirmation.

Occupational health programs assess fitness-to-work in health care workers with possible respiratory illness. An employee with new-onset cough and rhinorrhea, for example, could be deployed to a non–patient care assignment rather than the PICU or sent home. The occupational health program should ensure immunization status for employees is current and offer annual influenza vaccine programs in addition to ensuring access to vaccines against other infections that can be transmitted in the health care setting (hepatitis B, pertussis, measles, mumps, rubella, varicella, diphtheria). Regular education in the use of Standard Precautions/Routine Practices is recommended so that health care workers will use hand hygiene appropriately, understand how to use PPE, implement isolation practices when they suspect a communicable infection in a patient, and be aware of organization-wide and unit-specific infection prevention and control policies and procedures.

As part of the hospital and PICU admission process, screening of the patient for symptoms and signs of infectious illness should be conducted to determine appropriate placement. In the winter respiratory season, screening of all symptomatic children for viral infections and placing them on contact and droplet isolation until results are available have been reported to limit nosocomial spread. Screening admitted children with suspected viral infection is now done, and depending on the local laboratory capabilities, covers RSV, metapneumovirus, influenza A and B, parainfluenza, adenovirus, and rhinovirus.

**Ventilator-Associated Pneumonia.** Strategies of prevention are directed against the three mechanisms by which VAP is thought to occur: aspiration of secretions, colonization of the aerodigestive tract, and use of contaminated equipment. General recommended measures are to conduct active surveillance for VAP, minimize the duration of ventilation and use noninvasive ventilation whenever possible, perform daily assessments of readiness to wean from ventilation, and educate health care workers who care for ventilated patients about VAP.\textsuperscript{71}

Effective individual interventions that prevent VAP have been combined into bundles by the Institute for Healthcare Improvement.\textsuperscript{76} Implementation of the bundles has shown documented evidence of a reduction in pediatric VAP; in one center a reduction of 5.6 to 0.3 infections per 1000 ventilator days over a 3-year period was observed.\textsuperscript{69}

Recommended practices to prevent VAP are mostly based on studies conducted in adult patients.\textsuperscript{71} The strategies to prevent VAP prepared by the Society for Healthcare Epidemiology and the Infectious Disease Society of America\textsuperscript{2} highlight practical recommendations focused on this device-specific infection. Comprehensive recommendations published by the CDC provide background scientific rationale and guidance for detecting and preventing HAI pneumonia.\textsuperscript{77} The original bundles include general care strategies for critically ill patients not related to VAP prevention (e.g., peptic ulcer prophylaxis and deep venous thrombosis prophylaxis). Oral hygiene protocols may reduce colonization by pathogenic bacteria in the oropharynx and are recommended.\textsuperscript{77} Meta-analyses of trials conducted to date in adults indicate reduced risk of VAP in patients treated with oral chlorhexidine.\textsuperscript{78} The CDC guidelines make no recommendation for routine use of chlorhexidine or antimicrobials for this purpose.\textsuperscript{77}

Most recent pediatric VAP bundles have removed the general care strategies along with the adult-based recommendations of a daily sedation holiday and use of continuous aspiration of secretions above the endotracheal tube cuff.\textsuperscript{77} Safety concerns for children (daily sedation) and tube design limitations in pediatrics are the rationale for elimination of the latter strategies. The pediatric bundle has recently been updated and published by Safer Healthcare Now. Specific
The surveillance definition of VAP (see Table 97-2) permits comparison of HAI rates over time and between institutions but serves a different purpose than for diagnosis and clinical treatment. VAP is difficult to diagnose accurately because of the inaccessibility of the lower respiratory tract. The gold standard for diagnosis is microbiologic confirmation from a lower respiratory tract specimen, such as lung biopsy. Obtaining uncontaminated lower respiratory tract specimens in children by bronchoalveolar lavage, lung biopsy, or transthoracic biopsy are procedures with inherent risks, but diagnostic criteria have been proposed. Despite the accepted shortcomings, tracheal aspirates remain the most common specimen for guiding initial empiric antibiotic therapy in a child with suspected VAP.

Aggressive and prompt treatment is required when nosocomial pneumonia is suspected in a critically ill patient because it is a life-threatening illness. Initial empiric therapy for VAP should be broadly based, with consideration of local microbiologic data on antibiotic resistance and a plan to reevaluate and narrow antibiotic selection when results of cultures or other diagnostic information are available. If aspiration is suspected, coverage for anaerobes can be considered (e.g., ticarcillin-clavulanate or clindamycin). If methicillin-resistant S. aureus is suspected, vancomycin or linezolid should be used. The appropriate duration of therapy for VAP in children is not known. Most experts recommend a 7- to 14-day course of therapy for VAP.

Sinusitis

Although acute viral rhinosinusitis (inflammation of the nose and paranasal sinuses) is a common infection in childhood, data on its occurrence in the PICU are scarce. Care in the ICU was first associated with increased risk of sinusitis in adult ICU patients in the 1970s, following case reports of sinusitis ipsilateral to the nasotracheal tube. Since that time, observational studies have supported this finding and indicate that prolonged nasal cannulation is associated with increased incidence of sinusitis, that larger nasal cannulae appear to accelerate this process, and that fewer devices in the nose decrease risk of infection.

Epidemiology

There are few reports of sinusitis complicating the care of critically ill children in the ICU setting, and active surveillance for this HAI is not done by most programs. In one retrospective review, 1 of 98 children ventilated for at least 7 days had sinusitis noted in a follow-up visit that resolved spontaneously.

Sinusitis can be categorized as acute or subacute bacterial, recurrent acute bacterial, chronic, or acute on chronic in nature. Although the ethmoid and maxillary sinuses are present at birth, the sphenoid and frontal sinuses are not pneumatized until age 5 and 7 years, respectively. Diagnosis of sinusitis is challenging in children, particularly in the intubated child. Direct sinus puncture to permit microbiologic identification of infecting organisms is the gold standard for diagnosis, although it is rarely performed because it is invasive, time-consuming, and painful. Normal sinus radiographs and CT scans provide evidence that sinusitis is absent, but mucosal thickening is a nonspecific finding. The surveillance definition of health care–associated sinusitis is seen in Table 97-2.

Acute sinusitis is most commonly caused by respiratory flora such as S. pneumoniae, H. influenzae, and Moraxella spp. In ventilator-associated sinusitis, S. aureus, Pseudomonas aeruginosa, enteric gram-negative bacilli, and streptococcal infection need to be considered.

Prevention

The paranasal sinuses are contiguous with the nasopharynx and mostly lined with pseudostratified ciliated respiratory epithelium. The normal defense of the sinuses against infection is the mucociliary apparatus; secretions capture particulate matter that is then propelled by cilia to the sinus ostia. Factors that would be expected to predispose to sinus obstruction or decreased mucociliary function include foreign bodies in the nasopharynx (e.g., nasogastric or endotracheal tubes), previous viral respiratory infection, preexisting abnormalities such as ciliary disorders or cystic fibrosis, and craniofacial anatomic abnormalities or facial trauma. Orotracheal intubation is recommended over nasotracheal intubation because the latter increases the risk of sinusitis, which in turn may increase the risk of VAP. Judicious use of antibiotics in the ICU would be expected to decrease the risk of colonization of the respiratory tract with gram-negative and antibiotic-resistant organisms.
Management

Because of their proximity to the brain, bacterial or fungal infection of the sinuses may be complicated by contiguous spread. If microbiologic confirmation obtained by sinus puncture is not possible, systemic antimicrobial therapy should be directed broadly to cover anaerobic respiratory flora, gram-positive and gram-negative bacteria such as *Pseudomonas* spp., and enteric flora. Options for antibacterial coverage include a third-generation cephalosporin or monobactam or an extended-spectrum penicillin–clavulanic acid combination with the addition of vancomycin to cover MRSA or penicillin-resistant pneumococcus, depending on antimicrobial susceptibility and epidemiology.

An otolaryngologist should be consulted in the care of children with complicated sinusitis to determine if surgery is necessary to remediate ostial obstruction or drainage of abscesses. Involvement of the central nervous system requires neurosurgical intervention. The infectious disease team should also be involved to assist in determining optimal antibiotic combinations and duration of therapy in these complicated cases with central nervous system involvement.

Urinary Tract Infections

The spectrum of illness associated with urinary tract infection (UTI) in the PICU can range from asymptomatic bacteruria in the presence of a catheter to a funguria that becomes a source of life-threatening disseminated fungal infection.

Epidemiology

A mean of 5.0 catheter-associated UTIs (CA-UTIs) occurred per 1000 catheter days (median, 3.0 per 1000 catheter days) in the U.S. National Health Safety Network surveillance system, with 37 pediatric medical-surgical ICUs reporting. This rate is very similar to the CA-UTI frequency of 5.4 infections per 1000 urinary catheter days determined 10 years earlier in a survey of 35 PICUs and 33 NICUs. In a recent review, secondary bacteremia occurs in about 3% of catheterized critically ill children.

A urinary catheter is both a foreign body in the urinary tract and a conduit for microorganisms to ascend to the bladder, ureters, and kidney and potentially to the bloodstream. Voiding is an important defense mechanism for the urinary tract in which periurethral flora are flushed out regularly. Because of the urethra’s anatomic location in the perineum, the most common organisms causing community and health care–associated UTI are normal periurethral or perirectal flora such as *E. coli* and *Klebsiella pneumoniae*. However, enterobacteria such as *Pseudomonas* spp. and opportunistic organisms such as *S. aureus*, *S. epidermidis*, and *Candida* spp. also can be involved.

In addition to the general factors that increase risk for HAI in the PICU, children at increased risk for UTI include those with preexisting uropathies, especially neurogenic bladder.

Prevention

Guidelines for the prevention of CA-UTI in acute care hospitals focus on certain key strategies, all related to urinary catheter use: (1) recommendations for which patients should receive indwelling urinary catheters, (2) recommendations for catheter insertion, (3) recommendations for catheter maintenance, and (4) quality improvement programs to achieve appropriate placement, care, and removal of catheters. The most important action that PICU staff can take to prevent CA-UTIs is to limit the use of urinary tract instrumentation, particularly indwelling urinary catheters. Systemic morphine infusions are not a contraindication to the removal of the urinary catheter.

Proper technique for catheter insertion includes hand hygiene before and after any manipulation of the device, use of aseptic technique, use of the smallest bore catheter needed, and proper securement of the catheter after insertion to prevent movement. The catheter should be maintained as a closed drainage system with unobstructed urine flow. The catheter and collecting system should be replaced if the system is disconnected or leaks occur. Standard Precautions should be used for any manipulation of the catheter or collecting system (e.g., use of gloves and gowns as appropriate). Neither systemic antimicrobials, bladder irrigation with antimicrobials, nor complex drainage systems with antiseptics are recommended to prevent CA-UTIs. Special catheter materials (e.g., antimicrobial impregnation) are only recommended if a comprehensive strategy to reduce CA-UTI rates is unsuccessful.

A number of quality improvement resources are available to assist with systemic approaches to the prevention of CA-UTI. The Association for Professionals in Infection Control and Education produced the “Guide to the Elimination of Catheter-Associated Urinary Tract Infection” in 2008, and the Institute for Healthcare Improvement has developed a program for the prevention of CA-UTI. Overall approaches for reduction of CA-UTI rates include the avoidance of unnecessary urinary catheters, use of aseptic technique when inserting urinary catheters, maintenance of urinary catheters based on recommended guidelines, and prompt daily review of urinary catheter necessity.

Management

Surveillance definitions for UTI acquired in the health care setting are found in Table 97-2. Of note, infection may be asymptomatic or symptomatic. In the critically ill PICU patient diagnosis of UTI may be difficult because of inability to determine symptoms and signs; therefore laboratory criteria from aseptically obtained urine specimens are essential.

For CA-UTI, the catheter should be removed as soon as possible because it is an ongoing source of infection. Once removed, intermittent catheterization may be required if spontaneous voiding does not occur. Therapy should be the narrowest spectrum agent that will treat the offending pathogen; appropriate empiric choices before availability of antimicrobial susceptibility should include consideration of common infecting organisms in that PICU, but appropriate initial choices include aminoglycosides, an extended-spectrum penicillin, or a third-generation cephalosporin.

Skin and Surgical Site Infections

Although almost all surgical procedures are performed in the operating room, a substantial component of care in the PICU is postoperative care for critically ill children. Procedures may also need to be performed in the PICU in patients who are too unstable for transport to the surgical suite or do not have primary closure of the surgical wound (e.g., open chest after cardiac surgery). The integument is the largest organ in the human body; it is a barrier to invasion of microorganisms and
plays a role in thermal regulation and fluid homeostasis. Disruption of the skin, whether by surgery, insertion of biomedical devices, or pressure sores, interrupts a key defense against infection.

**Epidemiology**

In an NNIS study of 61 U.S. PICUs from 1992 to 1999, skin and soft tissue and surgical site infections (SSIs) combined accounted for one quarter to one third of nosocomial infections in PICUs.43 The NNIS reports SSIs according to operative procedure and risk index category but does not report the ward where the patient was cared for (e.g., ICU or not) or patient age.17 In a prospective 6-month surveillance project in 17 European PICUs, postsurgical infections accounted for 7% of all HAIs.67 A national Canadian pediatric point prevalence survey identified approximately 3% of the population with an SSI.93 Complications of SSIs include contiguous or systemic spread and, in adults, an increased length of stay of 7 to 10 days and increased risk of death.94 Depending on preexisting comorbidities, site, and severity of infection, the estimated costs of SSIs are between $3000 and $29,000.94

Surgical sites have bacterial contamination by the end of the procedure despite appropriate skin antisepsis.95 Most commonly, the source of infection is the patient’s own flora that migrate into the wound, but other sources include the surgical staff and contaminated instruments. The probability of a wound becoming infected is thought to result from the interaction of four key clinical variables: the inoculum of bacteria, the virulence of the infecting organism, the microenvironment of the wound (e.g., foreign body), and the state of host defenses.95 Given this pathogenesis, it is not surprising that skin flora are the most common infecting organisms. *S. aureus* is the most common pathogen in SSIs without biomedical device placement, but *P. aeruginosa* and other gram-negative bacteria have been found.72,96,97 Often a single microbiologic cause is not identified because the surgical site is open and contiguous with skin or mucosa. In procedures in which a device is implanted (e.g., neurosurgical cerebrospinal fluid shunts), the most common organism isolated is CONS. Of growing importance are infections caused by multidrug-resistant organisms, such as MRSA, and fungi.

Risk for an SSI can be predicted in adult patients by using the National Nosocomial Infections Surveillance System index, which combines the traditional four-category wound classification system of clean, clean-contaminated, contaminated, and dirty or infected with the American Society of Anesthesiology score and duration of procedure time.95 An equivalent validated scoring system to identify high-risk children has not been developed. Multiple variables associated with increased risk for SSI in various studies include intrinsic factors (e.g., age, glucose control, obesity/malnutrition, smoking, steroid use, prolonged preoperative hospital stay, prolonged nares colonization with *S. aureus*, perioperative transfusion and immunosuppressive medications, presurgical comorbidity) and extrinsic factors (e.g., preoperative antiseptic showering, preoperative hair removal, patient skin preparation in the operating room, preoperative hand/forearm antisepsis, management of infected or colonized surgical personnel, antimicrobial prophylaxis). In pediatric cardiac surgery patients, an open sternum is a risk factor for SSIs.96,97 Operative risk factors are surgical scrub by the team, skin preparation of the patient, appropriate and timely antibiotic prophylaxis, surgical drapes and attire, surgeon skill and technique, asepsis, and operative time. Operating room characteristics are also considered extrinsic factors. They include ventilation, traffic, and sterilization of surgical equipment. Postoperative factors incorporate incision care and discharge planning.

**Prevention**

Prevention of SSIs is directed at addressing the clinical variables that increase the probability of infection, as previously mentioned.95 For example, patient skin preparation, health care worker hand hygiene, and antimicrobial prophylaxis affect the inoculum of bacteria into the wound. Optimal glucose and temperature control enhance the capacity of the host to deal with invading organisms. CDC recommendations for the prevention of SSIs are available,36 and a compendium of strategies to prevent SSIs in acute care hospitals has been published.94

**Surgical Site Infection Bundle**

Most SSI bundles include measures to improve timing and choice of antimicrobial prophylaxis, appropriate hair removal, and prospective surgical wound infection surveillance with provision of feedback to individual surgeons. The surveillance definitions for SSI are provided in Table 97-2.

A considerable body of research has demonstrated that perioperative antibiotic prophylaxis is most effective when given 1 hour before the incision to maximize tissue concentration during cut time—when the antibiotic (as narrow spectrum as possible and as short a course as possible) is active against the likely contaminating organisms. Although the duration of administration varies by procedure, the optimal duration ranges from the operative period to the 24 hours after the surgery. Doses beyond this interval do not prevent infection and put the patient at risk of developing infections with resistant bacteria and fungi. The choice and duration of antibiotic prophylaxis depends on the surgical procedure, degree of wound contamination, emergency or elective surgery, and patient allergy.36 Vancomycin should not be routinely used as prophylaxis but instead reserved for specific clinical situations such as an MRSA-positive patient with a SSI.94

Postoperative surgical site care includes regular observations and documentation of the integrity of the site. Recommendations for postoperative incision care include protecting a primary closure incision with a sterile dressing for 24 to 48 hours postoperatively, adhering to hand hygiene principles, applying sterile technique when changing dressings, promoting proper incision care, and identifying complications by educating patients and families.36

**Management**

Recognition of SSIs requires regular wound inspection for the usual signs of inflammation, with or without pus. Microbiologic confirmation of infection is often not possible or definitive because of contamination of the operative site by contiguous external surfaces. Treatment of SSIs includes appropriate empiric antimicrobials directed at the likely infecting organisms and subsequent narrowing of the spectrum when organism identification and susceptibility are available. Drainage of the infected area should be facilitated (e.g., removal of staples), and wound debridement may be required. Foreign bodies may need to be removed.95 The extent of the infection will determine the wound care requirements, which
may involve packing the wounds or use of a negative-pressure wound therapy.

**Ventriculostomy-Related Infections**

The incidence of ventriculostomy-associated infection varies widely in the literature and is influenced by both patient characteristics and system factors, such as infection control policies and procedures pertaining to placement and maintenance of external ventricular drains. The risk increases with increasing duration of catheterization and with repeated insertions, but routine replacement is not recommended. The use of local antibiotic irrigation or prophylactic systemic antibiotics is not recommended. Routine surveillance cultures of cerebrospinal fluid are not more likely to detect infection than are cultures obtained when clinically indicated.98,99

**Hospital-Associated Diarrhea**

*Clostridium difficile*-associated diarrhea is a potentially life-threatening illness that can range in clinical presentation from diarrhea to colitis and megacolon. Although less common in children, it can cause problematic illness in oncology patients. Outbreaks of rotavirus and norovirus can occur in critical care settings, where close health care worker/patient contact can facilitate spread of secretions. Prevention of diarrheal illness is accomplished by prompt isolation of patients with diarrhea before laboratory results are available, careful hand hygiene, and regular and thorough environmental cleaning focusing on high-touch surfaces.

References are available online at http://www.expertconsult.com.