PREVENTION OF HEALTHCARE-ASSOCIATED INFECTIONS
IN U.S. HOSPITAL SETTINGS

JaHyun Kang

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Approved by:
Barbara A. Mark, PhD
Cheryl B. Jones, PhD
Todd A. Schwartz, DrPH
Andrea K. Biddle, PhD
David J. Weber, MD, MPH
William A. Rutala, PhD, MPH
ABSTRACT

JAHYUN KANG: Prevention of Healthcare-Associated Infections in U.S. Hospital Settings
(Under the direction of Barbara A. Mark, PhD)

Healthcare-associated infections (HAIs) are among the most common adverse events that threaten patient safety in the United States. However, many aspects of HAIs related to hospital infection control are unknown. Using a “chain of HAIs” conceptual model, this dissertation study examined HAIs from the agent (the healthcare-associated pathogen) to the infection control measures that can interrupt the interactions (transmission) among agent, host, and environment at the hospital level by connecting three areas that lacked critical information.

First, changes in the incidence of HAIs by pathogen were examined using hospital-wide surveillance data. This study found significant changes in the incidence rate of HAIs by healthcare-associated pathogen that occurred between 2005 and 2011. Overall, across all service categories, the incidence of both overall HAIs and device-associated HAIs caused by the top 10 pathogens decreased, despite a significant increase in the number of patient-days. Only Clostridium difficile showed a significant increase in incidence.

Second, a cost-effectiveness analysis was conducted using a decision-tree model to determine the most cost-effective active surveillance screening strategy for methicillin-resistant Staphylococcus aureus (MRSA) from an academic hospital perspective. Despite the possibility of variation and uncertainty in the input parameters, our model was robust and
demonstrated that targeted surveillance of intensive care unit patients was the dominant cost-saving strategy for reducing MRSA HAIs.

Third, current hospital policies regarding visitor use of personal protective equipment when entering the rooms of patients on isolation precautions were examined using an online survey of North Carolina hospitals. Among 82 participating acute care hospitals, 71% had a hospital visitor policy. This study illuminated variations in hospitals’ policies regarding visitor isolation precautions. The current problems with hospital visitor policies (e.g., refusal to comply) call for a standard guideline.

This study’s findings suggest a need for further research related to C. difficile, active surveillance screening for important HAI pathogens, implementing isolation precautions (including issues related to cost, ethics, and practice), hospital infection control efforts, and enhancing the host defense mechanism (e.g., immunoprophylaxis) to prevent HAIs. Although we may not be able to create the desired HAI-free hospital, the rigorous battle against invisible healthcare-associated pathogens should never stop.
ACKNOWLEDGEMENTS

During the 4-and-a-half-year endurance test of my PhD study at UNC Chapel Hill, I realized that all of my accomplishments (e.g., publications, awards, and dissertation) were made possible not only by my own talent and efforts, but by all of the great supporters in my life. With countless blessings from the Heavenly Father, my PhD life was beautifully orchestrated, and I learned many precious lessons from my PhD journey.

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Third, I am glad that I could meet these wonderful friends: Sue, my host family; Deanna, my conversation partner; Vickie, Emily, Becky, Brenda, Tina, Lisa, Kirk, Debby, and Amy at the UNC Healthcare Department of Hospital Epidemiology; Kathy and Jennifer at SON OASS, who made me choose UNC despite another university’s 5-year fellowship offer; Chris at the Odum Institute; and my wonderful colleagues in our PhD program and the Royster society.

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<th>Full Form</th>
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<tbody>
<tr>
<td>AAMC</td>
<td>Association of American Medical Colleges</td>
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<td>AHA</td>
<td>American Hospital Association</td>
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<tr>
<td>AIDS</td>
<td>Acquired immunodeficiency syndrome</td>
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<tr>
<td>APIC</td>
<td>Association for Professionals in Infection Control and Epidemiology</td>
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<tr>
<td>BSI</td>
<td>Bloodstream infections</td>
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<tr>
<td>CAUTI</td>
<td>Catheter-associated urinary tract infection</td>
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<tr>
<td>CDC</td>
<td>Centers for Disease Control and Prevention</td>
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<tr>
<td>CEA</td>
<td>Cost-effectiveness analysis</td>
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<td>CEAC</td>
<td>Cost-effectiveness acceptability curves</td>
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<tr>
<td>CLABSI</td>
<td>Central line-associated bloodstream infection</td>
</tr>
<tr>
<td>CMS</td>
<td>Centers for Medicare and Medicaid Services</td>
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<tr>
<td>CoNS</td>
<td>Coagulase-negative staphylococci</td>
</tr>
<tr>
<td>DHHS</td>
<td>Department of Health and Human Services</td>
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<tr>
<td>EID</td>
<td>Estimated incidence difference</td>
</tr>
<tr>
<td>ESBL</td>
<td>Extended-spectrum β-lactamase</td>
</tr>
<tr>
<td>FTE</td>
<td>Full-time equivalent</td>
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<tr>
<td>HAI</td>
<td>Healthcare-associated infection</td>
</tr>
<tr>
<td>HCP</td>
<td>Healthcare personnel</td>
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<td>HEPA</td>
<td>High-efficiency particulate air</td>
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<tr>
<td>HICPAC</td>
<td>Healthcare Infection Control Practices Advisory Committee</td>
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<td>HIV</td>
<td>Human immunodeficiency virus</td>
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<td>HMO</td>
<td>Health maintenance organizations</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>ICER</td>
<td>Incremental cost-effectiveness ratio</td>
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<tr>
<td>ICU</td>
<td>Intensive care unit</td>
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<tr>
<td>IHI</td>
<td>Institute for Healthcare Improvement</td>
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<tr>
<td>IOM</td>
<td>Institute of Medicine</td>
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<tr>
<td>IP</td>
<td>Infection preventionist</td>
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<tr>
<td>JCAHO</td>
<td>Joint Commission on Accreditation of Healthcare Organizations</td>
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<tr>
<td>MD</td>
<td>Medical doctor</td>
</tr>
<tr>
<td>MDR</td>
<td>Multidrug resistant</td>
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<tr>
<td>MI</td>
<td>Median incidence</td>
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<tr>
<td>MRSA</td>
<td>Methicillin-resistant <em>Staphylococcus aureus</em></td>
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<tr>
<td>NHSN</td>
<td>National Healthcare Safety Network</td>
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<tr>
<td>NNIS</td>
<td>National Nosocomial Infections Surveillance System</td>
</tr>
<tr>
<td>NS</td>
<td>Not significant</td>
</tr>
<tr>
<td>NSS</td>
<td>No surveillance screening</td>
</tr>
<tr>
<td>PCR</td>
<td>Polymerase chain reaction</td>
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<tr>
<td>PPE</td>
<td>Personal protective equipment</td>
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<tr>
<td>QI</td>
<td>Quality improvement</td>
</tr>
<tr>
<td>RID</td>
<td>Relative incidence difference</td>
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<tr>
<td>RN</td>
<td>Registered nurse</td>
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<tr>
<td>SARS</td>
<td>Severe acute respiratory syndrome</td>
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<tr>
<td>SENIC</td>
<td>Study on the Efficacy of Nosocomial Infection Control</td>
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<tr>
<td>SDU</td>
<td>Step-down units</td>
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<td>SPICE</td>
<td>Statewide Program for Infection Control and Epidemiology</td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>SSI</td>
<td>Surgical site infection</td>
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<tr>
<td>TJC</td>
<td>The Joint Commission</td>
</tr>
<tr>
<td>TSS</td>
<td>Targeted surveillance screening</td>
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<tr>
<td>UNC</td>
<td>University of North Carolina</td>
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<tr>
<td>UNCHC</td>
<td>University of North Carolina Health Care</td>
</tr>
<tr>
<td>USS</td>
<td>Universal surveillance screening</td>
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<tr>
<td>UTI</td>
<td>Urinary tract infection</td>
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<tr>
<td>VAP</td>
<td>Ventilator-associated pneumonia</td>
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<tr>
<td>VRE</td>
<td>Vancomycin-resistant enterococci</td>
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CHAPTER 1

INTRODUCTION:
HEALTHCARE-ASSOCIATED INFECTIONS AND INFECTION CONTROL
IN HOSPITALS IN THE UNITED STATES

Background

Healthcare-associated infections

The terms *nosocomial infections* and *hospital-acquired infections* have traditionally been used to indicate acute infections that occur in inpatient settings during hospitalization (Archibald, 2012). However, as the delivery of healthcare has evolved to encompass not only hospitals, but also ambulatory centers, outpatient clinics, long-term care facilities (e.g., nursing homes), and home care services, these infections may occur across any level of healthcare; therefore, the term *healthcare-associated infections (HAIs)* has replaced the above traditional terms (Archibald, 2012; Ostrowsky, 2007). Because the risk factors for and characteristics of HAIs in non-hospital type healthcare facilities are relatively unknown compared to those of acute-care hospitals (Archibald, 2012), this dissertation study focuses on HAIs and infection control in acute care hospital settings in the United States.

Hospitals in the United States

According to the 2010 annual survey from the American Hospital Association (AHA), 36,915,331 people were admitted to 941,995 staffed beds at 5,754 AHA-registered hospitals in the United States; 87% (n=4,985) of these were community hospitals, including university hospitals (American Hospital Association, 2012). The total expense for all U.S. hospitals was $750 billion in 2010 (American Hospital Association, 2012). Overall, 7.9% of the U.S.
population was admitted to a hospital at least once in 2010, and the average length of hospital stay in 2009 was 4.9 days (CDC, 2012). Although the average length of hospital stay has decreased along with the decreasing number of hospitalized patients, the severity of patients’ illness has increased among hospitalized populations, and the highly complicated U.S. hospital environment presents the serious potential to cause adverse events, including HAIs (Nettleman, Roach, & Wenzel, 2012). The more that the factors that contribute to HAIs (e.g., aging patient population, increasing severity of illness, and increased use of invasive indwelling devices and broad-spectrum antibiotics) increase in U.S. hospital settings, the greater the risk that hospitalized patients acquire HAIs (Nettleman et al., 2012).

**Significance of healthcare-associated infections**

HAIs are one of the most common adverse events that threaten patient safety in the United States (Burke, 2003; Pittet & Donaldson, 2006). HAIs are estimated to be one of the top 10 causes of death in the United States (United States Government Accountability Office, 2008). In the most recent data available, the Centers for Disease Control and Prevention (CDC) reported that approximately 1.7 million HAIs and 99,000 HAI-related deaths occurred in the U.S. in 2002 alone (Klevens et al., 2007). In addition, HAIs place a substantial economic burden on the healthcare system, contributing an estimated $28.4 to 33.8 billion per year in additional healthcare costs (Scott, 2009).

Governmental authorities, accreditation bodies, and payers have responded to concerns about continuing patient safety, public health and economic issues related to HAIs by taking several actions (Anderson et al., 2007; Klevens et al., 2007). The Joint Commission (TJC; formerly the Joint Commission on Accreditation of Healthcare Organizations [JCAHO]) has raised awareness about the perils of HAIs by including HAI prevention in their accreditation
criteria as a key element of national patient safety goals (Anderson et al., 2007; JCAHO, 2006; Weinstein, 1998). The first TJC standards, published in 1976, emphasized hospital infection control programs, while recent TJC standards have focused on infection control and prevention (Bartley, 2009). TJC added HAI reduction as a National Patient Safety Goal in the 2004 standards and expanded this goal in the 2009 standards (Bartley, 2009).

Following the Deficit Reduction Act in 2006, the Centers for Medicare and Medicaid Services (CMS) on October 1, 2008 began prohibiting hospitals from receiving additional payment for hospital-acquired conditions that were not present on admission, including such HAIs as vascular catheter-associated infections, catheter-associated urinary tract infection, and selected surgical site infections (SSIs) following coronary artery bypass graft, certain orthopedic procedures, and bariatric surgery for obesity (CMS, 2011; Graves & McGowan, 2008; Stone, 2009; Wachter, Foster, & Dudley, 2008). Currently, CMS has considered expanding “pay for performance” and “no pay for errors” policies by adding additional HAI conditions to the list, including the following: ventilator-associated pneumonia (VAP), Clostridium difficile-associated disease, and methicillin-resistant Staphylococcus aureus (MRSA) infections (Wachter et al., 2008). Following CMS’s lead, some health maintenance organizations (HMOs) in the United States no longer reimburse costs for selected HAIs (Carlet, Fabry, Amalberti, & Degos, 2009).

Furthermore, in January 2009, the Department of Health and Human Services (DHHS) and nine other federal organizations, including the CDC, announced an Action Plan to Prevent Healthcare-Associated Infections that provides priority recommendations (DHHS, 2009). In addition, HAIs have received increasing attention as a key component for improving quality and safety in healthcare reform (DHHS Press Office, 2009). Within the American Recovery and Reinvestment Act of 2009, Public Law 111-5 (ARRA), $50 million was assigned to support the
prevention and reduction of HAIs (CDC, 2009a), and the CDC announced plans to allocate $40 million to state health authorities to support HAI prevention (CDC, 2009b). This funding is expected to advance infection control efforts, including HAI surveillance, collaboration for implementing interventions, training the healthcare workforce, and measuring outcomes (CDC, 2009a). In addition, the CDC reports an emerging movement to mandate that healthcare facilities report HAIs to federal and state agencies as part of healthcare reform (CDC, 2010). Between 2003 and 2010, 28 states mandated hospital reporting of selected HAIs (Mascola, Kainer, & Pollock, 2010). As of October 2011, 27 states have developed HAI-related laws requiring the public reporting of HAI rates, while two states (Nebraska and Nevada) have laws that mandate the confidential reporting of HAI rates to state bureaus. Three states (Arkansas, Arizona, and Wisconsin) allow voluntary public reporting of HAI information, while five states (Alaska, Georgia, Indiana, New Mexico, and North Carolina) have considered public reporting laws, and several other states have pending bills for public reporting (Committee to Reduce Infection Deaths, 2011).

Concurrently, public concerns about HAIs and requests to improve HAI prevention have increased markedly. The Consumers Union, the nonprofit publisher of Consumer Reports, has actively pressured hospitals for more effective infection control by campaigning to reduce HAIs and lobbying state legislatures to enact the Consumers Union Model Hospital Infections Disclosure Act (Edmond & Eickhoff, 2008). This act asks states to enforce such penalties as terminating the licensure of hospitals that violate its provisions (Consumers Union, 2006). Another example of increasing public concern is the Institute for Healthcare Improvement (IHI). The IHI, a non-profit organization, created the “100,000 Lives Campaign” and the “5 Million Lives Campaign” to emphasize best practices for reducing HAIs (McCannon, Hackbarth, &
Griffin, 2007). The “5 Million Lives Campaign” aimed to achieve a decrease of 5 million unintended medical harms between December 2006 and December 2008 by adding six new interventions—including the reduction of MRSA rates. This campaign was modeled after the “100,000 Lives Campaign” which focused on six interventions, including the prevention of central line infections, SSI, and VAP, and which attracted more than 3,100 hospitals and avoided an estimated 122,000 deaths between December 2004 and December 2006 (McCannon et al., 2007).

**Occurrence of Healthcare-Associated Infections**

An HAI is defined as “a localized or systemic condition resulting from an adverse reaction to the presence of an infectious agent(s) or its toxin(s)” with no evidence of infection at the time of admission (Hidron et al., 2008; p. 309). Infections that develop within 48 hours of admission are not usually considered HAIs because of the typical incubation period of bacterial pathogens (Garner, Jarvis, Emori, Horan, & Hughes, 1996).
Figure 1.1 Explanatory diagram for the chain of healthcare-associated infections. Adapted from the CDC guidelines for environmental infection control in health-care facilities: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), MMWR, 2003: 52(RR10); p.4 ‘Box 3. Chain of infection components’.

The “Chain of HAIs” model (Figure 1.1) serves as a useful framework for understanding how HAIs occur (CDC, 2003). This model identifies the characteristics of the infectious agent itself; potential reservoirs of infection in hospitals; how the agent is communicated, including the portal of exit, the mode of transmission, and the portal of entry; and includes the characteristics of hospital patients that increase their susceptibility to infection.

**Infectious agent.** The first link in the chain describes the characteristics of the specific healthcare-associated pathogen as an infectious agent. Most HAIs are caused by bacteria and viruses, and some are caused by fungi (Ostrowsky, 2007). The factors that differentiate the agent are dose, pathogenicity, virulence, infectiousness, infectivity, specificity, and antimicrobial
resistance (Ostrowsky, 2007). *Dose* is the amount of an agent needed to cause an HAI (Ostrowsky, 2007). The greater the number of microorganisms present, the greater the possibility that an infection will occur. *Pathogenicity* is the agent’s ability to induce HAIs (Ostrowsky, 2007). *Virulence*, as an element of pathogenicity, refers to the infection-evoking power of a healthcare-associated pathogen in a given host (Last, 2001). Sometimes, avirulent or low-virulence pathogens, such as *Serratia marcescens*, are isolated from HAIs under particular conditions (e.g., a high infecting dose or/and host immunodeficiency; Archibald, 2012; Ostrowsky, 2007). *Infectiousness* refers to the number of infected people among susceptible hosts after exposure to an agent (Ostrowsky, 2007). *Infectivity* is the ability of a healthcare-associated pathogen to transmit from a source to a host (Ostrowsky, 2007). *Specificity* refers to the specific range of hosts for an agent (Ostrowsky, 2007). *Antimicrobial resistance* refers to the agent’s acquired resistance to antibiotics. Antimicrobial resistance may increase the frequency of HAIs because of the spread of resistant strains of pathogens (Ostrowsky, 2007).

National Healthcare Safety Network (NHSN) data from 2006 to 2007 reported the top 10 most commonly isolated healthcare-associated pathogens as follows: coagulase-negative staphylococci (CoNS; 15.3%), *Staphylococcus aureus* (14.5%), *Enterococcus* species (12.1%), *Candida* species (6.8%), *Escherichia coli* (9.6%), *Pseudomonas aeruginosa* (7.9%), *Klebsiella pneumonia* (5.8%), *Enterobacter* species (4.8%), *Acinetobacter baumannii* (2.7%), and *Klebsiella oxytoca* (1.1%; Hidron et al., 2008). However, the spectrum of healthcare-associated pathogens may have changed over time as a result of the increased use of broad-spectrum antibiotics and invasive procedures and increasing numbers of immunocompromised patients (Weber, Rutala, Samsa, Wilson, & Hoffmann, 1992). Recently, multidrug-resistant (MDR) pathogens (e.g., MRSA) have emerged as significant healthcare-associated pathogens. MDR
pathogens are defined as “microorganisms, predominantly bacteria, that are resistant to one or more classes of antimicrobial agents” (P. S166; Siegel, Rhinehart, Jackson, & Chiarello, 2007). In describing MDR pathogens, “resistant” refers to the loss of susceptibility to major antimicrobial treatments, which may be either a first-line antimicrobial (e.g., oxacillin for \textit{S. aureus}) that is preferred because of its low toxicity or superior efficacy or a marker-antimicrobial for broader resistance (e.g., ceftazidime-resistant \textit{K. pneumonia} that produces extended-spectrum \textit{β}-lactamase [ESBL]; Lin, Weinstein, & Hayden, 2007). Although a particular MDR pathogen’s name implies resistance to only one antimicrobial agent (e.g., MRSA, vancomycin-resistant enterococci [VRE]), these pathogens are typically resistant to many other antimicrobial agents, and treatment options for MDR pathogens are often limited (Siegel et al., 2007). Thus, the treatment and prevention of HAIs caused by MDR pathogens poses an increasing challenge in hospital settings (Hidron et al., 2008).

**Reservoir.** A reservoir is the place where an infectious agent can live and multiply. Reservoirs can be any person, animal, or inanimate substance, such as water and soil (Last, 2001). In hospital settings, reservoirs for healthcare-associated pathogens can be humans and the hospital environment, including any surface of the patient care area (CDC, 2003). Human reservoirs are people in the hospital setting, including hospitalized patients, healthcare personnel (HCP), environmental cleaning personnel and hospital visitors (Siegel, Rhinehart, Jackson, & Chiarello, 2007). For example, humans are the principal reservoir of \textit{S. aureus}. According to the National Health and Nutrition Examination Survey 2004, approximately 1.5% of U.S. residents carry MRSA in their nasal cavities (Gorwitz et al., 2008). VRE outbreak investigation reports provide another example. VRE contamination is often found on various hospital surfaces that are
frequently touched by patients and HCP, including bedrails, computer tables, blood pressure cuffs, doorknobs, and gowns (CDC, 2003).

Portal of exit. The portal of exit of healthcare-associated pathogens is generally respiratory tracts, gastrointestinal tracts, skin, blood, and wounds (Ostrowsky, 2007). In fact, depending on the pathogen, any patient’s secretion or excretion can be a portal of exit (Ostrowsky, 2007). For example, VRE and *C. difficile* are contained in patients’ stool. Thus, patients with bowel incontinence or uncontained secretions secondary to poor personal hygiene (e.g., infants and patients with altered mental status) represent a significant source of enteric pathogen outbreaks (Siegel et al., 2007).

Mode of transmission. The mode of transmission differs by type of healthcare-associated pathogen and includes contact (direct or indirect), droplet, and airborne transmission (Siegel et al., 2007a). Some pathogens are transmitted via more than one transmission route (e.g., *S. aureus*, which can be transmitted via direct or indirect contact), and some are not transmitted from person to person at all (e.g., *Legionella*; Siegel et al., 2007a). Contact transmission is the most common mode of transmission, and it consists of two subgroups: direct and indirect contact (Siegel et al., 2007a). Direct contact transmission occurs when pathogens are transmitted from a source patient to another person without an intermediate object or person (Siegel et al., 2007a). Indirect contact transmission of a pathogen occurs through contact with a contaminated object (e.g., endoscopes or isolation gowns) or intermediate people (Siegel et al., 2007a). The transmission of MDR pathogens results primarily from direct or indirect contact, including an HCP’s contaminated hands or contaminated equipment (Salgado & Farr, 2006). Droplet transmission involves respiratory droplets containing pathogens. Such droplets are generated by patients coughing, sneezing, or talking, or during procedures (e.g., suctioning; Siegel et al.,
Droplets are usually defined as greater than 5 μm in size, and the typically defined distance of risk for droplet transmission is 3 feet, based on prior epidemiologic research (Siegel et al., 2007a). Droplet transmission occurs when infectious droplets are deposited on the host’s mucosal surface (e.g., conjunctiva; Ostrowsky, 2007). Examples of droplet-transmitted pathogens are the influenza virus, *Bordetella pertussis*, and *Neisseria meningitides* (Siegel et al., 2007a). Airborne transmission occurs when airborne droplet nuclei smaller than 5 μm travel with air currents, which carry such infectious pathogens as *Mycobacterium tuberculosis*, varicella-zoster virus and rubeola virus (Siegel et al., 2007a). Airborne microorganisms can be suspended in the air for hours or days and may be inhaled by a susceptible host at a much greater distance than non-airborne pathogens are; thus, a respiratory protection program (e.g., education regarding the proper use of a mask/respirator) is required to reduce infection risk (Siegel et al., 2007a; Ostrowsky, 2007).

**Portal of entry.** The portal of entry refers to an opening that permits the healthcare-associated pathogen to enter the susceptible host. Portals include body orifices, mucous membranes, skin wounds, and medical devices, such as Foley catheters and endotracheal tubes. HCP experience occupational exposure to blood from patients with hepatitis B virus, hepatitis C virus, and human immunodeficiency virus (HIV) via percutaneous injuries, direct contact with mucous membranes and nonintact skin as portals of entry in hospital settings (O’Malley et al., 2007). For droplet and airborne routes of transmission, portals of entry may include mucosal surfaces, such as conjunctivae and nasal mucosa (Siegel et al., 2007a).

**Susceptible host.** A susceptible host is a person who becomes infected by a healthcare-associated pathogen secondary to reduced immunity or body function. In hospital settings, patients, HCP, and visitors may be susceptible hosts. Host-specific factors, such as underlying
comorbidities (e.g., malignancy, diabetes) or poor physiologic reserve (e.g., old age), can increase the risk of infection (Siegel et al., 2007a). In addition, the administration of antimicrobials impairs the growth of normal intestinal flora and is a well-known risk factor for *C. difficile* infection (Lo Vecchio & Zacur, 2012). Furthermore, specific medical treatments, such as surgery or radiation therapy, can impair host defense mechanisms, thus increasing the risk of infection. Invasive devices (e.g., endotracheal tubes, central-line catheters) can facilitate the occurrence of HAIs by allowing pathogens to avoid local biologic defenses that would normally allow the host to resist pathogen invasion. This occurs because the device provides a surface that allows pathogens to develop biofilms, which enhance their adherence to device surfaces and confer protection from antimicrobials (Siegel et al., 2007a). Although many patients may be exposed to the same healthcare-associated pathogen, exposure results vary; some patients become transient or permanent asymptomatic carriers, whereas others become severely ill (Ostrowsky, 2007; Siegel et al., 2007). The patient’s immune status at the time of exposure to a healthcare-associated pathogen, the virulence of the healthcare-associated pathogen, and the host-agent interaction are important factors that affect patient outcomes (Siegel et al., 2007a).  

Considering the chain of HAIs (Figure 1.1), the solution for controlling and preventing HAIs, particularly in the hospital setting is to break any link in the chain. However, the most effective infection control intervention breaks the chain of an HAI at its weakest point (Ostrowsky, 2007). Knowing the chain of HAIs should help guide the development of specific interventions to control HAIs and help avoid the atheoretical adoption of nonspecific interventions (Ostrowsky, 2007). However, predictions about HAI occurrences and the development of effective infection control measures, which are assumed to be straightforward based on the chain of HAIs, are surprisingly difficult in hospital settings. This difficulty arises
because both the occurrence and prevention of HAIs involves more than one component of the chain of HAIs. In fact, the occurrence of HAIs depends on a variety of factors, particularly those related to healthcare-associated pathogens, mode of transmission, and host susceptibility. In addition, even when many patients experience identical exposure to a healthcare-associated pathogen, their outcomes may differ (from asymptomatic colonization to death due to HAI) depending on host factors (Archibald, 2012; Ostrowsky, 2007). Thus, it is difficult to guarantee that HAIs will be controlled by interrupting any one specific component in the chain of infection. The interruption of a single component may not be effective enough to completely prevent the occurrence of HAIs.

*Figure 1.2* Explanatory diagram for the interaction between healthcare-associated pathogens and a susceptible host within the hospital environment. Note. Six components of the chain of HAIs are marked to show multifactorial interactions (created by the author).

Although the chain of HAIs model provides six conceptual components of HAI occurrence, in brief, HAIs result from multifactorial interactions (*Figure 1.2*) between a
A healthcare-associated pathogen and a susceptible host (i.e., a hospitalized patient) within the environmental ecology of HAIs (Archibald, 2012; Ostrowsky, 2007). As the explanatory diagram in Figure 1.2 shows, the multifactorial interactions (transmission) can occur via any mode of transmission (e.g., contact, airborne, and droplet; from portal of exit to portal of entry) between a HAI pathogen (an infectious agent) and a hospitalized patient (a susceptible host) within the hospital environment. The hospital environment may affect the chain of HAIs because a patient in a hospital bed is frequently surrounded by multiple medical devices or equipment and surfaces (Ostrowsky, 2007). For example, the humidity of a patient’s room can affect multiple components in the chain of HAIs: the persistence of the healthcare-associated pathogen at the reservoir, the transmission of pathogens through the airflow, and the effectiveness of the host’s mucous membrane resistance (Ostrowsky, 2007).

The risk of HAIs during patient care in hospitals is most influenced by the healthcare-associated pathogen’s mode of transmission (Fauerbach, 2002). Therefore, most infection control intervention efforts aim to affect various factors to prevent the transmission of healthcare-associated pathogen among susceptible hosts in the hospital environment rather than focusing on one specific component in the chain of infection. For example, hand hygiene or wearing gloves is primarily directed at interrupting the contact transmission route, wearing a surgical mask is directed at interrupting the droplet transmission route, and surface disinfection is directed at both eliminating the reservoir of the hospital environment and interrupting the contact transmission route. Thus, when infection control guidelines are applied in hospital settings, interventions (e.g., isolation precautions) simultaneously address multiple components of the chain of HAIs and interrupt interactions (transmission) among them.
The Control and Prevention of Healthcare-Associated Infections

CDC/Healthcare Infection Control Practices Advisory Committee (HICPAC) guidelines

To assist hospital infection control intervention efforts, the CDC and HICPAC have published a variety of guidelines (e.g., CDC/HICPAC, Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008) based on scientific evidence (Rutala, Weber, & HICPAC, 2008; Umsheid, Agarwal, Brennan, & HICPAC, 2009). All of the recommendations in the CDC/ HICPAC guidelines were developed using targeted systematic reviews of the best available evidence for preventing HAIs by interrupting components of the chain of HAIs (Umsheid et al., 2009). Each recommendation in the guidelines is categorized into five levels (IA, strongly recommended and supported; IB, strongly recommended; IC, required by regulations or standards; II, suggested; and III, unresolved issue) based on the strength of evidence, such as the existing theoretical rationale, scientific data, economic impact, and practical applicability across the six components of the chain of HAIs (O'Grady et al., 2011).

Isolation precautions

Isolation precautions have been recommended as standard infection control practices for HCPs across the range of care. Isolation precautions can simultaneously affect several components in the chain of HAIs and prevent the potential transmission of healthcare-associated pathogens in hospital environments. In terms of the traditional concept of quarantine, “isolation” means isolating people with communicable disease from interactions with others (Patterson, 2004). Precautions indicate the set of interventions (e.g., gloving) required to prevent the potential transmission of communicable disease. Overall, “isolation precautions” can be described as the physical isolation of the identified patient to avoid the cross-transmission of infectious disease to other patients. Isolation precautions require that the HCP implement extra
precautions when caring for the isolated patient. The use of isolation precautions is becoming more important in hospital settings to control potential exposure to patients with emerging disease events, such as severe acute respiratory syndrome (SARS) world-wide epidemic (Patterson, 2004).

The terminology for isolation precautions has changed since 1970, when the CDC published the first *Isolation Techniques for Use in Hospitals* guidelines. These guidelines consisted of two general approaches: a category-specific system with limited isolation protocols based on categorized infectious diseases, and a disease-specific system that presented specific measures for each disease (Van den broek, 2003). Increased awareness of the dangers of blood and blood-containing body fluids resulted from the emergence of acquired immunodeficiency syndrome (AIDS) epidemic; therefore, in 1985, the recommendations were changed to the universal precautions and body substance isolations because of the difficulty of verifying which patients are infectious on admission (Van den broek, 2003). Later, standard precautions were developed to emphasize the importance of hand hygiene and the use of personal protective equipment (PPE; gloves, gown, mask/respirator, eye shield, and face shield) for routine patient care while reducing the number of different isolation precautions (Van den broek, 2003). The most recent CDC/HICPAC isolation guidelines, the 2007 Guideline for Isolation Precautions: *Preventing Transmission of Infectious Agents in Healthcare Settings*, recommend three types of transmission-based isolation precautions—contact precautions, droplet precautions, and airborne precautions—along with standard precautions in hospital settings (Siegel et al., 2007a). Transmission-based precautions are preferred when standard precautions alone do not completely interrupt transmission of pathogens (Siegel et al., 2007a). For pathogens with
multiple transmission routes, such as SARS, more than one set of transmission-based precautions may be needed to reduce the risk of HAIs (Siegel et al., 2007a).

**Standard precautions.** Standard precautions are a set of universal precautions and body substance isolations that includes hand hygiene, safe injection practices, proper management of contaminated items, and the use of PPE when appropriate (Siegel et al., 2007a). Recently, three new practices were added to standard precautions: respiratory hygiene/cough etiquette for cold symptoms in a healthcare facility (including education, sign posting, the use of a surgical mask, hand hygiene, and spatial separation), safe injection practices for ambulatory care facilities (the use of single-use disposable needles and syringes), and use of a surgical mask for lumbar puncture procedures to prevent the transmission of clinicians’ oral flora to patients (Siegel et al., 2007a).

**Contact precautions.** Contact precautions are recommended to prevent the transmission of healthcare-associated pathogens via direct or indirect contact with patients (Siegel et al., 2007a). Contact precautions are needed for contact-transmitted pathogens, such as MDR pathogens, and for patients who have body discharges, including fecal incontinence and excessive wound drainage (Siegel et al., 2007a). For patients with contact precautions, a private room is preferred, and HCP need to use PPE whenever they interact with the patient or with contaminated items in the patient’s room (Siegel et al., 2007a). Contact precautions require HCP to perform hand hygiene, to wear gown and gloves on room entry, and to dispose of gown and gloves properly upon room exit for all care practices that involve any contact with a patient or the patient’s environment (Clock, Cohen, Behta, Ross, & Larson, 2010; Siegel et al., 2007). However, reports regarding adherence to contact precautions in actual practice are limited, and there is no guideline for evaluating adherence to contact precautions (Clock et al., 2010). It is
challenging for hospitals to implement contact precautions concurrently with other infection control strategies, such as the timely detection of infected/colonized patients with MDR pathogens, the prompt initiation of single room placement, and communication for HCP and visitor adherence to isolation precautions (Clock et al., 2010).

**Droplet precautions.** Droplet precautions are needed for droplet-transmitted pathogens, such as influenza virus, adenovirus, rhinovirus, *Bordetella pertussis, Neisseria meningitidis*, and group A streptococcus (Siegel et al., 2007a). A single patient room is preferred, and HCP need to wear a mask when entering the patient’s room (Siegel et al., 2007a). If a single room is not available, the patient needs to be separated from other patients by a minimum of 3 feet, and the patient should wear a mask and maintain respiratory hygiene/cough etiquette (Siegel et al., 2007a).

**Airborne precautions.** Airborne precautions are required for infectious particles (e.g., *M. tuberculosis*) that can be suspended in air and travel long distances (Siegel et al., 2007a). The preferred room for a patient requiring airborne precautions is a single-occupancy airborne infection isolation room that meets American Institute of Architects/Facility Guideline Institute standards. These standards include monitoring negative pressure, 12 air exchanges per hour for areas under construction/renovation and six air exchanges per hour for already constructed area, and air exhaustion through high-efficiency particulate air [HEPA] filtration (Siegel et al., 2007a). Airborne precautions also include education about respirator use and an N95 mask fitting test for HCP (Siegel et al., 2007a). A properly fitting personal-use respirator or N95 mask must be worn by HCP while they are in the airborne isolation room.
**Precautions for multidrug-resistant pathogens**

Although the above four types of isolation precautions are recommended based on the mode of transmission of specific healthcare-associated pathogens in hospital settings, more than one type of transmission-based precautions may be necessary to control MDR pathogens and emerging diseases (e.g., SARS) to ensure the most effective implementation of infection control for each component in the chain of HAIs and for the interactions among the components. As a part of the 2007 *Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings*, CDC also published *Management of Multidrug-Resistant Organisms in Healthcare Settings, 2006* to enhance the prevention of MDR pathogens (Siegel et al., 2007a). To prevent the transmission of epidemiologically important healthcare-associated pathogens (e.g., MRSA), patient isolation in a private room and the implementation of contact precautions is generally recommended (Salgado & Farr, 2006; Siegel et al., 2007b). Contact precautions require wearing gown and gloves before entering the isolation rooms of patients who are infected with or colonized by MDR pathogens. Such precautions have been reported to be successful measures for reducing MDR pathogen transmission in hospital settings (Salgado & Farr, 2006). In addition, hand hygiene, environmental cleaning (or disinfection), and detection of MRSA-colonized patients and placing them under contact precautions have been emphasized as prevention strategies (Diekema & Climo, 2008). Furthermore, antimicrobial stewardship, reducing the lengths of hospital stays, ensuring an appropriate staff-patient ratio, “staff cohorting” (i.e., assigning staff to infected/colonized patients to prohibit staff from crossover care for uninfected/uncolonized patients), and staff education may help prevent the transmission of MDR pathogens (Henderson, 2006a). The CDC guideline *Management of Multidrug-Resistant Organisms in Healthcare Settings, 2006* recommends a combination of interventions (e.g.,
contact precautions, active surveillance screening, environmental cleaning) to control the spread of MDR pathogens, including MRSA (Siegel et al., 2007b). However, the efficacy of each individual intervention remains unknown because many studies report the results of the simultaneous implementation of several control interventions and because MDR pathogen transmission involves multiple complex factors in hospital settings (Henderson, 2006).

**Hospital infection control program**

To implement infection control guidelines for the prevention of HAIs, an effective infection control program is essential in hospital settings. A CDC Study on the Efficacy of Nosocomial Infection Control (SENIC) reported the four essential components of a hospital infection control program that contributed to a 32% reduction in HAIs: conducting active surveillance, employing a trained infection control physician, having a full-time infection control nurse for every 250 beds, and providing surgeons with feedback about HAI rates (Haley et al., 1985).

Surveillance has been the core scientific foundation of hospital epidemiology and the essential function of infection control programs in the United States since the 1960s (Archibald, 2012). The general goals of surveillance are to determine the endemic incidence rate of HAIs, to identify an epidemic event, and to evaluate the efficacy of interventions and programs (Weber, Sickbert-Bennett, Brown, & Rutala, 2007). Since 1989, when the CDC National Nosocomial Infections Surveillance System (NNIS) did not recommend hospital-wide surveillance (NNIS, 1998), most hospitals have conducted targeted HAIs surveillance, either unit-directed (e.g., intensive care units [ICU]) or site-directed (e.g., for specific surgical procedures). Targeted surveillance is widely used because infection control resources are scarce and because data acquisition through surveillance is both labor-intensive and costly (Edmond, 2007). Thus, it has
become increasingly difficult to acquire the information necessary to evaluate the hospital-wide incidence of HAIs, hospital-wide epidemic events, and hospital-wide interventions. However, to comprehensively understand epidemiologically important healthcare-associated pathogens (e.g., MRSA), hospital-wide surveillance may be necessary (Siegel et al., 2007a). In addition, hospital-wide surveillance can provide the critical infection control function of case-finding (a single patient or cluster of patients) to help isolate infectious patients using the appropriate transmission-based precautions (Siegel et al., 2007a).

Understaffing is a constant problem in hospital infection control. In 1985, SENIC recommended that one full-time infection control nurse be available for every 250 occupied beds in acute healthcare facilities; in 2002, the Association for Professionals in Infection Control and Epidemiology (APIC) suggested the staffing ratio of 0.8 to 1.0 infection control nurse for every 100 occupied acute care beds (O'Boyle, Jackson, & Henly, 2002). However, most hospital infection control departments are still understaffed and do not have adequate administrative support (Wright et al., 2010). Despite rapidly evolving infection control issues and a 145% increase in infection control activities between 1982 and 2001, resources for infection control have persistently lagged behind increased infection control activities (Goldrick, 2005).

The primary goal of a hospital infection control program is to prevent HAIs in a cost-effective manner (Jones & Woeltje, 2007). To reduce HAIs, effective infection control methods should be applied continuously and collaboratively in daily practice by every healthcare provider (Aziz & Murphy, 2009). Unfortunately, although detailed evidence-based guidelines are available, hospitals often deviate from existing guidelines that have clear descriptions about what is recommended and what should be avoided. For example, according to a 2007 Leapfrog Group survey, 87% of U.S. hospitals failed to put recommended guidelines into practice to prevent
HAI (Sprague, 2009). As the Institute of Medicine (IOM) report To Error Is Human: Building a Safer Health System on medical errors stated, improving patient safety calls for a systems approach to modify conditions that contribute to errors, which are often caused by a convergence of multiple factors (IOM, 2000). Flawed systems—processes that make HCP fail—can also contribute to HAI (Murphy, Alvarado, & Fawal, 2002). A multifaceted approach, including continuous assessment of HCP and modifications of work environments, is required to increase adherence to infection control recommendations in healthcare practices (Siegel et al., 2007a).

**Outline of Dissertation Study**

Although prior research has been conducted since the national adoption of hospital infection control programs in the 1970s, and it has provided useful evidence in infection control (Jones & Woeltje, 2007), further studies are still needed to fill the gaps between our knowledge and the reality of the HAI that currently occur in hospital settings. Among the many unknown aspects of HAI and hospital infection control issues, this dissertation study examined three areas related to hospital infection control that lacked critical information: the change in the incidence of HAI by healthcare-associated pathogen, the cost-effectiveness analysis of MRSA active surveillance screening, and current hospital policies for isolation precautions for visitors (see Figure 1.3). Under the overarching theme of prevention of HAI, this dissertation demonstrated an infection-control connection among three research areas. The study began with basic data-driven evidence (area 1, basic incidence) based on an examination of the HAI incidence by each pathogen group. It then progressed to the proactive intervention of finding carriers upon their admission to the hospital (area 2, guideline issue), and then proceeded to examine hospital policy issues regarding PPE use for visitors of patients on isolation precautions (area 3, implementing policy). The aims for each research area are described below.
Area 1. Basic incidence (Chapter 2: The Changes in the Incidence of Healthcare-Associated Infections by Pathogen at a University Hospital from 2005 to 2011)

Research needs. Although the CDC/HICPAC isolation precautions guideline recommends transmission-based precautions for pathogen-specific HAIs, current knowledge is limited concerning the change in the HAI incidence by pathogen, which plays a role as an infectious agent in the “chain of HAIs”. However, without knowing the incidence of HAIs by pathogen across hospital settings, we cannot plan infection control measures that focus on epidemiologically important healthcare-associated pathogens (e.g., MRSA) or identify patients who should be isolated and treated under transmission-based precautions. Thus, studies of the change in the HAI incidence by pathogen (i.e., information about longitudinal outcomes associated with the surveillance guideline-concordant interventions) within a hospital with an effective hospital infection control program is necessary to provide much-needed evidence with robust outcomes data to support desirable infection control policy in hospital settings.
**Aim.** This study aimed to examine the incidence of HAIs by pathogen using hospital-wide surveillance data to describe the epidemiology of HAIs at a university hospital. Using the incidence density per 1,000 person-days (patient-days or device-days), the incidence change in HAIs by pathogen was examined over time in the following categories: service (medicine, surgery, and pediatrics; ICU vs. non-ICU); device-associated infections (central line-associated bloodstream infection [CLABSI], CAUTI, and VAP); and MDR pathogens (MRSA, VRE, MDR Acinetobacter, and MDR Pseudomonas).

**Area 2. Guideline issue (Chapter 3: Cost-Effectiveness Analysis of Active Surveillance Screening for Methicillin-Resistant Staphylococcus aureus in an Academic Hospital Setting)**

**Research needs.** When the guidelines provided by CDC/HICPAC or other professional societies cannot recommend solutions for HAI problems secondary to insufficient knowledge or evidence, hospitals must determine their own policy/intervention based on their unique characteristics, such as acute care setting or long-term care facility status. In particular, MRSA active surveillance screening remains a controversial topic that has conflicting guidelines from the Society for Healthcare Epidemiology of America (SHEA) and HICPAC (Jackson, Jarvis, & Scheckler, 2004). Thus, further study is needed to compare the costs and outcomes among different MRSA surveillance screening strategies and to provide evidence regarding the most cost-effective MRSA screening policy on patient admission to academic hospitals that have distinctive characteristics (e.g., acute care facilities with more severely ill patients and frequent transfer-ins from other facilities).

**Aim.** This study aimed to evaluate the cost-effectiveness of three alternative active screening strategies for MRSA in an academic hospital setting (from the hospital perspective) to detect MRSA-colonized patients who should be isolated with contact precautions upon hospital
admission. The screening strategies were universal surveillance screening (USS) for all hospital admissions, targeted surveillance screening (TSS) for ICU admissions, and no surveillance screening (NSS). From the academic hospital perspective, a cost-effectiveness analysis was conducted using a decision-tree model to determine the most cost-effective active surveillance screening strategy for MRSA.

Area 3. Implementing policy (Chapter 4: Survey of North Carolina Hospital Policies Regarding Visitor Use of Personal Protective Equipment for Entering the Rooms of Patients on Isolation Precautions)

Research needs. Every human has many endogenous microorganisms within his or her own body and can be either a susceptible host or an intermediate transmission route of infectious agents. HCP are required to adhere to isolation precautions during their daily interactions with infected/colonized patients. However, there are no clear recommendations for hospital visitors, who could acquire healthcare-associated pathogens as susceptible hosts or could transmit these pathogens as reservoirs during their visit. Thus, a study on current hospital visitor policies is needed to suggest appropriate hospital policies related to isolation precautions.

Aim. This study explored the range of hospital policies for visitor use of personal protective equipment when entering the rooms of patients on isolation precautions. Using an online survey of hospitals in North Carolina, this study examined current hospital visitor policies related to isolation precautions and, based on lessons from infection preventionists (IPs)’ experience, suggested appropriate future policy directions, including difficulties with such policies and ideas for improving them.
REFERENCES


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CHAPTER 2

THE CHANGES IN THE INCIDENCE OF HEALTHCARE-ASSOCIATED INFECTIONS BY PATHOGEN AT A UNIVERSITY HOSPITAL FROM 2005 TO 2011

Background

Surveillance for incidence of healthcare-associated infections

Monitoring the changes in the HAI incidence rate through surveillance is essential to planning, implementing, and evaluating infection control measures to prevent HAIs in hospital settings. According to a dictionary of epidemiology, “incidence” refers to the new cases of a disease in a defined population for a specific time period, and incidence density refers to the incidence rate per person-time (Last, 2001). Healthcare-associated infection (HAI) surveillance is the systematic, ongoing collection, analysis, and dissemination of HAI data (Allen-Bridson, Morrell, & Horan, 2012). Its goals are reducing the overall HAI incidence, establishing endemic rates, detecting outbreaks, convincing administrators and healthcare personnel to take measures against HAIs, evaluating control measures, satisfying accrediting and regulatory requirements, defending the institution against lawsuits, and comparing HAI rates within or between hospitals (Andrus, Horan, & Gaynes, 2007; Perl & Chaiwarith, 2010). To compare the incidence rate of HAIs in a hospital (across units or hospitals) over time, the incidence rate must be adjusted using the incidence-density approach for variations in the distribution of denominators (population at risk), such as length of hospital stay and device use (Allen-Bridson et al., 2012; Tokars, 2012). In this dissertation, incidence is used interchangeably with incidence density.
Healthcare-associated pathogens

Information about pathogens isolated from patients’ HAIs has implications for both treatment and the implementation of infection control and prevention strategies (Henderson, 2006). However, in contrast to the increasing focus on antimicrobial-resistant pathogens, there are few reports on HAI pathogens (McDonald, 2006). In addition, data on HAIs occurring outside of intensive care units (ICU) are scarce since targeted (priority-based) surveillance emerged as a cost-effective method, leading to the discontinuation of hospital-wide surveillance in the Centers for Disease Control and Prevention (CDC) National Nosocomial Infections Surveillance System (NNIS) in 1986 (NNIS, 1998). However, according to a recent study comparing the number of HAIs included in targeted surveillance (the National Healthcare Safety Network [NHSN] surveillance) and hospital-wide surveillance, targeted surveillance found only 77.7% of the bloodstream infections (BSIs), 74.5% of the surgical site infections (SSIs), 62.3% of the urinary tract infections (UTIs), and 18.6% of the respiratory tract infections (including 100% of the ventilator-associated pneumonia [VAP] cases) that were identified with hospital-wide surveillance (Weber, Sickbert-Bennett, Brown, & Rutala, 2012). Therefore, comprehensive data on healthcare-associated pathogens based on hospital-wide surveillance data is currently lacking in most hospitals using targeted surveillance.

A healthcare-associated pathogen is an organism that causes healthcare-associated infections (HAIs) within a healthcare setting, thus serving as the infectious agent in the “Chain of HAIs” model (see Chapter 1, Figure 1.1). Healthcare-associated pathogens include bacteria, fungi, and viruses (Ostrowsky, 2007). The NHSN report from 2006 to 2007 named the 10 most common infectious agents, which were isolated from 84% of the reported HAIs. They were coagulase-negative staphylococci (CoNS; 15.3%), Staphylococcus aureus (14.5%),
Enterococcus species (12.1%), Candida species (6.8%), Escherichia coli (9.6%), Pseudomonas aeruginosa (7.9%), Klebsiella pneumonia (5.8%), Enterobacter species (4.8%), Acinetobacter baumannii (2.7%), and Klebsiella oxytoca (1.1%; Hidron et al., 2008). According to a study that examined the relative frequency of healthcare-associated pathogens at one university hospital from 1980 to 2008, 18 groups of HAI agents were found through hospital-wide surveillance: in order of decreasing frequency, the agents were S. aureus, E. coli, CoNS, “Candida and other yeast”, Enterococcus species, Pseudomonas aeruginosa, Klebsiella species, Enterobacter species, other streptococci, “Clostridium difficile and other anaerobes”, Proteus species, Serratia species, Acinetobacter species, Haemophilus species, Bacteroids species, Citrobacter species, Group B streptococci, and others (Kang, Sickbert-Bennett, Brown, Weber, & Rutala, 2012b).

The characteristics of the main healthcare-associated pathogens

Staphylococcus aureus. S. aureus has been the predominant healthcare-associated pathogen in hospital settings since the 1950s. It is a common community pathogen that causes soft tissue infections and furuncles (John & Shukla, 2012). S. aureus is commonly part of the normal flora of the human body. It is not an environmental pathogen, but it can persist on hospital surfaces for hours to days (John & Shukla, 2012; Salgado & Calfee, 2012). Asymptomatic colonization of S. aureus has been reported in one-third of the human population, and hospitalization itself is a risk factor for S. aureus colonization (John & Shukla, 2012; Salgado & Calfee, 2012). S. aureus may cause bacteremia, endocarditis, SSI, pneumonia, burn wound infections, hemodialysis shunt infections, meningitis, prosthetic device infections, urinary tract infection (UTI), osteomyelitis, septic arthritis, and toxic shock syndrome (John & Shukla, 2012). Methicillin-resistant S. aureus (MRSA) is a S. aureus strain that is resistant to antistaphylococcal penicillins (e.g., methicillin, oxacillin) and most of the currently available
beta-lactam antibiotics, such as cephalosporins (except ceftaroline which is a new cephalosporin that has activity against MRSA) and carbapenems (Salgado & Calfee, 2012). Since the first report of MRSA in 1961, it has become a common, endemic HAI problem in hospital settings throughout much of the world except Netherlands (Salgado & Calfee, 2012).

**Coagulase-negative staphylococci.** CoNS are low-pathogenic bacteria that reside on human skin and mucosa. They are a rare source of disease in healthy individuals outside the hospital setting (Ziebuhr & Flückiger, 2012). *Staphylococcus epidermidis* is the most common HAI pathogen among the CoNS, which also include *S. capitis, S. haemolyticus, S. hominis, S. lugdunensis, S. saprophyticus, S. schleiferii*, and *S. swarneri* (Ziebuhr & Flückiger, 2012). In recent decades, CoNS have emerged as common HAI pathogens among patients who are critically ill, immunocompromised, have central venous access devices, and experiencing long-term hospitalization. CoNS infection has been linked to the use of foreign materials, such as indwelling medical devices (Ziebuhr & Flückiger, 2012). CoNS may cause BSI associated with central-line catheters, prosthetic valve endocarditis related to pacemakers or implantable defibrillators, sternum osteomyelitis after cardiac surgery, prosthetic joint infections after joint replacement, meningitis/encephalitis associated with cerebrospinal fluid shunt implantation, and other device-related infections (Ziebuhr & Flückiger, 2012).

**Enterococcus species.** Enterococci are normally found in the human intestinal flora, but they may be found on hospitalized patients’ skin and wounds (e.g., pressure ulcers) and in the hospital environment, including the surfaces of medical equipment (Shuman & Chenoweth, 2012). *E. faecalis, E. faecium*, and *E. gallinarum* are the major healthcare-associated pathogen groups among the 33 species of *Enterococcus*, and they cause UTI, BSI, endocarditis, intra-abdominal/pelvic infections, and skin/soft tissue infections (Shuman & Chenoweth, 2012). Most
enterococci have inherent antimicrobial resistance to many antibiotics. In the past 10-20 years, vancomycin-resistant enterococci (VRE) have become increasingly challenging to treat with the small number of options (e.g., linezolid, daptomycin, and tigecycline), and infection control is difficult because of heavy environmental contamination (Shuman & Chenoweth, 2012).

**Gram-negative bacilli.** The reservoirs for Gram-negative bacilli (e.g., *P. aeruginosa*, *Acinetobacter* species) are water, soil, human body (e.g., the pharyngeal, genitourinary and gastrointestinal tracts), and hospital environments (Black, Bonten, & Weinstein, 2012; Stosor & Flaherty, 2012). The human gastrointestinal tract is a reservoir for *E. coli* and *Klebsiella* species (Black et al., 2012). *Enterobacter* species thrive in moist environments (e.g., infusion fluids and humidifiers), and *Serratia* species have been found in contaminated solutions, patients’ urinary and respiratory tracts, and such devices as endotracheal tubes (Black et al., 2012). Gram-negative bacilli can cause UTI, BSI, SSI, respiratory tract infections, and central nervous system infections (Black et al., 2012; Stosor & Flaherty, 2012). *P. aeruginosa* and *Acinetobacter* species have become important HAI pathogens often associated with multiclass antimicrobial resistance (Stosor & Flaherty, 2012).

**Clostridium difficile.** *C. difficile* is the etiologic pathogen of most healthcare-associated gastrointestinal infections such as healthcare-associated diarrhea and antibiotic-associated pseudomembranous colitis (Johnson & Gerding, 2012). *C. difficile* infection occurs under three conditions: 1) the disruption of normal intestinal microbiota after the use of broad spectrum antibiotics (e.g., third-generation cephalosporins, quinolones); 2) exposure to a *C. difficile* strain through asymptomatic carriers, or exposure to *C. difficile* spores from contaminated environmental surfaces; and 3) conducive host factors, such as host antibody response or the presence of intestinal epithelial cell receptors for *C. difficile* toxin A (Gough, Shaikh, & Manges, 2012).
Over the past several years, *C. difficile* has been reported as a leading HAI pathogen, and it has replaced MRSA as the leading HAI pathogen in community hospitals in the southeastern United States (Miller, Chen, Sexton, & Anderson, 2011).

**Candida.** The only source of *Candida* is the endogenous fungal flora of the patients’ own skin and gastrointestinal tract, although *Candida* species have been isolated from hospital environments (McNeil & Chiller, 2012). The HAIs caused by *Candida* are BSI, SSI, and mucocutaneous infections (e.g., neonatal oral thrush) usually among immunocompromised patients, such as low-birth weight infants and cancer patients undergoing chemotherapy (McNeil & Chiller, 2012). According to a NHSN report, *Candida* was the fourth most common HAI pathogen and the second most common etiologic agent for central line-associated bloodstream infection (CLABSI) from 2006 to 2007 (Hidron et al., 2008).

**Multidrug-resistant pathogens.** Multidrug-resistant (MDR) pathogens refer primarily to bacteria that have developed resistance to more than two unrelated key antimicrobial agents that are usually used as first-choice treatments for a given infection (Lin et al., 2007). The mortality rate is high for patients with MDR pathogen infections, and treatment options are few and challenging (Maragakis, 2010). Risk factors for MDR pathogen infection include prior antimicrobial exposure, intensive care unit (ICU) admission, and prolonged hospital stays (French, 2012). In addition to MRSA and VRE, MDR *Pseudomonas* and MDR *Acinetobacter* have recently emerged as important healthcare-associated MDR pathogens (French, 2012; Maragakis, 2010).

**Aim of this study**

Changes in the spectrum of healthcare-associated pathogens may arise from increasing numbers of immunocompromised patients, older patients with multiple comorbidities, and the
increased use of broad-spectrum antibiotics and invasive procedures (Weber et al., 1992). According to a study of the relative frequency of healthcare-associated pathogens (n=33,797) from 1980 to 2008 in a university hospital setting, the occurrence of S. aureus, CoNS, Enterococcus species, and “C. difficile and other anaerobes” significantly increased, while the relative proportion of E. coli, P. aeruginosa, Klebsiella species, Enterobacter species, and other streptococci significantly decreased during the study period (Kang et al., 2012b). Based on infection site, this study showed significant increasing trends for the following pathogens and sites: S. aureus in UTIs, SSIs, and respiratory tract infections; CoNS in BSIs and SSIs; Candida in SSIs; and Enterococcus in BSIs and UTIs. However, a study on the incidence of HAIs by pathogen is needed to better interpret the relative frequency of healthcare-associated pathogens because relative frequency calculations are influenced by the magnitude of the actual numbers of isolated pathogens, and they allow each pathogen’s proportions to change in response to the proportion changes in the other isolated pathogens (Kang et al., 2012b).

There is no established framework for determining the incidence of HAIs according to pathogen based on hospital-wide surveillance data. Despite challenges (e.g., potential inaccuracy if the population of patients at risk is small), hospital-wide surveillance has the strong advantage of providing comprehensive HAI data, including information about HAI pathogens isolated across hospital settings. Therefore, this study aimed to review the hospital-wide incidence of HAIs by pathogen using hospital-wide surveillance data to describe the epidemiology of HAIs at a university hospital.
Methods

Study Design

This study was designed as an epidemiological study focusing on the incidence of HAIs by pathogen among a cohort of hospitalized patients. This incidence-density study, a type of cohort study, used person-time at risk as a denominator (Tokars, 2012). This study involved a secondary analysis of preexisting HAI data collected through prospective hospital-wide surveillance, which is an ongoing descriptive study of HAI occurrence using standard CDC definitions and methods (Abramson, 2012). This study was approved by the UNC Biomedical Institutional Review Board.

Setting/Sample

This study was conducted at University of North Carolina Health Care (UNCHC), an 806-bed academic facility. UNCHC consists of North Carolina Memorial Hospital, a children’s hospital, a women’s hospital, a cancer hospital, and a neurosciences hospital. UNCHC has conducted comprehensive hospital-wide surveillance by trained full-time infection preventionists (IPs) using CDC NNIS/NHSN HAI definitions since 1980. All information about HAI cases detected by surveillance through hospital inpatient records has been stored in the UNCHC electronic epidemiology database’s clinical repository. The study sample included all HAIs that occurred among hospitalized patients during the study period from January 1, 2005 to December 31, 2011.

Data Collection

The collected data for this study were both numerators and denominators to calculate incidences. For the numerator, all healthcare-associated pathogen data with information about
the service location (nursing station), HAI category, and MDR were extracted from the UNCHC electronic epidemiology database for 2005 to 2011. The denominator data included patient-days, including overall total hospital stay, to calculate the service-associated incidence and device-days to calculate the incidence of device-associated infection. Patient-days data were extracted from hospital census data (DSS Business Universe) for the study period (2005 to 2011). Device-days (e.g., ventilator-days, central-line days, and Foley-catheter days) were extracted for the years 2006 to 2011 because of incomplete data for 2005, which was when UNCHC first mandated the daily recording (QuadraMed Acuity Plus®) of device-days at each nursing station.

Data Management/Measures

Pathogen data. Based on previous studies at UNCHC (Kang et al., 2012b; Weber et al., 1992), pathogens were grouped into 18 categories of related species (Figure 2.1). Non-informative data about pathogens, such as “no growth” and “mixed flora”, were deleted. To investigate changes in the incidence of MDR pathogens, the following additional subgroups of MDR pathogens were created for data analysis using MDR information from the epidemiology database: MRSA, VRE, MDR Acinetobacter, and MDR Pseudomonas (Figure 2.1).
Categorization for analysis. To analyze the incidence of isolated pathogens in device-associated HAI, all pathogens related to device utilization were sorted according to infection site information and then classified into five major categories: CLABSI, catheter-associated urinary tract infection (CAUTI), VAP, SSI, and other infections (e.g., endocarditis, osteomyelitis, and meningitis), as specified by NHSN definitions (Horan, Andrus, & Dudeck, 2008). To analyze the pathogen incidence according to service type, all cases (regardless of infection site) and all pathogen-isolated locations (based on nursing station and inpatient hospital service location) were classified into major service categories: two acuity-based categories (ICU vs. non-ICU) and four service-based categories (medicine vs. surgery vs. pediatrics vs. other services [e.g.,
dermatology, gynecology, psychiatry, ophthalmology, rehabilitation medicine)). Step-down units (SDU) were categorized as non-ICU because the HAI rates in SDUs were closer to those rates in the general wards than to the rates in the ICUs (Weber et al., 2007). Denominator data (device-days and patient-days) were classified into the same major infection site and service categories as the numerator (pathogens) data.

**Incidence density calculation.** The incidence densities of HAIs according to the healthcare-associated pathogen for each service and overall hospital total were calculated as the number of HAIs per 1,000 patient-days for each service (Formula 2.1; Tokars, 2012). In this study, the incidence density is defined as the incidence rate per 1,000 person-days at risk (operational definition of incidence, also can be called as adjusted incidence).

Formula 2.1

\[
\text{Incidence Density}_{\text{general}} = \frac{\text{The number of HAIs by pathogen}}{\text{The number of patient-days}} \times 1,000
\]

The incidence of device-associated HAIs (CLABSI, CAUTI, and VAP) according to healthcare-associated pathogen were calculated as the number of each device-associated HAI per 1,000 device-days: i.e., central-line days for CLABSI (Formula 2.2), Foley-catheter days for CAUTI (Formula 2.3), and ventilator days for VAP (Formula 2.4).

Formula 2.2

\[
\text{Incidence Density}_{\text{CLABSI}} = \frac{\text{The number of CLABSI by pathogen}}{\text{The number of central-line days}} \times 1,000
\]

Formula 2.3

\[
\text{Incidence Density}_{\text{CAUTI}} = \frac{\text{The number of CAUTI by pathogen}}{\text{The number of Foley-catheter days}} \times 1,000
\]

Formula 2.4

\[
\text{Incidence Density}_{\text{VAP}} = \frac{\text{The number of VAP by pathogen}}{\text{The number of ventilator-days}} \times 1,000
\]
Data Analysis

SAS Version 9.2 (SAS Institute, Cary, NC) was used to compute descriptive statistics (e.g., the total number of isolated *S. aureus* cases in the ICU in 2005, the mean incidence, the median incidence, and the incidence range) of the yearly incidence density of HAIs for the study period for each category of analysis (Figure 2.2). The mean incidence was used for the “overall (hospital total)” and “by service” analyses. The median incidence was used for “device-associated HAI” and “MDR pathogens” because missing or insufficient yearly numbers for isolated pathogens in some categories made the use of the mean incidence inappropriate.

Because the number of patient-days is a continuous variable, simple linear regression (dependent variable: patient-days; independent variable: year) was used to test for overall changes in patient-days during the study period to reflect the yearly total numbers of hospitalized patients and the total length of hospital stay at UNCHC for each patient.

![Diagram](image)

*Figure 2.2 Conceptual data analysis framework for each category. MDR = Multidrug resistant; ICU = Intensive care unit; CLABSI = Central line-associated bloodstream infection; CAUTI = Catheter-associated urinary tract infection; VAP = Ventilator-associated pneumonia.*
To estimate the yearly incidence densities of HAI according to pathogen across the study years, Poisson regression analysis that treated each year discretely was used to determine goodness of fit and adjust for overdispersion. Poisson regression is a valid method to determine the incidence density by accounting for person-days (e.g., patient-days and device-days; Tokars, 2012). When the overall effect of the Poisson regression model was statistically significant (i.e., the null hypothesis that there are no differences among the yearly incidence densities over time was rejected), logistic regression models were conducted for portions of each HAI occurrence by pathogen using linear fit across time to estimate the trend change (increase or decrease) in incidence densities across the study years. Where appropriate, the incidence difference between the first and last years of the study was estimated using the linear fit of logistic regression (Figure 2.3). When the Poisson regression found non-significant differences in the pathogen-specific HAI incidence densities, no linear distribution over time was assumed, and the incidence density difference was not estimated using logistic regression.

* Null hypothesis line (slope = 0): there is no difference in the incidence density over time

Figure 2.3 The concept of estimated incidence density difference based on the linear fit of the logistic regression.
To help interpret the incidence density difference, the relative difference in incidence density (the proportion of the first year to the last year, based on the estimated trend line; Tolley, 2012) was calculated using Formula 2.5.

**Formula 2.5**

Relative incidence difference (RID)

\[
\text{Relative incidence difference (RID)} = \left| \frac{\text{The incidence density of the first year} - \text{The incidence density of the last year}}{\text{The incidence density of the first year}} \right| \times 100 \, (\%)
\]

**Results**

Overall, at least one pathogen was isolated for 8,784 (87.2%) of the 10,070 HAIs that occurred during the 7-year study period. Because some HAIs had multiple pathogens, a total of 10,585 pathogens were isolated (Table 2.1). The mean number of pathogens per HAI was 1.21. For the remaining 1,286 HAIs, no pathogen was isolated. During the study period, the number of total patient-days per year increased significantly \((p\text{-value}, <0.05)\). However, among the top 10 pathogens, the incidence of *E. coli*, *Enterococcus* species, CoNS, “*Candida* and other yeasts”, *Enterobacter* species, and “other streptococci” decreased significantly, whereas the incidence of *C. difficile* increased significantly per 1,000 patient-days (Table 2.1, Figure 2.4). The estimated incidence density of *C. difficile* increased by 0.42 per 1,000 patient-days between 2005 and 2011; the relative incidence difference was 159% during that period.
Table 2.1

Overall Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Mean (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>1</td>
<td>1,743</td>
<td>1.26</td>
<td>1.06</td>
<td>0.86</td>
<td>1.16</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>2</td>
<td>1,149</td>
<td>0.74</td>
<td>0.80</td>
<td>0.95</td>
<td>0.71</td>
</tr>
<tr>
<td><em>Enterococcus species</em></td>
<td>3</td>
<td>1,114</td>
<td>0.73</td>
<td>0.79</td>
<td>0.79</td>
<td>0.70</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>4</td>
<td>849</td>
<td>0.77</td>
<td>0.74</td>
<td>0.57</td>
<td>0.50</td>
</tr>
<tr>
<td><em>Candida and other yeast</em></td>
<td>5</td>
<td>792</td>
<td>0.80</td>
<td>0.59</td>
<td>0.55</td>
<td>0.35</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>6</td>
<td>747</td>
<td>0.53</td>
<td>0.56</td>
<td>0.43</td>
<td>0.49</td>
</tr>
<tr>
<td><em>Clostridium difficile</em></td>
<td>7</td>
<td>685</td>
<td>0.32</td>
<td>0.33</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td><em>Klebsiella species</em></td>
<td>8</td>
<td>608</td>
<td>0.40</td>
<td>0.42</td>
<td>0.44</td>
<td>0.35</td>
</tr>
<tr>
<td><em>Enterobacter species</em></td>
<td>9</td>
<td>563</td>
<td>0.49</td>
<td>0.35</td>
<td>0.36</td>
<td>0.40</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>10</td>
<td>292</td>
<td>0.26</td>
<td>0.21</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td><em>Proteus species</em></td>
<td>11</td>
<td>224</td>
<td>0.14</td>
<td>0.12</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td><em>Serratia species</em></td>
<td>12</td>
<td>193</td>
<td>0.15</td>
<td>0.08</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td><em>Acinetobacter species</em></td>
<td>13</td>
<td>176</td>
<td>0.05</td>
<td>0.07</td>
<td>0.12</td>
<td>0.20</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>14</td>
<td>94</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td><em>Haemophilus species</em></td>
<td>15</td>
<td>92</td>
<td>0.11</td>
<td>0.03</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Bacteroides species</em></td>
<td>16</td>
<td>91</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Citrobacter species</em></td>
<td>17</td>
<td>83</td>
<td>0.08</td>
<td>0.04</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Other</td>
<td>18</td>
<td>1,090</td>
<td>0.76</td>
<td>0.74</td>
<td>0.67</td>
<td>0.70</td>
</tr>
</tbody>
</table>

| Total pathogens isolated           | 10,585 | 1,581 | 1,505 | 1,535 | 1,495 | 1,386 | 1,486 | 1,597 |
| Total patient-days                 | 1,582,872 | 205,390 | 213,709 | 226,723 | 230,016 | 229,971 | 234,389 | 242,674 |

Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression.
The incidences according to pathogen and service category are summarized in Table 2.2 (see Appendix Table 2.9-2.13 for details of incidence according to each service category). Overall, across service categories, decreasing trends in incidence density were observed for all pathogens except *C. difficile*. *C. difficile* was the most frequently occurring healthcare-associated pathogen in medicine service, and it showed a significantly increased incidence across almost all service categories except pediatrics. *S. aureus* was the most common pathogen in other service categories, and it showed a significantly decreased incidence in medicine and ICUs. A significant decrease in *E. coli* incidence was observed in medicine and
non-ICU settings. CoNS and “Candida and other yeast” showed significant decreases in incidence in all categories of service. *Enterococcus* species and *P. aeruginosa* showed significant decreases in incidence in medicine services. *Enterobacter* species showed significant decreases in medicine and ICU settings. Other streptococci showed significantly decreased incidences in pediatrics and non-ICU settings.

**Device-associated infections.** Overall and across service categories, all device-associated HAIs by pathogen showed significant decreases or no significant change in the incidence rate per 1,000 device-days (Tables 2.3–2.5). The incidence of specific pathogens decreased most in CLABSI cases, less so in CAUTI cases, and least in VAP cases.
Table 2.2

The Overall Incidence Rate (per 1,000 Patient-Days) of the Top 10 Healthcare-Associated Pathogens by Service Category over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>Pathogen group (Overall top 10)</th>
<th>Service-based category</th>
<th>Acuity-based category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medicine</td>
<td>Surgery</td>
</tr>
<tr>
<td></td>
<td>R Mean</td>
<td>EID</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>4 0.62</td>
<td>-0.26$^f$</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>3 0.64</td>
<td>-0.37$^f$</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>2 0.65</td>
<td>-0.29$^f$</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>6 0.41</td>
<td>-0.59$^f$</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>5 0.61</td>
<td>-0.60$^f$</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>7 0.24</td>
<td>-0.19$^f$</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>1 0.71</td>
<td>0.87$^f$</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>8 0.24</td>
<td>NS</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>9 0.14</td>
<td>-0.12$^f$</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>10 0.14</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. R = Rank within the category; EID = Estimated incidence difference for the compared incidences from 2005 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference for the compared incidence from 2005 to 2011, based on the estimated trend line from linear fit of logistic regression; $^f$ = 0.01≤ p <0.05; $^f$ = p <0.01. See Appendix Table 2.9-2.13 for details for each service category.
Central-line associated bloodstream infection. The incidence changes in CLABSI according to pathogen are summarized in Table 2.3 (see Appendix Table 2.14 for overall incidence of CLBSI over a 6-year period). Overall, the incidence of CLABSI decreased significantly for most pathogens, with the exception of *E. coli*. Of note, the incidence of CoNS and “Candida and other yeast” in CLABSI decreased significantly across all service categories. Areas of significant decreases for each pathogen were as follows: *S. aureus* overall and in medicine and non-ICU settings; *Enterococcus* species overall and in medicine, surgery, and non-ICU settings; *Klebsiella* species overall and in surgery and non-ICU settings; *Enterobacter* species overall and in pediatrics, and ICU settings; and *P. aeruginosa* and other streptococci overall.

Table 2.3

The Incidence Change in Central-Line Associated Bloodstream Infections Caused by the Top 10 Pathogens per 1,000 Central-Line Days over a Six-Year Period (2006-2011)

<table>
<thead>
<tr>
<th>Pathogen group (overall top 10)</th>
<th>Overall</th>
<th>Medicine</th>
<th>Service-based</th>
<th>Acuity-based</th>
<th>Medicine</th>
<th>Service-based</th>
<th>Acuity-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incidence median (range)</td>
<td>EID</td>
<td>RID (%)</td>
<td>EID</td>
<td>RID (%)</td>
<td>EID</td>
<td>RID (%)</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>0.31 (0.10-0.38)</td>
<td>-0.25</td>
<td>73</td>
<td>-0.41</td>
<td>93</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>0.19 (0.08-0.23)</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>0.49 (0.32-0.71)</td>
<td>-0.36</td>
<td>55</td>
<td>0.36</td>
<td>36</td>
<td>0.85</td>
<td>92</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>0.63 (0.29-1.00)</td>
<td>-0.71</td>
<td>71</td>
<td>0.57</td>
<td>53</td>
<td>-0.50</td>
<td>78</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>0.22 (0.10-0.53)</td>
<td>-0.34</td>
<td>81</td>
<td>0.39</td>
<td>83</td>
<td>0.30</td>
<td>82</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>0.12 (0.01-0.16)</td>
<td>-0.09</td>
<td>93</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>0.17 (0.13-0.26)</td>
<td>-0.15</td>
<td>46</td>
<td>NS</td>
<td>NS</td>
<td>0.30</td>
<td>82</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>0.19 (0.06-0.26)</td>
<td>-0.21</td>
<td>77</td>
<td>NS</td>
<td>NS</td>
<td>-0.34</td>
<td>76</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>0.09 (0.05-0.18)</td>
<td>-0.09</td>
<td>44</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: ICU = Intensive care unit; EID = Estimated incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression.
**Catheter-associated urinary tract infection.** Overall CAUTI incidence showed significant decreases for all of the top 10 pathogens except *S. aureus* and “other streptococcus” (Table 2.4; see Appendix Table 2.15 for overall incidence of CAUTI over a 6-year period).

According to service category, the significantly decreased pathogens were as follows: *E. coli* and *Klebsiella* species overall and in medicine, surgery, and non-ICU settings; *Enterococcus* species overall and in medicine and non-ICU settings; CoNS, *P. aeruginosa*, and *Enterobacter* species overall and in surgery and non-ICU settings; and “*Candida* and other yeast” overall and in pediatrics and ICU settings.

### Table 2.4

The Incidence Change in Catheter-Associated Urinary Tract Infections Caused by the Top 10 Pathogens per 1,000 Foley-Days over a Six-Year Period (2006-2011)

<table>
<thead>
<tr>
<th>Pathogen group (overall top 10)</th>
<th>Overall</th>
<th>Medicine</th>
<th>Surgery</th>
<th>Pediatrics</th>
<th>ICU</th>
<th>Non-ICU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incidence median (range)</td>
<td>EID</td>
<td>RID (%)</td>
<td>EID</td>
<td>RID (%)</td>
<td>EID</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>0.07 (0.05-0.15)</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>1.00 (0.48-1.59)</td>
<td>-1.01</td>
<td>51</td>
<td>-1.55</td>
<td>78</td>
<td>-0.84</td>
</tr>
<tr>
<td><em>Enterococcus</em> species</td>
<td>0.63 (0.58-1.06)</td>
<td>-0.34</td>
<td>25</td>
<td>-0.96</td>
<td>72</td>
<td>NS</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>0.09 (0.03-0.25)</td>
<td>-0.19</td>
<td>88</td>
<td>NS</td>
<td>-</td>
<td>-0.20</td>
</tr>
<tr>
<td><em>Candida</em> and other yeast</td>
<td>0.64 (0.48-1.02)</td>
<td>-0.36</td>
<td>36</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>0.45 (0.23-0.62)</td>
<td>-0.26</td>
<td>26</td>
<td>NS</td>
<td>-</td>
<td>-0.47</td>
</tr>
<tr>
<td><em>Clostridium difficile</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Klebsiella</em> species</td>
<td>0.37 (0.14-0.60)</td>
<td>-0.40</td>
<td>69</td>
<td>-0.32</td>
<td>85</td>
<td>-0.56</td>
</tr>
<tr>
<td><em>Enterobacter</em> species</td>
<td>0.21 (0.16-0.33)</td>
<td>-0.17</td>
<td>47</td>
<td>NS</td>
<td>-</td>
<td>-0.34</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>0.03 (0.02-0.03)</td>
<td>-</td>
<td>-</td>
<td>NS</td>
<td>-</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. ICU = Intensive care unit; EID = Estimated incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression.

**Ventilator-associated pneumonia.** For the VAP incidence changes (Table 2.5), only *S. aureus* showed a significant decrease overall (see Appendix Table 2.16 for overall incidence of VAP over a 6-year period). In the surgery service, there was a significant decrease in the incidence density of VAP caused by *S. aureus*, and *Klebsiella* species.
Table 2.5

*The Incidence Change in Ventilator-Associated Pneumonia Caused by the Top 10 Pathogens per 1,000 Ventilator-Days over a Six-Year Period (2006-2011)*

<table>
<thead>
<tr>
<th>Pathogen group (overall top 10)</th>
<th>Overall</th>
<th>Service-based</th>
<th>Acuity-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incidence median (range)</td>
<td>EID</td>
<td>RID (%)</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>0.95 (0.64-1.23)</td>
<td>-0.53</td>
<td>48</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>0.16 (0.11-0.27)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>0.10 (0.10-0.21)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>0.10 (0.06-0.11)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>0.06 (0.05-0.11)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>0.71 (0.50-0.86)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>0.29 (0.11-0.32)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>0.31 (0.26-1.02)</td>
<td>NS</td>
<td>-</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>0.15 (0.05-0.24)</td>
<td>NS</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note. ICU = Intensive care unit; EID = Estimated incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression.*

**Multidrug-resistant pathogens.** All MDR pathogens (MRSA, VRE, MDR Acinetobacter, and MDR *Pseudomonas*) showed no significant change in the overall HAI incidence in almost all service categories (Table 2.6-2.7).

Table 2.6

*Overall Incidence of Healthcare-Associated Infections by Multidrug Resistant Pathogens per 1,000 Patient-Days over a Seven-Year Period (2005-2011)*

<table>
<thead>
<tr>
<th>MDR-Pathogen</th>
<th>No.</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>MRSA</td>
<td>798</td>
<td>0.56</td>
<td>0.52</td>
<td>0.39</td>
<td>0.51</td>
<td>0.54</td>
</tr>
<tr>
<td>VRE</td>
<td>212</td>
<td>0.09</td>
<td>0.12</td>
<td>0.17</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>MDR Acinetobacter</td>
<td>95</td>
<td>0.00</td>
<td>0.00</td>
<td>0.07</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>MDR Pseudomonas</td>
<td>21</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression*
Only MRSA showed a significantly increased incidence in pediatrics, with an estimated 0.29 incidence difference per 1,000 patient-days between 2005 and 2011 based on the estimated trend line from linear fit logistic regression. The relative incidence density difference of MRSA was a 264% increase between 2005 and 2011 (Table 2.7); however, the total number of MRSA cases isolated in the pediatric service was only 92 (data are not shown).

Table 2.7

The Overall Incidence Rate (per 1,000 Patient-Days) of Multidrug Resistant Pathogens by Service Category over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>MDR pathogen</th>
<th>Service-based category</th>
<th>Acuity-based category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medicine</td>
<td>Surgery</td>
</tr>
<tr>
<td></td>
<td>MI</td>
<td>EID</td>
</tr>
<tr>
<td>MRSA</td>
<td>0.34</td>
<td>NS</td>
</tr>
<tr>
<td>VRE</td>
<td>0.23</td>
<td>NS</td>
</tr>
<tr>
<td>MDR Acinetobacter</td>
<td>0.00</td>
<td>-</td>
</tr>
<tr>
<td>MDR Pseudomonas</td>
<td>0.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: MDR = Multidrug resistant; ICU = Intensive care unit; MI = Median incidence; EID = Estimated incidence difference for the compared incidence from 2005 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence density difference for the compared incidence from 2005 to 2011, based on the estimated trend line from linear fit of logistic regression; MRSA = Methicillin-resistant Staphylococcus aureus; VRE = Vancomycin-resistant enterococci; NS = Not significant.

For CLABSI (Table 2.8), MRSA showed significant decreases overall and in non-ICU settings, medicine, and surgery settings, and the incidence of VRE decreased among CLABSI cases in the surgery service. Other MDR pathogens showed no significant change or could not be included in the incidence analysis because too few cases were isolated. For the other device-associated HAIs (CAUTI and VAP), there was no significant trend in incidence density change among the MDR pathogens.
Table 2.8

The Incidence Change in Central-Line Associated Bloodstream Infections Caused by Multidrug Resistant Pathogens per 1,000 Central-Line Days over a Six-Year Period (2006-2011)

<table>
<thead>
<tr>
<th>MDR pathogen</th>
<th>Overall MI</th>
<th>EID (%)</th>
<th>RID (%)</th>
<th>Service-based category</th>
<th>Acuity-based category</th>
<th>Non-ICU MI</th>
<th>EID (%)</th>
<th>RID (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medicine MI</td>
<td>EID (%)</td>
<td>RID (%)</td>
<td>Surgery MI</td>
<td>EID (%)</td>
</tr>
<tr>
<td>MRSA</td>
<td>0.15</td>
<td>-0.20</td>
<td>75</td>
<td>-0.22</td>
<td>-0.33</td>
<td>94</td>
<td>-0.14</td>
<td>-0.27</td>
</tr>
<tr>
<td>VRE</td>
<td>0.17</td>
<td>NS</td>
<td>-</td>
<td>0.33</td>
<td>NS</td>
<td>-</td>
<td>0.06</td>
<td>-0.18</td>
</tr>
<tr>
<td>MDR Acinetobacter</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>0.09</td>
<td>-</td>
</tr>
</tbody>
</table>

Note. MDR = Multidrug resistant; ICU = Intensive care unit; MI = Median incidence; EID = Estimated incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference for the compared incidence from 2006 to 2011, based on the estimated trend line from linear fit of logistic regression; MRSA = Methicillin-resistant Staphylococcus aureus; VRE = Vancomycin-resistant enterococci; NS = Not significant.

Discussion

This study is unique because it provided information about changes in HAI incidence by pathogen based on hospital-wide surveillance, which is not commonly used in U.S. hospitals. This study examined the incidence of HAIs by pathogen for each category of interest and provided many kinds of HAI incidence information across hospital categories. Using hospital-wide surveillance, this study found significant changes in the incidence rate of infections caused by healthcare-associated pathogens during the study period. Overall, and across service categories, decreasing trends in the incidence rate of HAIs per 1,000 patient-days were observed for all pathogens except C. difficile. Overall and across all service categories, all device-associated HAIs by pathogen showed significant decreases or no significant change in the incidence rate per 1,000 device-days.

This study has several strengths. First, it reflects the hospital-wide magnitude of HAIs by pathogen, based on prospective, comprehensive (hospital-wide) surveillance during the study period.
period (2005 to 2011). In the absence of a hospital-wide surveillance system, a point-prevalence survey method has been used in U.S. hospitals to estimate the magnitude of the HAI burden (Magill et al., 2012). However, some reported point-prevalence data can be criticized as an undefined mixture of both prevalence and incidence; furthermore, it can suffer from overestimation caused by the calculation method used (e.g., the number of HAIs on the visit day/the number of beds visited), and its findings may be ungeneralizable over time, even for the studied institution (Allen-Bridson et al., 2012). Thus, this study fills a need by accessing the comprehensive magnitude of hospital-wide HAIs in a way that point-prevalence studies and targeted surveillance do not. Second, this incidence analysis of HAI according to pathogen and across service categories was made possible by the use of hospital-wide surveillance; targeted surveillance does not detect any HAIs outside of selected units, nor does it always detect infections based on its own priorities. One study reported that approximately 50% of HAIs were missed when targeted surveillance method results were compared with the results of comprehensive, hospital-wide surveillance (Weber et al., 2012). Third, this study used incidence density based on person-days at risk (e.g., patient-days, central-line days) by pathogen as the representative measure of the HAI rate. To our knowledge, very few studies have reported incidence density according to pathogen; thus, our result may be used as reference data for pathogen-categorized HAI incidence. In sum, our study provides information about HAI incidence density by person-days at risk by pathogen across every hospital-related category (e.g., service type and device-related HAIs), thus providing information that has not previously been available in HAI studies.

This study also has some limitations. First, the method we used to estimate incidence difference (i.e., the use of a trend line based on the linear fit of logistic regression) might not be
an exact statistical tool for determining the possible non-linear distribution of yearly incidence density for the study period. However, we believe this method provides the best possible statistical measurement of trend changes given the absence of a gold standard for analyzing trends in the incidence of HAIs. Second, we were unable to examine the causative factors behind the changes in the HAI pathogen spectrum. Most likely the decreasing incidence of many pathogens was related to dramatic decreases in the incidence of HAIs including CLABSI, CAUTI, and VAP. Other factors may have included changes in the hospitalized patients’ underlying diseases and changes in antimicrobial use, such as the defined daily dose per 1,000 beds recommended by the World Health Organization’s Alliance for the Prudent Use of Antibiotics (Polk, 2003). To understand the association between the significant increase in *C. difficile* incidence and the changes in the use density of various antimicrobials, further study is necessary. Third, the changes in the incidence of specific healthcare-associated pathogens may not be representative of all acute care university hospitals in the United States. However, this study adds clinical support to recent HAI studies’ reports of a significant increase in *C. difficile* and its emergence as a healthcare-associated pathogen in hospital settings.

Despite the significant increase in person-time at risk (patient-days) over the study period, the study hospital showed successful reductions in both overall HAIs and device-associated HAIs for all pathogens except *C. difficile*. Although we could not identify exactly what kinds of infection control interventions reduced the HAI incidence according to pathogen between 2005 and 2011, the observed decrease in the incidences of HAIs by most healthcare-associated pathogens was assumed to be the result of continuous, comprehensive infection control efforts at the study hospital. The following factors are assumed to be involved in the success of infection control efforts at the study hospital.
First, the outstanding infection control program that has been implemented for more than three decades might be the most important driving force for success. Since 1980, the study hospital has been a leading infection control program in North Carolina and has shared two faculty leaders with the North Carolina Statewide Program for Infection Control and Epidemiology (SPICE). SPICE provides mandatory educational courses as the administrator of North Carolina-approved infection control courses under North Carolina Infection Control Law 10A NCAC 41A. 0206 Infection Prevention – Health Care Settings (North Carolina Office of Administrative Hearings, 2012; SPICE, 2012). As of October 2012, the study hospital Department of Hospital Epidemiology is led by two world-renowned infection control experts and employs six IPs, one laboratory technician, and one public health epidemiologist, without frequent changes in personnel. Because it is difficult and expensive to recruit qualified IPs and to train new ones (Leape, 2002), the low turnover rate of IPs over time might help to maintain the study hospital’s outstanding infection control program and professional work atmosphere. Its stable, congenial work environment allows the study hospital’s department of hospital epidemiology to continuously conduct hospital-wide surveillance. Periodic feedback from department of hospital epidemiology to each service and nursing station based on the hospital-wide surveillance may improve healthcare personnel’s attention to HAI prevention. In addition, efficient and cooperative communication might have made it possible for the study hospital team to find solutions to infection control issues based on their long-term teamwork within the hospital epidemiology department and their rapport with healthcare personnel outside the department.

Second, the implementation of multiple infection control interventions based on scientific evidence guidelines might have led to the reduction in HAIs at the study hospital. For example, a
73% reduction in CLABSIs was reported at the study hospital between 1999 and 2008 as a result of multiple infection control measures: enhanced medical staff education for proper catheter insertion and the use of ChloraPrep (70% isopropyl alcohol plus 2% chlorhexidine) for skin preparation in 2000; mandatory nurse training in intravenous line care in 2001; the introduction in 2003 of a customized central catheter insertion kit that included ChloraPrep, a large sterile drape, and safety devices to prevent sharps injuries; enhanced nurse education in catheter care in 2004; the introduction of a revised customized central catheter insertion kit in 2005, which added a second-generation antibiotic- (or antiseptic-) impregnated catheter; introduction of the Institute for Healthcare Improvement (IHI) central line bundle in the medical ICU in 2006; and the use of the IHI central line bundle in all ICUs in 2007 (Weber, Brown, Sickbert-Bennett, & Rutala, 2010).

Third, organizational efforts to improve the quality of care at the study hospital, including the introduction of the Six Sigma quality improvement (QI) process, may have contributed to the reduced incidence of HAIs across all hospital services. Statistically, Six Sigma means an error-free rate of 99.99966%, and the hospital quality improvement culture is expected to be achieved via purposely training healthcare teams to implement a rigorous Six Sigma processes of define, measure, analyze, improve, and control (Ruiz & Simón, 2012). In fact, the study hospital reported a reduction in HAIs (CLABSIs and VAP) and a 2.3% decrease in the mortality rate in the pediatric ICU between 2007 and 2009 by improving compliance with hand hygiene, oral care, and central-line catheter care using the Six Sigma QI process (Harris et al., 2011).

Lastly, the infection control liaison program, which was established in the fall of 2007 at the study hospital, may have contributed to the sustained reduction in HAIs by pathogen by collaborating with nursing leadership, enhancing education, improving bedside care infection
control practices, and including more than 100 personnel from more than 50 clinical areas. The study hospital’s infection control liaison program was associated with a 10% increase in compliance with hand hygiene procedures and a substantial reduction in HAIs (47% for CLABSI, 44% for CAUTI, and 36% for VAP), which exceeded the original objectives set to be achieved by March 1, 2008 (Brown, 2012). In fact, the establishment of infection control liaison nurses has been reported as a successful strategy for reducing CLABSI in neonatal ICU because these nurses served as highly visible infection control resource people who could monitor practices, collect data, and provide appropriate feedback (Wright, Stover, Wilkerson, & Bratcher, 2002).

The only HAI pathogen that emerged as problematic at the study hospital over the study period was *C. difficile*. Given that other recent HAI studies have reported a significant increase in the incidence of *C. difficile* (Miller et al., 2011), the emergence of this pathogen may be inevitable in modern healthcare settings characterized by the frequent use of antimicrobial agents, prolonged hospital stays, and an increased number of immunocompromised patients. However, because no single intervention has proven effective in controlling and preventing *C. difficile* infections (Johnson & Gerding, 2012), it would be very challenging to reduce the incidence of *C. difficile* in every hospital setting. Although some control measures including barrier precautions (e.g., patient isolation, hand hygiene, and gloving), environmental cleaning/disinfection, antimicrobial restriction, and the identification/treatment of asymptomatic carriers of *C. difficile* (Johnson & Gerding, 2012), more research is needed to establish the gold standard of infection control practice for *C. difficile* infection in hospital settings.
REFERENCES


Feltovich, F., & Fabrey, L. J. (2010). The current practice of infection prevention as demonstrated by the practice analysis survey of the Certification Board of Infection

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Harris, B. D., Hanson, C., Christy, C., Adams, T., Banks, A., Willis, T. S., & Maciejewski, M. L. (2011). Strict hand hygiene and other practices shortened stays and cut costs and


resistant *Staphylococcus aureus* screening upon admission in hospitals. *Infect Control Hosp Epidemiol*, 32(8), 797-803. doi: 10.1086/660875


68
10.1093/intqhc/mzi093


Shenoy, E. S., Walensky, R. P., Lee, H., Orcutt, B., & Hooper, D. C. (2012). Resource burden associated with contact precautions for methicillin-resistant *Staphylococcus aureus* and
vancomycin-resistant enterococcus: The patient access managers' perspective. *Infect Control Hosp Epidemiol*, 33(8), 849-852. doi: 10.1086/666629


multiple interventions. *Infect Control Hosp Epidemiol, 31*(8), 875-877. doi: 10.1086/655438


Wright, P. J. (2012). *Contact precautions for MRSA/VRE: How and when should they be discontinued?* Paper presented at the APIC 39th Annual Educational Conference & International Meeting, San Antonio, TX.

## Appendix 2.1

### Table 2.9

The Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens in Medicine Service over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>1</td>
<td>340</td>
<td>0.37</td>
<td>0.49</td>
<td>0.58</td>
<td>0.48</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>2</td>
<td>310</td>
<td>0.80</td>
<td>0.89</td>
<td>0.67</td>
<td>0.58</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>3</td>
<td>306</td>
<td>0.82</td>
<td>0.71</td>
<td>0.87</td>
<td>0.68</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>4</td>
<td>299</td>
<td>0.99</td>
<td>0.66</td>
<td>0.42</td>
<td>0.64</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>5</td>
<td>294</td>
<td>1.29</td>
<td>0.76</td>
<td>0.45</td>
<td>0.38</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>6</td>
<td>197</td>
<td>0.86</td>
<td>0.63</td>
<td>0.39</td>
<td>0.29</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>7</td>
<td>117</td>
<td>0.42</td>
<td>0.38</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>8</td>
<td>117</td>
<td>0.26</td>
<td>0.27</td>
<td>0.30</td>
<td>0.12</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>9</td>
<td>69</td>
<td>0.19</td>
<td>0.17</td>
<td>0.22</td>
<td>0.09</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>10</td>
<td>69</td>
<td>0.26</td>
<td>0.14</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>Proteus species</td>
<td>11</td>
<td>53</td>
<td>0.11</td>
<td>0.08</td>
<td>0.19</td>
<td>0.12</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>12</td>
<td>23</td>
<td>0.03</td>
<td>0.06</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>13</td>
<td>21</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Serratia species</td>
<td>14</td>
<td>13</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>15</td>
<td>11</td>
<td>0.06</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Bacteroides species</td>
<td>16</td>
<td>10</td>
<td>0.02</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>17</td>
<td>8</td>
<td>0.05</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>18</td>
<td>227</td>
<td>0.59</td>
<td>0.46</td>
<td>0.48</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Total pathogens isolated</strong></td>
<td></td>
<td></td>
<td><strong>478,753</strong></td>
<td><strong>62,551</strong></td>
<td><strong>63,249</strong></td>
<td><strong>67,012</strong></td>
</tr>
<tr>
<td><strong>Total patient-days</strong></td>
<td></td>
<td></td>
<td><strong>1,582,872</strong></td>
<td><strong>205,390</strong></td>
<td><strong>213,709</strong></td>
<td><strong>226,723</strong></td>
</tr>
</tbody>
</table>

Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression.
Table 2.10

*The Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens in Surgery Service over a Seven-Year Period (2005-2011)*

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>1</td>
<td>1018</td>
<td>2.81</td>
<td>2.40</td>
<td>1.94</td>
<td>2.79</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>2</td>
<td>551</td>
<td>1.43</td>
<td>1.37</td>
<td>1.63</td>
<td>1.30</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>3</td>
<td>531</td>
<td>1.29</td>
<td>1.44</td>
<td>1.58</td>
<td>1.36</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>4</td>
<td>432</td>
<td>1.14</td>
<td>1.22</td>
<td>1.02</td>
<td>1.21</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>5</td>
<td>371</td>
<td>1.14</td>
<td>1.20</td>
<td>0.78</td>
<td>1.05</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>6</td>
<td>339</td>
<td>1.20</td>
<td>0.90</td>
<td>1.08</td>
<td>0.54</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>7</td>
<td>316</td>
<td>1.10</td>
<td>0.67</td>
<td>0.78</td>
<td>0.96</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>8</td>
<td>302</td>
<td>0.86</td>
<td>0.75</td>
<td>0.92</td>
<td>0.79</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>9</td>
<td>208</td>
<td>0.39</td>
<td>0.45</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>10</td>
<td>148</td>
<td>0.47</td>
<td>0.43</td>
<td>0.36</td>
<td>0.43</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>11</td>
<td>134</td>
<td>0.14</td>
<td>0.17</td>
<td>0.38</td>
<td>0.66</td>
</tr>
<tr>
<td>Proteus species</td>
<td>12</td>
<td>123</td>
<td>0.33</td>
<td>0.32</td>
<td>0.36</td>
<td>0.32</td>
</tr>
<tr>
<td>Serratia species</td>
<td>13</td>
<td>111</td>
<td>0.39</td>
<td>0.24</td>
<td>0.23</td>
<td>0.25</td>
</tr>
<tr>
<td>Bacteroides species</td>
<td>14</td>
<td>64</td>
<td>0.18</td>
<td>0.15</td>
<td>0.19</td>
<td>0.13</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>15</td>
<td>53</td>
<td>0.26</td>
<td>0.09</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>16</td>
<td>43</td>
<td>0.06</td>
<td>0.09</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>17</td>
<td>40</td>
<td>0.12</td>
<td>0.06</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>Other</td>
<td>18</td>
<td>541</td>
<td>1.63</td>
<td>1.52</td>
<td>1.30</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Total pathogens isolated: 396,234; Total patient-days: 1,582,872

*Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression*
### Table 2.11

*The Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens in Pediatrics Service over a Seven-Year Period (2005-2011)*

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>266</td>
<td>0.80</td>
<td>0.70</td>
<td>0.62</td>
<td>0.84</td>
<td>0.89</td>
</tr>
<tr>
<td>Coagulase negative <em>staphylococci</em></td>
<td>229</td>
<td>0.84</td>
<td>0.95</td>
<td>1.04</td>
<td>0.53</td>
<td>0.65</td>
</tr>
<tr>
<td><em>Enterococcus</em> species</td>
<td>172</td>
<td>0.40</td>
<td>0.60</td>
<td>0.42</td>
<td>0.67</td>
<td>0.51</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>160</td>
<td>0.24</td>
<td>0.48</td>
<td>0.62</td>
<td>0.51</td>
<td>0.36</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>153</td>
<td>0.44</td>
<td>0.52</td>
<td>0.34</td>
<td>0.51</td>
<td>0.40</td>
</tr>
<tr>
<td><em>Klebsiella</em> species</td>
<td>140</td>
<td>0.33</td>
<td>0.46</td>
<td>0.36</td>
<td>0.45</td>
<td>0.49</td>
</tr>
<tr>
<td><em>Enterobacter</em> species</td>
<td>137</td>
<td>0.51</td>
<td>0.46</td>
<td>0.22</td>
<td>0.59</td>
<td>0.42</td>
</tr>
<tr>
<td><em>Candida</em> and other yeast</td>
<td>124</td>
<td>0.42</td>
<td>0.54</td>
<td>0.48</td>
<td>0.39</td>
<td>0.22</td>
</tr>
<tr>
<td><em>Clostridium difficile</em></td>
<td>79</td>
<td>0.33</td>
<td>0.14</td>
<td>0.24</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td><em>Serratia</em> species</td>
<td>61</td>
<td>0.20</td>
<td>0.08</td>
<td>0.16</td>
<td>0.25</td>
<td>0.16</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>46</td>
<td>0.24</td>
<td>0.17</td>
<td>0.18</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td><em>Haemophilus</em> species</td>
<td>28</td>
<td>0.13</td>
<td>0.02</td>
<td>0.08</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>24</td>
<td>0.11</td>
<td>0.08</td>
<td>0.04</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td><em>Proteus</em> species</td>
<td>17</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td><em>Citrobacter</em> species</td>
<td>17</td>
<td>0.09</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td><em>Acinetobacter</em> species</td>
<td>13</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td><em>Bacteroides</em> species</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Other</td>
<td>245</td>
<td>0.64</td>
<td>0.74</td>
<td>0.68</td>
<td>0.67</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression
Table 2.12

The Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens in Intensive Care Units over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>1</td>
<td>531</td>
<td>2.58</td>
<td>1.76</td>
<td>1.33</td>
<td>1.45</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>2</td>
<td>410</td>
<td>2.09</td>
<td>1.67</td>
<td>1.52</td>
<td>0.80</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>3</td>
<td>365</td>
<td>1.24</td>
<td>1.40</td>
<td>1.04</td>
<td>1.06</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>4</td>
<td>360</td>
<td>1.10</td>
<td>0.94</td>
<td>1.48</td>
<td>1.08</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>5</td>
<td>359</td>
<td>1.34</td>
<td>1.38</td>
<td>0.93</td>
<td>1.13</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>6</td>
<td>311</td>
<td>1.58</td>
<td>1.31</td>
<td>1.25</td>
<td>0.87</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>7</td>
<td>299</td>
<td>1.48</td>
<td>0.91</td>
<td>0.78</td>
<td>1.13</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>8</td>
<td>249</td>
<td>0.83</td>
<td>0.71</td>
<td>0.82</td>
<td>0.71</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>9</td>
<td>159</td>
<td>0.34</td>
<td>0.36</td>
<td>0.30</td>
<td>0.37</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>10</td>
<td>132</td>
<td>0.17</td>
<td>0.18</td>
<td>0.47</td>
<td>0.76</td>
</tr>
<tr>
<td>Serratia species</td>
<td>11</td>
<td>129</td>
<td>0.54</td>
<td>0.27</td>
<td>0.36</td>
<td>0.48</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>12</td>
<td>66</td>
<td>0.34</td>
<td>0.22</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>13</td>
<td>66</td>
<td>0.39</td>
<td>0.13</td>
<td>0.13</td>
<td>0.22</td>
</tr>
<tr>
<td>Proteus species</td>
<td>14</td>
<td>55</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>15</td>
<td>29</td>
<td>0.12</td>
<td>0.02</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>16</td>
<td>28</td>
<td>0.19</td>
<td>0.13</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Bacteroides species</td>
<td>17</td>
<td>12</td>
<td>0.05</td>
<td>0.04</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Other</td>
<td>18</td>
<td>482</td>
<td>1.85</td>
<td>1.92</td>
<td>1.31</td>
<td>1.78</td>
</tr>
</tbody>
</table>

Total pathogens isolated | 324,739 | 41,082 | 44,902 | 47,302 | 46,191 | 48,164 | 47,270 | 49,828 |
Total patient-days        | 1,582,872 | 205,390 | 213,709 | 226,723 | 230,016 | 229,971 | 234,389 | 242,674 |

Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression
Table 2.13

The Incidence (per 1,000 Patient-Days) of Healthcare-Associated Pathogens in Non-Intensive Care Unit Settings over a Seven-Year Period (2005-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2005-2011)</th>
<th>Incidence rate per 1,000 patient-days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>1</td>
<td>1212</td>
<td>0.93</td>
<td>0.87</td>
<td>0.73</td>
<td>1.08</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>2</td>
<td>789</td>
<td>0.65</td>
<td>0.77</td>
<td>0.81</td>
<td>0.62</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>3</td>
<td>749</td>
<td>0.60</td>
<td>0.62</td>
<td>0.72</td>
<td>0.61</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>4</td>
<td>538</td>
<td>0.57</td>
<td>0.59</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Clostridium difficile</td>
<td>5</td>
<td>526</td>
<td>0.31</td>
<td>0.32</td>
<td>0.39</td>
<td>0.28</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>6</td>
<td>388</td>
<td>0.32</td>
<td>0.34</td>
<td>0.30</td>
<td>0.33</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>7</td>
<td>382</td>
<td>0.48</td>
<td>0.31</td>
<td>0.29</td>
<td>0.23</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>8</td>
<td>359</td>
<td>0.29</td>
<td>0.34</td>
<td>0.33</td>
<td>0.26</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>9</td>
<td>264</td>
<td>0.24</td>
<td>0.20</td>
<td>0.25</td>
<td>0.21</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>10</td>
<td>226</td>
<td>0.24</td>
<td>0.20</td>
<td>0.20</td>
<td>0.17</td>
</tr>
<tr>
<td>Proteus species</td>
<td>11</td>
<td>169</td>
<td>0.14</td>
<td>0.12</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>Bacteroides species</td>
<td>12</td>
<td>79</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>13</td>
<td>66</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Serratia species</td>
<td>14</td>
<td>64</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>15</td>
<td>54</td>
<td>0.07</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>16</td>
<td>44</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>17</td>
<td>26</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Other</td>
<td>18</td>
<td>608</td>
<td>0.49</td>
<td>0.43</td>
<td>0.51</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Total pathogens isolated | 1,255,701 | 164,308 | 168,807 | 179,421 | 183,607 | 181,112 | 185,924 | 192,522 |
Total patient-days | 1,582,872 | 205,390 | 213,709 | 226,723 | 230,016 | 229,971 | 234,389 | 242,674 |

Note. EID = Estimated incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2005 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression
Table 2.14

The Overall Incidence of Central-Line Associated Bloodstream Infections Caused by Healthcare-Associated Pathogens per 1,000 Central-Line Days over a Six-Year Period (2006-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total pathogens isolated</th>
<th>Total central-line days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2006-2011)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>1</td>
<td>374</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>2</td>
<td>275</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>3</td>
<td>180</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>4</td>
<td>144</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>5</td>
<td>106</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>6</td>
<td>90</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>7</td>
<td>87</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>9</td>
<td>55</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>10</td>
<td>39</td>
</tr>
<tr>
<td>Serratia species</td>
<td>11</td>
<td>38</td>
</tr>
<tr>
<td>Bacteroides species</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Proteus species</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>17</td>
<td>131</td>
</tr>
</tbody>
</table>

Note. EID = Estimated incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression.
### The Overall Incidence of Catheter Associated Urinary Tract Infections Caused by Healthcare-Associated Pathogens per 1,000 Foley-Catheter Days over a Six-Year Period (2006-2011)

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2006-2011)</th>
<th>Incidence rate per 1,000 Foley-catheter days</th>
<th>Incidence Median (range)</th>
<th>EID (%)</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>No.</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>1</td>
<td>438</td>
<td>1.36</td>
<td>1.59</td>
<td>1.29</td>
<td>0.48</td>
</tr>
<tr>
<td>Candida and other yeast</td>
<td>2</td>
<td>329</td>
<td>0.90</td>
<td>1.02</td>
<td>0.48</td>
<td>0.56</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>3</td>
<td>291</td>
<td>0.77</td>
<td>1.06</td>
<td>0.64</td>
<td>0.61</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>4</td>
<td>181</td>
<td>0.62</td>
<td>0.55</td>
<td>0.44</td>
<td>0.23</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>5</td>
<td>153</td>
<td>0.45</td>
<td>0.60</td>
<td>0.51</td>
<td>0.27</td>
</tr>
<tr>
<td>Proteus species</td>
<td>6</td>
<td>104</td>
<td>0.30</td>
<td>0.44</td>
<td>0.33</td>
<td>0.18</td>
</tr>
<tr>
<td>Enterobacter species</td>
<td>7</td>
<td>103</td>
<td>0.32</td>
<td>0.33</td>
<td>0.21</td>
<td>0.16</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>8</td>
<td>54</td>
<td>0.25</td>
<td>0.16</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>9</td>
<td>36</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>Citrobacter species</td>
<td>10</td>
<td>30</td>
<td>0.07</td>
<td>0.11</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Acinetobacter species</td>
<td>11</td>
<td>26</td>
<td>0.05</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Serratia species</td>
<td>12</td>
<td>23</td>
<td>0.08</td>
<td>0.03</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>13</td>
<td>12</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>14</td>
<td>11</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Haemophilus species</td>
<td>15</td>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>16</td>
<td>118</td>
<td>0.45</td>
<td>0.33</td>
<td>0.28</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Total pathogens isolated: 1,910; Total Foley-catheter days: 363,225

Note: EID = Estimated incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression.
### Table 2.16

*The Overall Incidence of Ventilator Associated Pneumonia Caused by Healthcare-Associated Pathogens per 1,000 Ventilator Days over a Six-Year Period (2006-2011)*

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total pathogens isolated</th>
<th>Total ventilator days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (range)</td>
<td>114,437</td>
</tr>
<tr>
<td></td>
<td>EID (%)</td>
<td>20,309</td>
</tr>
<tr>
<td></td>
<td>p value*</td>
<td>18,709</td>
</tr>
<tr>
<td></td>
<td>RID (%)</td>
<td>17,582</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19,353</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18,071</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20,413</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pathogen group</th>
<th>Total (2006-2011)</th>
<th>Incidence rate per 1,000 ventilator days</th>
<th>Incidence Median (range)</th>
<th>EID</th>
<th>RID (%)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>1</td>
<td>149</td>
<td>1.23</td>
<td>1.12</td>
<td>0.97</td>
<td>0.88</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>2</td>
<td>93</td>
<td>0.74</td>
<td>0.86</td>
<td>0.68</td>
<td>0.78</td>
</tr>
<tr>
<td><em>Enterobacter species</em></td>
<td>3</td>
<td>68</td>
<td>0.30</td>
<td>0.27</td>
<td>1.02</td>
<td>0.26</td>
</tr>
<tr>
<td><em>Acinetobacter species</em></td>
<td>4</td>
<td>40</td>
<td>0.20</td>
<td>0.37</td>
<td>0.74</td>
<td>0.36</td>
</tr>
<tr>
<td><em>Klebsiella species</em></td>
<td>5</td>
<td>34</td>
<td>0.30</td>
<td>0.32</td>
<td>0.28</td>
<td>0.31</td>
</tr>
<tr>
<td><em>Serratia species</em></td>
<td>6</td>
<td>28</td>
<td>0.05</td>
<td>0.05</td>
<td>0.23</td>
<td>0.36</td>
</tr>
<tr>
<td><em>Haemophilus species</em></td>
<td>7</td>
<td>23</td>
<td>0.20</td>
<td>0.05</td>
<td>0.23</td>
<td>0.10</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>8</td>
<td>20</td>
<td>0.20</td>
<td>0.27</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td>Other streptococci</td>
<td>9</td>
<td>17</td>
<td>0.15</td>
<td>0.11</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Enterococcus species</em></td>
<td>10</td>
<td>8</td>
<td>0.10</td>
<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Coagulase negative staphylococci</td>
<td>11</td>
<td>7</td>
<td>0.10</td>
<td>0.11</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td><em>Candida and other yeast</em></td>
<td>12</td>
<td>6</td>
<td>0.05</td>
<td>0.11</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Group B Streptococcus</td>
<td>13</td>
<td>4</td>
<td>0.10</td>
<td>0.05</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Proteus species</em></td>
<td>14</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Citrobacter species</em></td>
<td>15</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>16</td>
<td>111</td>
<td>1.08</td>
<td>0.91</td>
<td>1.54</td>
<td>0.47</td>
</tr>
</tbody>
</table>

**Note.** EID = Estimated incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; RID = Relative incidence difference from comparison incidence 2006 to 2011 based on the estimated trend line from linear fit of logistic regression; NS = Not Significant; *based on Poisson regression.
CHAPTER 3

COST-EFFECTIVENESS ANALYSIS OF ACTIVE SURVEILLANCE SCREENING
FOR METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS
IN AN ACADEMIC HOSPITAL SETTING

Background

The treatment and prevention of healthcare-associated infections (HAIs) caused by antibiotic-resistant pathogens poses an increasing challenge in hospitals (Hidron et al., 2008). Methicillin-resistant *Staphylococcus aureus* (MRSA) has become the most prevalent antibiotic-resistant, healthcare-associated pathogen and is a substantial cause of morbidity and mortality as well as a financial burden on healthcare systems (Nelson, Samore, Smith, Harbarth, & Rubin, 2010; Shorr, 2007). According to a 2006-2007 report by the National Healthcare Safety Network (NHSN), 56.2% of *Staphylococcus aureus* isolated from HAIs was methicillin-resistant (Hidron et al., 2008). The National Nosocomial Infections Surveillance System reported that in 2002 more than 55% of HAIs in intensive care units (ICUs) were caused by MRSA (NNIS System, 2003).

According to the Centers for Disease Control and Prevention’s (CDC) guideline to control the spread of MRSA and other multidrug-resistant organisms, a combination of interventions is necessary (e.g., contact precautions, active surveillance screening, environmental cleaning; Siegel et al., 2007). However, the strength of the evidence for each intervention’s effectiveness and the validity of the specific recommendations are still debated (Jackson et al., 2004; Steinberg & Luce, 2005). Any intervention is likely to reduce MRSA HAI rates in high prevalence situations, although interventions in low prevalence situations may be less effective, and MRSA eradication may be more difficult or impossible (Peterson & Diekema, 2010).
Active surveillance screening has been considered an effective intervention at reducing MRSA HAI in high prevalence situations (Peterson & Diekema, 2010). Active surveillance screening is a microbiological screening method for detecting colonized patients at the time of admission to an inpatient unit or a hospital (McGinigle, Gourlay, & Buchanan, 2008). European countries such as the Netherlands have reported a very low prevalence of MRSA in the hospital setting after implementing aggressive “search and destroy” policies, which include universal surveillance screening for all admitted patients, contact precautions on admission before negative screening report, and closure of units when there are two or more MRSA-positive cases (McGinigle et al., 2008; Nulens et al., 2008; Siegel et al., 2007). Although Huang et al. reported a 75%-reduction in MRSA infections in an ICU through the use of active surveillance screening, the efficacy and cost-effectiveness of active surveillance screening have not been validated (Huang et al., 2006; McGinigle et al., 2008).

Moreover, expert groups disagree about whether the control of MRSA necessitates active surveillance screening (Jackson et al., 2004). The Society for Healthcare Epidemiology of America (SHEA) strongly supports active surveillance screening in order to guarantee the prompt isolation of colonized patients, whereas the Healthcare Infection Control Practices Advisory Committee (HICPAC) recommends that individual healthcare facilities make the decision of whether or not to implement active surveillance screening procedures (Jackson et al., 2004). Though, other related issues regarding active surveillance screening—including identification of target population, identification of microbiologic methods of active surveillance screening for MRSA, and the appropriate interval of active surveillance screening—have not been defined clearly in the U.S., at least two U.S. states and the Department of Veterans Affairs have recently introduced a policy requiring mandatory active surveillance screening for MRSA.
Overall, the issue of whether active surveillance screening is a cost-effective strategy to reduce the incidence of MRSA infection remains unresolved (McGinigle et al., 2008; Shorr, 2007). Most studies on the cost-effectiveness of active surveillance screening for MRSA have used a pre-post observational method for a targeted unit (e.g., surgery or ICU) or across associated hospitals (Anderson et al., 2009; Clancy et al., 2006; McGinigle et al., 2008; Murthy et al., 2010). Some studies investigated the effectiveness of screening all hospital admissions (Lee et al., 2010; Nelson et al., 2010). However, according to McGinigle et al., none of the active surveillance screening and MRSA-related outcomes studies in adult ICUs from 1955 to 2007 were of high quality, threatening the validity of the study results (McGinigle et al., 2008). Although various observational studies suggest that active surveillance screening has an effect on reducing MRSA infections, rigorous guidelines regarding the appropriateness of active surveillance screening have not been published due to the general poor quality of evidence and conflicting results (McGinigle et al., 2008). This study aimed to model the cost-effectiveness of alternative screening strategies for MRSA colonization upon admission: universal surveillance screening (USS) for all hospitalized patients, targeted surveillance screening (TSS) for ICU admitted patients only, and no surveillance screening (NSS).

**Methods**

**Setting**

This evaluation was modeled from the perspective of a large academic hospital defined as having approximately 800 beds, 40,000 annual admissions, and 6,000 ICU admissions (Huang et
al., 2006; Robicsek et al., 2008). The study cohort included all hospitalized patients except those patients with community-acquired MRSA infections on admission. The time horizon for this study is the period of hospitalization, since HAIs are defined as infections occurring during the course of hospitalization (Horan et al., 2008). In addition, we assume a real-time polymerase chain reaction (PCR) method is used for detecting MRSA-colonized patients via a nasal sample. We also assume that PCR method may contribute to prevent MRSA transmission by reducing the time interval between admission and isolation initiation (Conterno et al., 2007). This is the same logic that SHEA supports for active screening in terms of guaranteeing the prompt isolation of MRSA-colonized patients (Jackson et al., 2004).

**Modeling approach**

Three active surveillance screening strategies (USS, TSS, and NSS) are modeled using a decision tree (Figure 3.1). The decision node represents the choice among three surveillance screening strategies. The chance nodes indicate the pathways to the location (ICU vs. all other floors [non-ICU]), the active surveillance screening result (positive vs. negative), and the occurrence of MRSA HAI (yes vs. no) in order. The terminal node is the end point of hospitalization (discharge including transfer to other institution and death).
Model Inputs

Input probabilities, cost, and outcome (MRSA HAI) data (Table 3.1) were extracted from the MEDLINE PubMed database through a systematic literature review of U.S. studies published since 2000 using combinations of the following terms: methicillin-resistant *Staphylococcus aureus*, surveillance, screening, colonization, cost-effectiveness, intensive care unit, cost and economics.
Table 3.1

*Model Input Estimates and Ranges*

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Base-case</th>
<th>Range</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevalence of MRSA colonization at admission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU patients</td>
<td>0.083</td>
<td>0.037-0.12</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Non-ICU patients</td>
<td>0.063</td>
<td>0.009-0.085</td>
<td>3,4,5</td>
</tr>
<tr>
<td>Probability of MRSA HAI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>0.03</td>
<td>0.02-0.06</td>
<td>6,7</td>
</tr>
<tr>
<td>Non-ICU (% lower than ICU)</td>
<td>33%</td>
<td>10-75%</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Reduction in MRSA HAI rates due to screening and isolation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>33%</td>
<td>1-57%</td>
<td>8</td>
</tr>
<tr>
<td>Non-ICU</td>
<td>10%</td>
<td>1-33%</td>
<td>8</td>
</tr>
<tr>
<td>% of patients admitted to ICU</td>
<td>0.15</td>
<td>± 10%†</td>
<td>1</td>
</tr>
<tr>
<td>Incremental cost of MRSA HAI</td>
<td>$13,050</td>
<td>$5,202-$20,899</td>
<td>9</td>
</tr>
<tr>
<td>Cost of rapid PCR test</td>
<td>$50</td>
<td>$20-$80</td>
<td>10</td>
</tr>
<tr>
<td>Cost of contact precautions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost per gown</td>
<td>$0.9</td>
<td>± 10%†</td>
<td>10,11</td>
</tr>
<tr>
<td>Cost per pair of gloves</td>
<td>$0.08</td>
<td>± 10%†</td>
<td>10,11</td>
</tr>
<tr>
<td>Time to don gown and gloves</td>
<td>2 min</td>
<td>1-3†</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Cost/RN visit</td>
<td>$1.10</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Cost/physician visit</td>
<td>$2.80</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>No. of RN visits/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>30</td>
<td>20-40</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Non-ICU</td>
<td>15</td>
<td>10-20</td>
<td>Author assumption</td>
</tr>
<tr>
<td>No. of physician visits/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>6</td>
<td>3-9</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Non-ICU</td>
<td>3</td>
<td>1-6</td>
<td>Author assumption</td>
</tr>
<tr>
<td>Average length of stay (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>4.6</td>
<td>1-20†</td>
<td>13</td>
</tr>
<tr>
<td>Non-ICU</td>
<td>4.6</td>
<td>1-10†</td>
<td>13</td>
</tr>
</tbody>
</table>

*Note.* †Assumed range. All costs are reported in 2009$. * see Appendix for selected references. HAI = healthcare-associated infection; ICU = intensive care unit; MRSA = methicillin-resistant *Staphylococcus aureus*; RN = registered nurse; PCR = polymerase chain reaction.

All costs were adjusted to 2009 dollars using the medical care component of the Consumer Price Index (U.S. Bureau of Labor Statistics, 2010a). The cost of active surveillance
screening is the sum of the cost of screening patients and the additional cost associated with isolating patients who screen positive for MRSA. The cost of the rapid-PCR test includes the laboratory technician’s wage and fringe benefits. The depreciation cost of the test equipment was excluded due to the assumption that the test equipment had already been purchased. The additional costs associated with isolating patients were calculated by multiplying the additional cost of contact precautions by the number of daily contacts and the average length of stay. The cost of contact precautions includes the cost of time to don a gown and gloves and to conduct hand hygiene, which we assume takes approximately two minutes. The costs per visit of registered nurses and general physicians were calculated based on the 2009 mean hourly wage estimates for each profession obtained from the Bureau of Labor Statistics (U.S. Bureau of Labor Statistics, 2010b).

Analytical Approach

For each screening strategy, the total number of MRSA HAI was calculated, as well as the costs associated with each screening strategy, using Microsoft Excel® (2007 version, Microsoft, Redmond, WA). The difference in costs and outcomes between the screening strategies represents the additional costs and MRSA HAI prevented, respectively. The incremental cost-effectiveness ratios (ICERs; i.e., the additional costs to prevent a MRSA HAI) were calculated using the following formula,

\[
ICER = \frac{Cost\ _{Alternative\ 1} - Cost\ _{Alternative\ 2}}{Effectiveness\ _{Alternative\ 1} - Effectiveness\ _{Alternative\ 2}}
\]
where Alternative 1 and Alternative 2 correspond with the strategies compared (i.e., USS, TSS or NSS) and effectiveness is the number of MRSA HAI that would be expected to occur with each strategy.

Sensitivity analysis included one-way deterministic analysis and probabilistic analysis, conducted using Oracle Crystal Ball® (Oracle, Redwood Shores, CA). One-way sensitivity analysis consisted of allowing each input parameter, probability or cost, to vary from the minimum to the maximum value of its range. For probabilistic sensitivity analysis Monte Carlo simulations were conducted with 1,000 trials. In each trial, values were selected for each input parameter from a specific distribution and the incremental costs, effectiveness, and cost-effectiveness ratio was calculated. Probabilities were assumed to follow beta distributions, cost data were assumed to follow log-normal distributions, and count variables were assumed to follow gamma distributions (Briggs, Claxton, & Sculpher, 2006). Data from these trials are shown in an incremental cost-effectiveness ratio (ICER) plane and as cost-effectiveness acceptability curves (CEAC; Briggs et al., 2006).

Pairs of incremental costs and HAIs avoided were plotted on the ICER plane to show the possible variation in the ICERs and how a decision to accept a screening strategy might vary. Points lying in the northeast quadrant represent cost-effective strategies (compared to NSS)—that is, strategies that cost more but deliver better outcomes (i.e., fewer MRSA HAIs); points lying in the southeast quadrant indicate a cost-saving strategy (i.e., one that costs less and delivers better outcomes).

To calculate CEACs, we used the net-benefits framework, which involves implementing a screening strategy only if its ICER is less than a particular decision threshold (i.e., the amount a decision maker would be willing to avert a MRSA HAI; Stinnett & Mullahy, 1998). For each set
of trial values and a particular willingness to pay threshold, we calculated the net-benefit for each strategy and selected the one with the highest net-benefit. The CEAC for a strategy is the proportion of trials that strategy has the greatest net-benefit for all possible willingness to pay values (Briggs et al., 2006). The preferred strategy is generally the one with the highest likelihood of cost-effectiveness for a given willingness to pay threshold.

**Results**

TSS was found to be a dominant strategy compared to NSS in the base-case analysis; it cost less while preventing more MRSA HAI (Table 3.2). Relative to NSS, TSS prevented 59 MRSA HAI and cost $282,770 less. Also relative to NSS, USS prevented 93 MRSA HAI but cost $1,391,742 more than NSS, resulting in incremental cost-effectiveness ratio (ICER) of $14,955 per MRSA HAI prevented. Compared to targeted screening, universal screening would be expected to prevent an additional 34 MRSA HAI at an additional cost of nearly $1.7 million (ICER $49,749 per MRSA HAI prevented).

Table 3.2

*Base-Case Costs and Outcomes Comparing MRSA Surveillance Screening Strategies*

<table>
<thead>
<tr>
<th>Screening Strategy</th>
<th>Total Costs</th>
<th>Total MRSA HAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>USS</td>
<td>$8,133,372</td>
<td>423.5</td>
</tr>
<tr>
<td>TSS</td>
<td>$6,458,860</td>
<td>457.2</td>
</tr>
<tr>
<td>NSS</td>
<td>$6,741,630</td>
<td>516.6</td>
</tr>
</tbody>
</table>

Comparison

<table>
<thead>
<tr>
<th></th>
<th>Incremental Costs (A)</th>
<th>MRSA HAIs Prevented (B)</th>
<th>ICER (A/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USS vs. NSS</td>
<td>$1,391,742</td>
<td>93.1</td>
<td>$14,955</td>
</tr>
<tr>
<td>TSS vs. NSS</td>
<td>-$282,770</td>
<td>59.4</td>
<td>Dominant</td>
</tr>
<tr>
<td>USS vs. TSS</td>
<td>$1,674,512</td>
<td>33.7</td>
<td>$49,748</td>
</tr>
</tbody>
</table>

*Note.* Dominant indicates a strategy that costs less and prevents more MRSA HAI than the comparison strategy. Costs and incremental costs reported in 2009$. ICER = Incremental cost-effectiveness ratio; MRSA = Methicillin-resistant *Staphylococcus aureus*; HAI = Healthcare-associated infection; USS = Universal surveillance screening; TSS = Targeted surveillance screening; NSS = No surveillance screening.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Incremental Cost-Effectiveness Ratio</th>
<th></th>
<th></th>
<th></th>
<th>Meanings</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>USS vs. NSS</td>
<td>TSS vs. NSS</td>
<td>USS vs. TSS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevalence of MRSA colonization at admission</td>
<td>ICU</td>
<td>0.037-0.12</td>
<td>$13,638</td>
<td>$15,692</td>
<td>-$6,620</td>
<td>-$3,414</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>0.009-0.085</td>
<td>$10,989</td>
<td>$16,319</td>
<td>$</td>
<td>$</td>
<td>$39,211</td>
</tr>
<tr>
<td>Probability of MRSA HAI</td>
<td>ICU</td>
<td>0.02-0.06</td>
<td>$28,689</td>
<td>$863</td>
<td>-$740</td>
<td>-$8,947</td>
<td>$81,147</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>0.009-0.085</td>
<td>$24,075</td>
<td>$6,043</td>
<td>$</td>
<td>$</td>
<td>$194,183</td>
</tr>
<tr>
<td>Reduction in MRSA HAI rates due to screening and isolation</td>
<td>ICU</td>
<td>1%-57%</td>
<td>$60,446</td>
<td>$6,076</td>
<td>$260,505</td>
<td>-$8,251</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>1%-33%</td>
<td>$28,079</td>
<td>$2,086</td>
<td>$</td>
<td>$</td>
<td>$614,928</td>
</tr>
<tr>
<td>Additional cost of MRSA HAI</td>
<td>§</td>
<td>$5,202-$20,899</td>
<td>$22,624</td>
<td>$6,927</td>
<td>$3,005</td>
<td>-$12,692</td>
<td>$57,596</td>
</tr>
<tr>
<td>Cost of rapid PCR Test</td>
<td>§</td>
<td>$20-$80</td>
<td>$1,964</td>
<td>$27,588</td>
<td>-$7,843</td>
<td>-$1,843</td>
<td>$19,445</td>
</tr>
<tr>
<td>Cost of contact precautions</td>
<td>§</td>
<td>$20-$80</td>
<td>$1,964</td>
<td>$27,588</td>
<td>-$7,843</td>
<td>-$1,843</td>
<td>$19,445</td>
</tr>
<tr>
<td></td>
<td>Cost per gown</td>
<td>0.81-0.99</td>
<td>$14,526</td>
<td>$15,026</td>
<td>-$4,967</td>
<td>-$4,270</td>
<td>$49,274</td>
</tr>
<tr>
<td></td>
<td>Cost per pair of gloves</td>
<td>0.07-0.09</td>
<td>$14,748</td>
<td>$14,804</td>
<td>-$4,857</td>
<td>-$4,830</td>
<td>$49,695</td>
</tr>
<tr>
<td>Time to don gown and gloves</td>
<td>1-3 min</td>
<td>$12,899</td>
<td>$16,653</td>
<td>$5,773</td>
<td>-$3,913</td>
<td>$46,183</td>
<td>$53,312</td>
</tr>
<tr>
<td>No. of RN visits/day</td>
<td>ICU</td>
<td>20-40</td>
<td>$14,276</td>
<td>$15,277</td>
<td>-$5,625</td>
<td>-$4,062</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>10-20</td>
<td>$13,700</td>
<td>$15,852</td>
<td>$</td>
<td>$</td>
<td>$46,753</td>
</tr>
<tr>
<td>No. of physician visits/day</td>
<td>ICU</td>
<td>3-9</td>
<td>$14,500</td>
<td>$15,052</td>
<td>-$5,275</td>
<td>-$4,412</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>1-6</td>
<td>$13,984</td>
<td>$15,965</td>
<td>$</td>
<td>$</td>
<td>$47,543</td>
</tr>
<tr>
<td>Average length of stay (days)</td>
<td>ICU</td>
<td>1-20</td>
<td>$13,168</td>
<td>$21,653</td>
<td>-$7,353</td>
<td>$5,892</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>Non-ICU</td>
<td>1-10</td>
<td>$11,319</td>
<td>$19,962</td>
<td>$</td>
<td>$</td>
<td>$40,127</td>
</tr>
</tbody>
</table>

Note: Negative values indicate dominant strategies (i.e., those strategies that cost less and prevent more MRSA HAI). Meaningful thresholds are the value at which a strategy analyzed switches from being cost-effective to dominant, or vice versa. § indicates parameters that do not affect comparison. All costs are reported in 2009$. ICU = Intensive care unit; MRSA, methicillin-resistant *Staphylococcus aureus*; HAI, healthcare-associated infection; USS, universal surveillance screening; TSS, targeted surveillance screening; NSS, no surveillance screening; RN, registered nurse; PCR, polymerase chain reaction.
The dominance of TSS over NSS was found to be robust to variation in the majority of input parameters through one-way sensitivity analysis. In the one-way sensitivity analysis for MRSA HAI prevented (Table 3.3), TSS was a dominant strategy across the ranges of all but three input parameters—the effectiveness of screening and isolation in the ICU, the overall cost of a MRSA HAI, and the average length of stay in the ICU. When the effectiveness of screening in the ICU was above 21%, TSS was a dominant strategy. Similarly, when the cost of a MRSA HAI was above $8,291, TSS became a dominant strategy. Lastly, TSS was a dominant strategy when the average length of stay in the ICU was less than 11.4 days.

![Figure 3.2](image.png)

*Figure 3.2. Incremental cost-effectiveness ratio plan for MRSA HAI prevented comparing MRSA surveillance screening strategies to no surveillance screening. Incremental cost-effectiveness ratio (ICER) plane is a graph of the incremental costs and incremental outcomes from each of the 1,000 Monte Carlo simulations. ICER plane plots the incremental costs and incremental outcomes relative to no surveillance screening from each trial of the probabilistic sensitivity analysis. For points in the north-east quadrant the strategy costs more, but results in better outcome. Points in the south-east quadrant represent trials in which the strategy costs less and results in a better outcome (i.e., is dominant). USS = Universal surveillance screening; TSS = Targeted surveillance screening; MRSA = Methicillin-resistant *Staphylococcus aureus*; HAI = Healthcare-associated infection*
Probabilistic sensitivity analysis also supported the conclusion that TSS may be the most cost-effective surveillance screening strategy. As plotted on the ICER plane (Figure 3.2), all of the points associated with TSS lie to the left and below the USS points indicating that TSS is generally more cost-effective than USS when compared with no screening. Additionally, 61.1% of the simulations the TSS ICERs (relative to NSS) fell into the south-east quadrant of the ICER plane, indicating that TSS is cost-saving (i.e., cost less while preventing more MRSA HAI) than NSS; in the case of USS, only 6.9% of the simulations fall into the cost-saving quadrant and the ICERs are almost always greater than those of TSS (meaning that TSS would be preferred from a cost-effectiveness standpoint).

Figure 3.3. Cost-effectiveness acceptability curves for MRSA HAI prevented comparing MRSA surveillance screening strategies. Cost-effectiveness acceptability curve (CEAC) indicates the likelihood that each alternative is cost-effective at increasing willingness to pay for the prevention of an additional MRSA HAI. The indicated dollar value, at the intersection of the TSS and USS curves, indicates the willingness to pay at which USS becomes cost-effective. USS = Universal surveillance screening; TSS = Targeted surveillance screening; NSS = No surveillance screening
In the cost-effectiveness acceptability curve for MRSA HAI prevented (Figure 3.3), active screening, either TSS or USS, was found to always be the cost-effective strategy. Even if a decision maker were unwilling to pay anything to prevent a MRSA HAI, TSS would be the appropriate strategy two-thirds of the time. Only when the decision maker’s willingness to pay exceeds $94,750 per MRSA HAI prevented, USS is the more cost-effective strategy.

**Discussion**

Despite the possibility of variation and uncertainty in the input parameters, our model was robust and demonstrated that targeted surveillance of ICU patients was the dominant or cost-saving strategy for reducing MRSA HAIs. Altering the input parameters of our model demonstrated instances when TSS would not be cost-saving. When the cost of MRSA HAI is low it follows that active screening would not be cost-effective because the cost of screening and isolating patients outweighs the savings from preventing fewer MRSA HAIs. Similarly, when TSS is not effective at reducing the rate of MRSA HAI (less than a 21%-reduction) in the ICU, it is no longer a cost-effective strategy. TSS most likely would be a cost-effective strategy in high endemic situations of MRSA because TSS is likely to reduce MRSA HAI rate by more than 21%, as any intervention has a substantial likelihood to significantly reduce the MRSA HAI rate in high prevalence situation (Peterson & Diekema, 2010). These results are supported by Huang et al.’s finding that TSS resulted in a 67%-reduction in hospital-wide healthcare-associated bloodstream infection (Huang et al., 2006). TSS would also not be a dominant strategy when the average length of stay in the ICU is more than 11.4 days. As length of stay is extended, TSS becomes more expensive as an intervention strategy because of the additional costs related to contact precautions and isolation for the extended hospitalization although we have assumed no
additional follow-up screening (e.g., weekly surveillance screening) in our model. Lastly, TSS is a cost-effective strategy at reasonable levels of willingness to pay for each prevented MRSA HAI. Although there is no widely agreed upon threshold for the willingness to pay for a prevented MRSA HAI, the thresholds (less than $94,750 per MRSA HAI prevented) observed for TSS suggests that it would be an attractive strategy (compared to universal or no screening at all) in most hospitals.

The main limitation of this study was the lack of reliable data for some key input parameters, which required assumptions based on clinical expertise and therefore may limit validity of study results. First, limited evidence exists regarding the overall, or relative, effectiveness of active surveillance and isolation in either the ICU or non-ICU settings. Because the effect of active surveillance screening on reducing MRSA HAI is not clearly established with strong evidence (Nyman et al., 2011), some researchers may disagree with our assumption that active surveillance screening with prompt isolation will reduce MRSA, which was based on Mangini et al.’s finding that the implementation of contact precautions reduced MRSA HAI rate significantly (Mangini et al., 2007). Second, it is difficult to identify evidence on the relative prevalence of MRSA HAI between the ICU and non-ICU because the CDC National Nosocomial Infections Surveillance System and NHSN have not published data on non-ICU rates of MRSA as CDC has only recently begun to accumulate data on non-ICU acquired HAI (Hidron et al., 2008; NNIS, 1998). Thus, we had to assume that MRSA HAI rate in the non-ICU setting is lower than the ICU rate based on the fact that the likelihood of MRSA HAI is assumed to be higher among ICU patients because of patients’ vulnerable characteristics, such as high severity of illness and higher frequency of invasive procedures (Garrison, 2009).
Although a decision tree model is most appropriate for comparison of effects from three alternative strategies on the study outcome, the validity of the results also may be limited by the modeling techniques used. First, although the number of deaths that were directly attributable to MRSA HAI can be a significant outcome, this study did not include it as one of the end points of hospitalization due to lack of reliable MRSA HAI-attributable mortality data. Second, this study did not model transmission timing or transmission pathways because transmission of MRSA from asymptomatic colonized patients is complex and largely uncertain (Shorr, 2007). Therefore, it is impossible to determine when patients were most likely to acquire a MRSA HAI and which transmission pathways screening and isolation impacted the most of MRSA HAIs. In addition, these study results also may not be applicable to small, community hospital settings. Active screening may be not feasible in small hospitals where infection control programs may have fewer staff and less funding and may lack capacity to perform PCR for detection of MRSA (Anderson & Sexton, 2008).

Although screening and prompt isolation of MRSA-colonized patients have been accepted as an effective measure to control MRSA outbreaks, many U.S. hospitals have hesitated to implement active surveillance screening in the absence of outbreaks due to the lack of evidence for routine active screening (Mangini et al., 2007). Although some studies have showed the impact of MRSA by estimating the costs of MRSA infection (Cosgrove et al., 2005; Elixhauser & Steiner, 2007), these studies did not specifically examine MRSA HAIs and did not differentiate community-acquired cases from cases acquired in the hospital setting. Recently, Nyman et al. reported that screening for MRSA in the ICU is likely to provide cost savings to a 279-bed Veterans Affairs hospital (Nyman et al., 2011). More recently, Leonhardt et al. demonstrated in two community hospitals that, compared to targeted screening, universal
screening was not cost-beneficial; the additional costs of universal screening would be recouped at a rate of $.50 on the dollar compared to the avoided costs of hospital-acquired MRSA infection, resulting in a net loss per patient (Leonhardt et al., 2011). However, to our knowledge, no cost-effectiveness study compares alternative surveillance screening strategies (i.e., all hospitalized patients vs. ICU patients only vs. no screening) using a modeling approach in the United States. Thus, our study fills a unique, but necessary niche, and complements Leonhardt et al.’s study.

Overall, the results of this modeling study indicate that TSS is cost saving compared to no surveillance screening, and cost-effective relative to universal screening of all admitted patients. However, more research is needed, including data from real-world hospital settings. First, further studies are needed in order to determine the recommended protocols for implementing active surveillance screening along with rigorous analyses of its cost-effectiveness. Second, more studies are necessary to determine where, and when, TSS is most effective at reducing MRSA HAIs. Currently, most research available regarding targeted surveillance focuses on ICU patients and surgical patients (Anderson et al., 2009; Clancy et al., 2006; McGinigle et al., 2008). Although these patients are likely to be most at risk for MRSA HAIs, it is important to determine among which categories of patients active surveillance is most effective at reducing MRSA HAI rates. Third, since control of MRSA is a significant concern across healthcare settings, more research is needed regarding the prevalence of MRSA HAIs and effectiveness of screening in various healthcare settings, including small community hospitals. The results of this study suggest that in academic hospital settings with a high prevalence of MRSA HAIs or high costs associated with MRSA HAIs, targeted active surveillance screening of ICU patients is the most cost-effective screening strategy.
REFERENCES


Appendix 3.1

Selected References for Input Parameters


Appendix 3.2
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CHAPTER 4

SURVEY OF NORTH CAROLINA HOSPITAL POLICIES REGARDING VISITOR USE OF PERSONAL PROTECTIVE EQUIPMENT FOR ENTERING THE ROOMS OF PATIENTS ON ISOLATION PRECAUTIONS

Background

Isolation precautions have been recommended for healthcare personnel (HCP) across the continuum of care as a standard infection control practice for infectious diseases with possible person-to-person transmission in the healthcare setting. The Centers for Disease Control and Prevention (CDC) 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings recommends that patients be isolated in a single room with proper transmission-based isolation precautions: contact precautions, droplet precautions, and airborne precautions (Siegel et al., 2007). Contact precautions target contact-transmitted pathogens (e.g., those transmitted by direct or indirect contact with patients), such as multidrug-resistant (MDR) pathogens (Siegel et al., 2007). When using contact precautions, HCP perform hand hygiene prior to room entry, and use gown and gloves for any contact with a patient or the patient’s environment (Siegel et al., 2007). Droplet precautions require HCP to wear a surgical mask in the rooms of patients who are isolated for droplet-transmitted pathogens, such as the influenza virus (Siegel et al., 2007). Patients with pathogens that are transmitted by the aerosol route (e.g., Mycobacterium tuberculosis) require airborne precautions, including a negative-pressure private room with direct out-exhausted air along with HCP use of an N95 mask (Siegel et al., 2007). Although enteric precautions are not listed in the current CDC guidelines and all enteric pathogens should prompt the use of contact precautions, some hospitals have developed and implemented enteric precautions to reinforce the use of isolation precautions for enteric
pathogens, especially for *Clostridium difficile*, which has become a major healthcare-associated pathogen in the past several years (Kang, Sickbert-Bennett, Brown, Weber, & Rutala, 2012a; Miller et al., 2011). In addition, protective precautions have been used to protect immunocompromised patients (e.g., those with hematologic malignancy, organ transplantation, and usually neutropenia) in hospital settings, although the CDC eliminated the use of these precautions in 1983 (Bowling, Cadena, & Patterson, 2012).

The use of isolation precautions can simultaneously disrupt several components in the chain of healthcare-associated infections (HAIs; see Figure 1.1 in Chapter 1 for detail) and prevent the transmission of healthcare-associated pathogens in hospital environments. The hospital environment comprises the animate environment (the human reservoir) as well as the inanimate environment (e.g., beds, medical equipment) as previously specified (see Chapter 1 Figure 1.2). The implementation of isolation precautions as a preventive method to disrupt/avoid transmission of infectious agents includes two main components: the reservoir (particularly the human reservoir) and the transmission in the chain of HAIs, as illustrated in Figure 1.1 in Chapter 1. In addition, the use of personal protective equipment (PPE: gloves, gown, mask, and N95 respirator) can disrupt the chain of HAIs by closing entry and exit portals; humans serve as both potential reservoirs and susceptible hosts, depending upon their current health condition and host defense mechanisms (e.g., specific immunity from vaccination). For example, wearing a mask can prevent both the spread of infectious droplets from an infectious person’s cough and a susceptible person’s inhalation of the infectious droplets. In fact, isolation precautions (contact, droplet, and airborne), including the use of appropriate PPE, can be a broadly effective prevention method by disrupting multiple components in the chain of HAIs.
The human reservoir includes patients, HCP, and visitors in hospital settings. To control patients’ role as human reservoirs who can spread infectious agents into the hospital environment, prompt implementation of appropriate isolation precautions is necessary for patients with a known or suspected communicable disease (Siegel et al., 2007) and those who are colonized or infected with an MDR pathogen (Siegel et al., 2007). In addition to appropriate isolation precautions, single-room isolation is recommended as a quarantine method for isolating infectious patients. For HCP with communicable diseases, appropriate occupational health management, including work restrictions, are used in hospital settings (Bolyard et al., 1998). Current CDC guidelines for isolation precautions recommend the use of PPE by HCP (Siegel et al., 2007). For patients on droplet or airborne isolation precautions, all persons entering the patient’s room (visitors and HCP) are required to wear either a surgical mask or an N95 (for tuberculosis, as required by the Occupational Safety and Health Administration) respirator, as recommended by the CDC guideline (Siegel et al., 2007). HCP entering the room of a patient on contact precautions for an MDR pathogen are required to wear gloves and a gown.

The association between visitors’ behavior in hospital settings and transmission risks has not been fully evaluated (Birnbach et al., 2011). Two infection control issues are related to hospital visitors: handling sick visitors to prevent the introduction of infections into hospitals and the use of PPE by visitors to prevent the transmission of HAIs in hospital settings. First, efforts to prevent visitors from introducing infections into hospitals focus on screening and excluding sick visitors. According to the current CDC guideline, visitors should maintain respiratory hygiene/cough etiquette if they have symptoms of a respiratory infection (Siegel et al., 2007). Hospital signs usually request that sick visitors not enter clinical areas (Clock et al., 2010). However, there have been several reports of visitors introducing infections into hospitals. During
the 2003 worldwide outbreak of severe acute respiratory syndrome (SARS), visitors were linked to 13 to 14% of all healthcare-associated SARS cases in Canadian hospitals (Quinlan, Loughrey, Nicklin, & Roth, 2003). Second, visitors have also been reported as the source of HAIs with *M. tuberculosis*, pertussis, influenza, and other respiratory viruses (Siegel et al., 2007a). Although visitors have been implicated in the introduction of airborne and droplet diseases (e.g., measles) into a hospital (Quinlan, Loughrey, Nicklin, & Roth, 2003; Siegel et al., 2007; Weber & Rutala, 2008), their role in the cross-transmission of MDR pathogens (e.g., methicillin-resistant *Staphylococcus aureus* [MRSA] and vancomycin-resistant *Enterococcus* [VRE]) has been less clear. Visitors are usually informed by hospital signs about recommendations for the prevention of HAIs (e.g., the importance of hand hygiene); however, visitor awareness of and compliance with behaviors requested by hospital signage is unknown. For example, despite the placement of additional signs and a freestanding dispenser of alcohol-based hand sanitizer in a hospital lobby, hospital visitor hand hygiene compliance remained lower than 10% in the lobby of a university teaching hospital (Birnbach et al., 2011). Recently, one observational study of adherence to contact precautions found environmental contamination even when visitors followed contact precautions, particularly when visitors removed their gloves in the isolation rooms (Clock et al., 2010). Additional studies of hospital visitors’ behavior and of the relationship between visitors and the transmission of healthcare-associated pathogens are critically needed.

In fact, the effectiveness of implementing isolation precautions among hospital visitors, including use of gowns, gloves, or masks in hospital settings, has not been studied well (Siegel et al., 2007a). Some studies have focused on the use of gowns and gloves to control MDR pathogens, but they did not measure the effectiveness of visitors’ use of these precautions. Some visitors who provide care and are in close contact with the patient can facilitate transmission if
they do not follow isolation precautions properly (Siegel et al., 2007a). The CDC recommends that each hospital determine specific recommendations for visitors by facility, unit, and level of interaction (Siegel et al., 2007a). However, research examining the diversity of hospital visitor recommendations does not exist. Such research is critically needed because visitors play significant roles as both reservoirs and susceptible hosts of healthcare-associated pathogens. Therefore, to examine the diversity of hospital policies for visitor PPE use when visiting patients on isolation precautions, we conducted a survey of hospitals in North Carolina.

Methods

Study Design

This study used an online survey to investigate current hospital policies for visitors and to guide the development of future policies for visitors’ isolation precautions in hospital settings. This study design includes survey questionnaire development, survey execution, and response analysis.

Sample/Setting

The study population was all acute care hospitals in North Carolina. Due to lack of the exact information about all of the acute care hospitals in North Carolina, the hospitals that were among all the healthcare facilities registered in the North Carolina Statewide Program for Infection Control and Epidemiology (SPICE) listserv were selected as a convenience sample for this survey. We do not know exactly what proportion of North Carolina hospitals is represented in the SPICE listserv, but we are certain the SPICE listserv provided a good sample of hospitals in North Carolina for the following reason: SPICE was established in 1980 to help develop
infection control programs at community hospitals and for tuberculosis management by a contract between the University of North Carolina (UNC) at Chapel Hill School of Medicine and the North Carolina Department of Human Resources (SPICE, 2012). Under the North Carolina Infection Control law 10A NCAC 41A. 0206 Infection Prevention – Health Care Settings, every healthcare organization that performs invasive procedures shall require the infection control staff to complete an approved course in infection control in order to prevent transmission of bloodborne pathogens, such as Human Immunodeficiency Virus (HIV), hepatitis B and hepatitis C (North Carolina Office of Administrative Hearings, 2012). As the administrator of the North Carolina- approved infection control courses, SPICE has provided educational courses and consultations, including outbreak investigation, to all North Carolina healthcare facilities since 2000 (SPICE, 2012). In the two decades from 1990 to 2009, SPICE provided 12,359 consults, 63 onsite investigations, 85 full courses, 352 workshops, and 61 newsletters (Hoffman, 2010). SPICE disseminates timely, up-to-date infection control information to course attendees and registered users of the SPICE website via newsletters and SPICE listserv-generated emails.

To select only hospitals from among the healthcare facilities registered in the SPICE listserv, the names and information of healthcare facilities were checked through their websites and the list of Hospitals Licensed by the State of North Carolina Department of Health and Human Services – Division of Health Service Regulation as of January 2012 (North Carolina Division of Health Service Regulation, 2012). The non-hospital type facilities, such as clinics, hospice care, student health services, psychiatric programs, county health departments, surgical centers, endoscopy centers, and ambulatory care centers, were excluded. In addition, healthcare facilities that had no identified email address in the SPICE listserv were excluded because an
email address of at least one infection preventionist (IP) at each hospital was required for online survey distribution.

IPs were chosen as the most appropriate respondent for this survey among HCP because IPs practice infection prevention. IPs’ practices include identifying HAI processes, surveillance, outbreak investigation, intervention to control HAI transmission, management of HCP after exposure to the risk of infectious disease (e.g., a sharps injury during surgery), participation in hospital policy-making processes for infection control (e.g., updates of hospital infection control policy and attendance at hospital infection control committee meetings), education and consulting, and research (Feltovich & Fabrey, 2010).

Measures/Survey Questionnaire Development

The questionnaire (see Appendix 4.1) was developed with both the director and the infectious diseases consultant of SPICE to examine hospital policy issues related to visitor isolation precautions. The final questionnaire included four parts: respondent information, hospital characteristics, isolation room characteristics, and specific hospital visitor policies for isolation precautions, including PPE use. The questions followed a categorical choice (e.g., Yes, No, and not applicable), multiple choice (e.g., please check all that apply), short text, or open-ended format, depending on the question context. A total of 29 questions were included in the main-request survey questionnaire.

Questions about respondent information. Questions about the name, hospital job title, hospital name, and contact information of the person completing the survey were included to identify duplicate responses from the same hospital, to identify non-responding hospitals and send reminder emails, and to contact the respondents for clarification of responses when indicated.
Questions about hospital characteristics. Information about the operating characteristics of the participating hospitals was collected through questions about the number of licensed beds, which was used to categorize the hospitals into three groups according to size (small, medium, and large); hospital type, with subcategories (general/acute care, subspecialty, long-term care, and other) to search for differences in visitor policy by hospital type; number of full-time equivalent (FTE) IPs, to examine staffing levels for infection control at the respondent hospitals; and number of patients admitted to the hospital between January 1, 2011 and December 31, 2011, to examine the hospital visitor policy and its correlation with admission volume. Because the IPs were not likely to know the yearly number of hospitalized patients without checking with their hospital administration departments or accessing their electronic administration systems, a “do not know” option was included.

Questions about isolation room characteristics. The following questions were included to examine the characteristics of the hospitals’ isolation rooms: the availability of inpatient airborne isolation rooms; the languages (English and Spanish) used on isolation precaution signs; visitor-specific content on isolation precaution signs; posted infection control information for visitors; whether visitor education for isolation precautions is provided and, if so, who provides education for visitors.

Questions about the hospital’s policy for visitors’ isolation precautions. Hospital policy information was explored through questions about the following issues: existing hospital visitor policy regarding isolation precautions; the IP’s opinions about this policy; the IP’s experience of related outbreaks; the hospital’s policy for handling non-compliant and sick visitors; and the IP’s suggestions for facilitating visitors’ compliance with isolation precautions. We included enteric precautions in addition to the three transmission-based precautions to
examine the current use of each precaution category in hospital settings. Although not all PPE (e.g., N95 mask, surgical mask, gown, and gloves) are required for each category of isolation precautions, these PPE were listed with a categorical choice option (e.g., “yes”, “no”, and “not applicable”) to examine whether PPE were available outside the isolation rooms under current hospital visitor policy. In addition, questions about age restrictions for visitors, differing policies for child visitors, and the management of non-compliant guardians were included because the needs of children who are visiting hospitals may differ from those of adult visitors. An open-ended description option was added to many questions in this section to capture the IPs’ unique experiences related to the issues of current hospital visitor policy regarding isolation precautions.

Questions for survey feedback (included in the pilot-request survey only). After the survey questionnaire was developed, two questions were added for the pilot-request survey phase to elicit feedback from pilot-requested hospitals. These two questions were used to identify unclear parts of questions and to improve the quality of the survey questionnaire.

Validation of questionnaire before survey execution. The questionnaire was reviewed by an expert in survey methodology at UNC Gillings School of Global Public Health to produce a questionnaire with an optimal structure and without critical errors. To estimate the response time and the clarity of the contents, and to ensure that the questions were appropriately interpreted, the questionnaire was pretested by three IPs at the Department of Hospital Epidemiology, UNC Health Care, which closely collaborates with SPICE at UNC. From a total of six IPs at UNC Health Care, three IPs were selected based on their level of infection control experience, which ranged from less than 1 year to more than 10 years, to assess the concurrence between the IPs’ understanding of the questions and the questions’ intended meaning.
Survey Execution Procedure

The survey was approved by the UNC Institutional Review Board. The survey was constructed using the commercial online survey program SurveyMonkey® (SurveyMonkey.com, LLC, Palo Alto, CA) because the IPs were familiar with the program through several prior SPICE listserv surveys. All of the SPICE listserv-enlisted IPs at the selected hospitals were invited to participate in this survey via an online survey link in the email requesting their participation. Thus survey request was sent to all enlisted IPs at the hospitals that were selected for this survey with the assumption that some IPs might not be available to respond to this survey request because of vacation, retirement, switching hospitals, or job demands. In the request (see Appendix 4.2), the IPs were informed that one response per hospital was sufficient and that duplicate responses would be deleted.

The pilot survey was conducted by sending emails to 10 hospitals that were randomly chosen from the selected hospitals in SPICE listserv February 6-20, 2012 using the random function of Microsoft Excel® (2007 version, Microsoft, Redmond, WA). After completion of the pilot study, email requests with a link to the survey were sent to IPs at hospitals who had not participated in the pilot survey between February 21, 2012 and March 6, 2012, with the online survey link remaining available for an additional two weeks. Hospitals that did not respond during that period of time were sent a reminder email between March 21 and March 30, 2012. To improve the response rate, the reminder email was sent to the non-respondent hospitals by the director of SPICE, who is well known to SPICE listserv members.

Data Analysis

Data management. Although pilot survey results are typically not included in the data analysis, we included the responses from our pilot survey for the following reasons: 1) the
primary questionnaire was exactly the same as the pilot questionnaire, except that the pilot email survey included feedback questions; and 2) the pilot survey respondents did not want to complete the survey again and confirmed that their pilot responses were correct so that their responses would be unchanged. Thus, we were able to include data collected from the pilot survey in the analysis. Any identifying information from the respondents was deleted prior to initiating data analysis to protect the confidentiality of responses. When duplicate responses were received from a hospital, only the most complete response (i.e., the one that answered the most questions) was retained for analysis.

After examining the initial data, we discovered that based on the responses provided to the question about hospital type, some of the respondent hospitals were not acute-care hospitals. This happened because we were not able to differentiate which of the hospitals selected from the SPICE listserv were acute care hospitals before we sent the survey emails. Thus, at this point, we excluded non-acute care hospitals, such as rehabilitation, prison, long-term care, psychiatric, and orthopedic hospitals, because these hospitals are likely to have different characteristics, such as average length of hospital stay and numbers of visitors, which can substantially affect hospital visitor policy. As a result, only the responses of short-term, general acute care hospitals were included in data analysis.

Because large hospitals may differ from small hospitals in their visitor policies for isolation precautions (due to possible differences in the number of visitors, services provided, and the availability of isolation rooms), we used the number of licensed beds provided by the survey respondents to group the respondent hospitals into three categories (small, \( \leq 200 \) beds; medium, 201-500 beds; and large, \( > 500 \) beds) based on the National Healthcare Safety Network (NHSN) hospital size category (Edwards et al., 2009). In addition, because teaching hospitals
may have a strong educational influence that affects hospital visitor policy, a “teaching status”
variable with a dichotomous value (teaching vs. non-teaching) was created by matching hospital
name with the Association of American Medical Colleges (AAMC) list of Member Teaching
Hospitals and Health Systems (AAMC, 2012).

Statistical analysis. Descriptive statistics (e.g., frequencies, percentages) were conducted
The percentage for each response with a categorical choice option was calculated as the response
number for each choice divided by the total number of responses for each question (i.e., by
letting denominator changes) and multiplied by 100 (not all respondents answered each question,
and several questions allowed multiple answers). The mean, standard deviation, and range were
calculated for numeric responses, such as the number of licensed beds, the number of FTE IPs,
and the total number of hospitalized patients for the year 2011. Mantel-Haenszel chi-square
statistics were used to test for general associations among hospital size groups. There were too
few teaching hospitals (less than 5) to permit a formal statistical test of comparison.

Summary of narrative responses to the open-ended questions. The narrative
responses to the questions with an open-ended description format (e.g., “Do you think a hospital
should have policies to encourage visitors to comply with isolation precautions? Why?”) were
thoroughly reviewed. Narrative responses with similar contents were grouped together to
summarize the narrative responses. Because certain similar themes (main categories and
subcategories) emerged when the narrative responses to different questions were reviewed, the
narrative responses were categorized together, not question-by-question. The main categories
were then determined based on the overall theme of each group that had similar contents. The
narrative responses in each main category group were reviewed again and then classified into
subcategories, which were based on the common themes that emerged for the grouped narrative responses.

Results

As of January 18, 2012, a total of 188 healthcare facilities were registered in the SPICE listserv. We excluded from our survey non-hospital type facilities (e.g., clinics) and hospitals for which no email address was identified in the SPICE listserv, leaving a total of 136 eligible hospitals; a total of 338 email addresses belonging to IPs were available. Of the 136 surveyed hospitals, 93 hospitals (68.4%) responded (six responses from the pilot survey and 87 responses from the survey: 51 from the primary email and 36 from the reminder email). Excluding 11 non-acute care hospitals from the respondents, the remaining 82 (60.3%) acute care hospitals were included in the data analysis (Figure 4.1).
Hospital characteristics. Hospital characteristics are summarized in Table 4.1. Overall, 62% (n=51) of the hospitals were small hospitals (≤200 beds). The mean number of licensed beds among the respondent hospitals was 272 (median, 149; standard deviation, 272), with a range of 18 to 1,023.
Table 4.1.

Characteristics of the Study Hospitals (n=82)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Descriptive statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital size, n (%)</td>
<td></td>
</tr>
<tr>
<td>Small (≤200 beds)</td>
<td>51 (62)</td>
</tr>
<tr>
<td>Medium (201-500 beds)</td>
<td>18 (22)</td>
</tr>
<tr>
<td>Large (&gt;500 beds)</td>
<td>13 (16)</td>
</tr>
<tr>
<td>Teaching, n (%)</td>
<td></td>
</tr>
<tr>
<td>Teaching</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Non-teaching</td>
<td>78 (95)</td>
</tr>
<tr>
<td>Number of full-time equivalent IPs</td>
<td></td>
</tr>
<tr>
<td>Overall (n=79), mean (range)</td>
<td>2.09 (0.25 – 8)</td>
</tr>
<tr>
<td>Only one IP, n (%), hospital bed range</td>
<td>40 (49%, 18 – 300)</td>
</tr>
<tr>
<td>Less than one IP, n (%), hospital bed range</td>
<td>7 (9%, 0.25 – 0.6, 21 – 149)</td>
</tr>
<tr>
<td>More than one IP, n (%), hospital bed range</td>
<td>32 (39%, 1.5 – 8, 135 – 1,023)</td>
</tr>
<tr>
<td>Number of patient admissions in 2011 (n=31)*, mean (range)</td>
<td>11,374 (280 – 97,533)</td>
</tr>
</tbody>
</table>

Note. *For medium and small hospitals; the large hospitals did not provide the number of patients admitted in 2011. IP = Infection preventionist

AAMC-listed teaching hospitals comprised only 5% of the sample (n=4). All four of the teaching hospitals were large (>500 beds). The mean number of FTE IPs among the respondent hospitals was 2.09 (range, 0.25-8; standard deviation, 1.97). Among the respondent hospitals, 49% had only one FTE IP, and 9% had fewer than one FTE IP. Among the 32 hospitals with more than one FTE IP, the mean number of FTE IPs was 3.85 (range, 1.5-8). The number of FTE IPs per 100 licensed beds among these hospitals ranged from 0.5 to 1.5. For the 39 respondent hospitals that provided the number of hospital admissions, the mean number of hospitalized patients was 11,374 (standard deviation, 17,478) in the year 2011.

Isolation room characteristics. Among the 79 hospitals that responded to this part of the questionnaire, 78 (99%) indicated they had an inpatient airborne isolation room(s). The hospital that did not have an isolation room had only 18 beds. All 79 hospitals posted isolation precaution signs in the isolation rooms; the types of isolation signs posted were airborne (n=68, 86% of 79 hospitals), droplet (n=65, 82%), contact (n=64, 81%), and enteric (n=57, 72%) precautions, as
well as protective precautions for immunocompromised patients (n=55, 70%). Twelve hospitals used combination signs (n=9, 11%) or special signs (n=3, 4%), such as strict contact isolation for highly resistant organisms such as “Klebsiella pneumonia carbapenemase producer”. Sixty-eight (87%) hospitals provided information in both English and Spanish, and 63 (81%) hospitals reported using visitor-specific signs that alert visitors to hospital policies regarding isolation precautions. No significant association between the use of visitor-specific signs and hospital size (small, 80%; medium, 82%; large, 82%; p=0.92) was noted. Other specific types of information provided to visitors included information on respiratory etiquette (89%) and hand hygiene (88%). Some hospitals used isolation signs for specific cases, such as C. difficile or “living with MRSA”.

Education for visitors was provided in 96% of the respondent hospitals via written materials (59%; e.g., brochures, handouts, and pamphlets) and direct education delivered by HCP (41%). The respondents indicated that nurses were the primary visitor educators (73%), whereas IPs (13%) and physicians (11%) were much less likely to be involved in providing visitor education.

**Hospital policies for visitors’ isolation precautions.** Substantial variations were observed in hospital policies requiring PPE for visitors entering patient isolation rooms (Table 4.2).

Table 4.2.

*Response Summary of Hospital Policies for Visitors’ Use of Personal Protective Equipment When Entering Each Type of Isolation Room*

<table>
<thead>
<tr>
<th>Isolation room</th>
<th>N95</th>
<th>Surgical mask</th>
<th>Gown</th>
<th>Gloves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Yes (%)</td>
<td>No (%)</td>
<td>NA (%)</td>
</tr>
<tr>
<td>Airborne</td>
<td>51</td>
<td>59</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>Droplet</td>
<td>35</td>
<td>6</td>
<td>74</td>
<td>20</td>
</tr>
<tr>
<td>Contact</td>
<td>36</td>
<td>-</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Enteric</td>
<td>34</td>
<td>-</td>
<td>65</td>
<td>35</td>
</tr>
</tbody>
</table>

*Note.* These responses were for multiple choice questions. n = total responses, % = (n in each category/total number of responses) x 100, NA = Not applicable in the respondent hospital.
The respondents reported that when rooms were designated for patients on airborne isolation precautions (e.g., patients with tuberculosis), 59% (n=30) of hospitals had policies that included the provision of N95 respirators for visitors, and 71% (n=37) had polices that provided visitors with surgical masks. Only one hospital (2%) did not have a policy that supported providing either an N95 respirator or surgical mask to visitors entering airborne isolation rooms (not shown in Table 4.2). When rooms were designated for patients on droplet isolation precautions (e.g., patients with influenza), 98% (n=62/63 respondents to this question) of the responding hospitals had a policy indicating that surgical masks should be provided to visitors, but only one hospital reported providing both N95 respirators and surgical masks (not shown in Table 4.2). The respondents reported that when rooms were designated for contact isolation precautions (e.g., for patients with MRSA), 54 (95%) had a policy that provided both a gown and gloves to visitors, yet only nine hospitals (24%) provided visitors with masks as well (not shown in Table 4.2). The respondents reported that when rooms were designated for enteric isolation precautions (e.g., for patients with *C. difficile* or norovirus), 56 hospitals (92%) provided both a gown and gloves for visitors. Only three hospitals (5%) reported providing “no gown and gloves” for both contact isolation and enteric isolation rooms.

Regarding age restrictions for visitors to each type of isolation room, age 12 was the most common minimum age for visiting restrictions for all types of isolation rooms. For the airborne isolation rooms, the respondents reported restricted ages of 6 (n=1), 12 (n=7), 16 (n=2), and 18 years (n=1). For the other types of isolation rooms (for droplet, contact, and enteric precautions), the restricted visiting ages were 0 (n=1), 12 (n=9; n=8 for enteric isolation rooms), and 16 years (n=1).
Overall, 71% of the hospitals (51/72 respondents to this question) answered affirmatively to having a hospital visitor policy for isolation precautions, including the use of PPE. However, 96% of the responding hospital IPs agreed that hospitals should have a visitor policy because visitors can transmit healthcare-associated pathogens in hospital settings. Only two hospital IPs disagreed with requiring visitors to comply with isolation precautions; for example, one IP stated that “until we have the evidence to support that visitors contribute HAIs, this is not a priority”. Importantly, only 14% of hospitals reported monitoring visitor compliance with precautions, with reported compliance rates ranging from “very low” to 97%. Three hospitals reported having different policies on gowning or gloving for adults and children because PPE designed for adult HCP may be too large for small children. Many hospitals (n=19, 28%) reported difficulty with implementing visitor isolation precautions policies, citing visitors’ hostility and refusal to comply. Non-compliant visitors were most often managed by nurses (n=64, 74%) and/or IPs (n=47, 57%). Eight hospitals (10%) reported using security personnel to help remove non-compliant visitors, and two hospitals reported excluding non-compliant guardians from visitation when they did not abide by hospital policies. Other approaches for handling non-compliant visitors were providing education, asking physicians to communicate with visitors, and inserting documentation in the patient’s chart. Nurses were considered critical for discouraging sick visitors from seeing patients and encouraging visitors to wear a surgical mask. Twenty-three hospitals (28%) handled sick visitors by excluding them from visitation. Only three hospitals used security personnel help to deal with sick visitors.

**Narrative responses to the open-ended questions.** All of the narrative responses fell into three main themes: need for/positive aspects of visitor policies for isolation precautions, difficulties/negative aspects of visitor policies, and suggestions (Figure 4.2). Although there were
many responses supporting hospital visitor policies on isolation precautions (positive aspects), these responses were thematically similar and could not be divided into subcategories. The responses that were categorized as negative aspects were classified into subcategories, such as visitors’ refusal to comply, hard to enforce, conflict with open visitation policy, no standard policy/lack of administrative support, and other. The responses that provided suggestions were sorted into subcategories, such as clear standard guidelines from authorities, administrative support, education, and need to focus on important aspects of isolation precautions.

![Figure 4.2. Summary overview for narrative responses on hospital visitor policy for isolation precautions](image)

Selected quotes from the IPs’ 158 narrative responses to the seven open-ended questions about visitor policies are summarized in Table 4.3. Across all narrative responses, no differences from a descriptive standpoint were observed; the responses were similar regardless of hospital size and teaching status.
Table 4.3.

Selected Quotes from Infection Preventionists about Hospital Visitor Policies for Isolation Precautions

1. Need for/positive aspects of visitor policies
   - “Visitors are free to move around the hospital outside the patient room and therefore can transfer pathogens to the environment.”
   - “For reasons of safety and liability.”
   - “To protect the visitors as well as the patients.”
   - “To reinforce the policies that healthcare workers utilize to prevent the transmission of infectious agents/organisms.”
   - “It gives them a feeling of security when you offer them PPE for their own protection.”

2. Difficulties/negative aspects of visitor policies

   **Visitors’ refusal to comply**
   - “Family members feel they already live with the ‘germ’”
   - “Family refused to wear PPE after education. ‘We do not wear anything at home, and we are not going to wear anything here.’ ‘We’ve been with them forever, so why do we need to do this? After all, we have already been exposed.’”
   - “Impossible. Some family members do what they want.”
   - “Hostility.”

   **Hard to enforce**
   - “We should encourage [it]; however, enforcement is another issue. Take a mother and baby, for instance: shouldn’t eat and drink in the room, but a gown and gloves all day? Not going to happen.”
   - “No legal recourse for handling noncompliant visitors.”
   - “Family members of extended-stay patients tend to be less compliant as time goes on.”
   - “Isolation precautions apply to all who enter the room. The problem is enforcement and patient satisfaction.”

   **Conflict with open visitation policy**
   - “With an open visitation policy, there is no one besides the nursing staff to encounter visitors, give education and request [that] they not visit.”
   - “We have an ‘open visitation’ policy, which was instituted to promote ‘family-centered care’. I have never liked this policy.”

   **No standard policy/lack of administrative support**
• “Policies vary depending on the department; some enforce, some don’t. [It is] very scattered and very inconsistent.”
• “Policies are inconsistent for visitors; we tell them to comply to prevent the spread to the hospital environment and the visitor, but it’s not clearly written that way in the policy.”
• “Hospital administrations are very worried about appearance and holding onto their market share, and this is a very unpopular topic with both patients and visitors.”

Other
• “It would be helpful to ensure that staff, MDs are compliant and then get the visitors to be compliant.”
• “Our gowns/gloves are too large for young children, so that population can’t wear them.”
• “No full-time staff to monitor [compliance].”

3. Suggestions

Clear standard guidelines from authorities
• “It would be helpful if the CDC made a recommendation about visitors. The public would comply if they knew this came from a credible organization and research.”
• “Regulations from DHHS would be good; something to back us up.”
• “Generic policy to fit all hospital sizes.”
• “It would be helpful if we had concrete information on this topic so we all were doing the same thing. [It is] difficult to enforce if not consistent from facility to facility.”
• “Sharing policy throughout the state.”
• “Would be great to have a state standard isolation practice for acute care so that we can all sing from the same page of music.”
• “I think our policy should state that the precaution applies to all entering the isolation room.”
• “A policy is worthless without teeth to back it up. Until there are clear guidelines, with some public health reinforcement, a policy would be useless”
• “Media campaigns regarding how to help loved ones while in the hospital. No one truly wants to make their loved ones sicker.”

Administrative support
• “Each facility has its own culture and handles the same situation in any number of ways that best suits that culture, so I feel if the administration supports the IP, then this will be what works in their facility.”
• “I think that noncompliant visitors should be excluded from visiting and if necessary trespassed [sic] from the property for refusal to follow our policies.”
• “The allowing of children under a certain age not to visit with patients on any precautions.”
• “Once hospital personnel are compliant, ask for support from administration.”

Education

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• “Educate as soon as they enter the facility by staff. Once up on the floors, the visitor might not see a nurse for awhile due to medication passes and other issues. If you set expectations early and educate prevention the right way, you can achieve higher compliance.”
• “I think visitors and families need more education. They don't take it seriously enough, even when stressing the importance of environmental cleaning and hand washing.”
• “A visitor-specific isolation DVD.”
• “We encourage visitation and therefore provide education in a positive manner, not excluding them from seeing their significant other.”

Concentration on the important parts of isolation precautions
• “Visitors don't do invasive tasks with our patient population as staff do, and if visiting from room to room, their transmission would be due to hands. If hand hygiene is performed upon entering and exiting the patient room, transmission of organisms from this environment is minimized. Until we have the evidence to support that visitors contribute to HAIs, this is not a priority.”
• “I think if they wash their hands, in most cases that is enough. If they are actually assisting with care of the patient, they may need a gown and gloves, but just sitting in the room, I think that is unnecessary”
• “I think it would be extremely difficult to totally enforce every visitor that enters our facility to comply with isolation precautions. I think we should concentrate more on airborne [and] droplet precautions and the importance of hand washing.”

Note. PPE = Personal protective equipment, MD = Medical doctor, CDC = Centers for Disease Control and Prevention, DHHS = Department of Health and Human Services, IP = Infection preventionist, HAI = Healthcare-associated infection

The IPs identified the following reasons that visitor policies on isolation precautions are needed: visitor’s potential transmission of pathogens; hospital safety and liability concerns; the reinforcement of hospital policies for HCP; and the feelings of security that arise from providing PPE for visitors. Many IPs pointed out the relationship between visitors’ mobility and the risk of pathogen transmission. For example, “Visitors may visit multiple patients at one time. Visitors also go to other areas of the hospital (gift shop, chapel, cafeteria), where they can contaminate surfaces”. The reported difficulties regarding the enforcement of visitor policies included: visitors’ refusal to comply, enforcement difficulties, conflict with an institution’s open visitation policy, the lack of a standard policy, and the lack of administrative support. One IP described one area of difficulty: “We face fights with visitors who refuse to comply often. Just this week,
we had visitors who insisted on using a shared patient bathroom, even though patient with whom it was being shared was on isolation for \textit{C. difficile}. [The] family member they were visiting now has \textit{C. difficile} at a long-term care facility”. The IPs’ suggestions for developing visitor policies in the future included the following: the need for clear standard guidelines from authorities (e.g., the CDC), the importance of administrative support, providing more education to visitors and HCP, and concentrating on the most important parts among many infection control practices (e.g., hand hygiene for visitors). The importance of standard guidelines was supported by the IPs in statements such as “Hospital administrations are very worried about appearance and holding onto their market share, and this is a very unpopular topic with both patients and visitors. Until there are clear guidelines, with some public health reinforcement, a policy would be useless” and “It would be helpful if we had concrete information on this topic so we all were doing the same thing. [It is] difficult to enforce if not consistent from facility to facility.”

\textbf{Discussion}

This survey found substantial variation in acute care hospitals’ policies for visitor use of PPE when entering patient isolation rooms. Our survey obtained a 68.4\% response rate, which was made possible by the long-term, established relationship between SPICE and the participating hospitals; without that relationship, there would have been no systematic method for contacting the IPs (Dillman, Smyth, & Christian, 2009). Although the 136 hospitals selected from the SPICE listserv was a convenience sample of North Carolina hospitals, we believe that there was no sampling error in this study because the SPICE listserv includes most of the hospitals in North Carolina.
However, to generalize the results of this study to other NC hospitals, we compared our sample hospitals to the non-respondent NC hospitals by matching hospital names with the individual hospital statistics for North Carolina from the American Hospital Directory\textsuperscript{®} (American Hospital Directory.com, 2012). For the 37 hospitals that were not included in our survey but were found on the NC hospital list, the proportions for each hospital size group were very similar to those of our studied hospitals: small, 64.8% (non-included hospitals) vs. 62% (included hospitals); medium, 21.6% vs. 22%; and large, 13.5% vs. 16% (Mantel-Haenszel chi-square test, $p=0.73$). The non-included hospitals were all non-teaching facilities. Thus, we believe our results from the 82 acute care hospitals surveyed are reasonably representative of hospitals in North Carolina.

The questionnaire itself as a survey instrument has several limitations that merit discussion. It is possible that the length of the survey (29 questions, estimated to take 10 to 30 minutes to complete) may have encouraged non-response given the substantial responsibilities of IPs, especially those from small- to medium-sized hospitals. The length of the survey may have resulted in reporting bias because IPs might have skipped questions or not completed open-ended description format questions due to their job demands or lack of willingness to respond. Research suggests that response rates may differ systematically between closed- and open-question formats. In particular, the non-response rate is usually higher for open-ended questions (Millar & Dillman, 2012). The use of an online survey request sent by email could have additional limitations. Survey requests delivered by email may be rejected by the security function of institutional email accounts or ignored by IPs due to job demands. We were able to monitor some of this information using email response-tracking functions and by noting returned emails. During the main survey phase, 8% of the selected hospitals’ spam-blocking software
rejected the survey request, and 45% of the selected hospital recipients did not open the survey request email during the main survey period.

We could not clearly separate PPE use for each category of isolation precautions in the survey questionnaire due to the lack of a supporting rationale to clearly separate each type of isolation precautions. In fact, the CDC guidelines for isolation precautions have changed greatly since the first publication of “Isolation Techniques for Use in Hospitals” in 1970 (Garner & Hospital Infection Control Practices Advisory Committee, 1996): diagnosis-driven, disease-specific and category-specific guidelines with seven categories (strict isolation, contact isolation, respiratory isolation, tuberculosis isolation, enteric precautions, drainage/secretion precautions, and blood/body fluid precautions) were published in 1983; universal precautions were recommended in 1987 due to increasing concerns about occupational exposure to HIV; body substance isolation (updated universal precautions) was recommended in 1988; standard precautions and transmission-based precautions were recommended in 1996; and the 1996 guideline was expanded to include respiratory etiquette in 2007 after the SARS epidemic, in response to increasing concern about pandemic influenza (Bowling et al., 2012). However, the use of terms indicating isolation precautions differ among hospitals, and some confusion among HCP remains as a result of changes in the guidelines (Bowling et al., 2012). Thus, we had to present multiple-choice options (“check all that apply”) for many questions to examine current visitor policies for isolation precautions across hospitals. Doing so may have contributed to the respondent burden and reduced the response rate in some systematic but unknown way.

In addition, we are unable to suggest a clear guideline or recommendation for visitor use of specific PPE for each isolation precaution category in clinical settings because no scientific evidence has shown that visitors should comply with isolation precautions in hospital settings the
same way as HCP. However, it is reasonable to require hospital visitors to comply with airborne precautions (e.g., for tuberculosis) and droplet precautions (e.g., for pertussis and influenza) to protect all visitors who are susceptible to these diseases. On the other hand, requirements that hospital visitors comply with contact precautions for MDR pathogens (e.g., MRSA and VRE) may need to be reassessed because it is questionable whether health visitors are vulnerable to these pathogens. However, it is recommended that visitors not move from one patient’s room to another’s because visitors can transmit HAI pathogens via touch to patients and hospital environments. In fact, the CDC recommends that visitors who enter the rooms of colonized/infected patients (e.g., those with MRSA) do not touch catheters or wound sites, that they maintain only casual contact with patients, and that they wash their hands when leaving a patient’s room (CDC, 2011).

Regarding the use of PPE by hospital visitors, some concerns arise; namely, its cost-effectiveness and its negative effects on patient satisfaction, such as their emotional well-being (Vinski et al., 2012). In addition, wearing masks could impair non-verbal communication, especially for pediatric patients (Beck et al., 2004). Nonetheless, PPE use provides potential benefit as a protective barrier (Puzniak, Leet, Mayfield, Kollef, & Mundy, 2002). For example, gowning decreased the risk of VRE acquisition (Puzniak et al., 2002), and gloving reduced the risk of sharps injury (Kinlin, Mittleman, Harris, Rubin, & Fisman, 2010). However, visitors’ compliance with gowning was reported to be low; therefore, more intensive efforts are needed to educate hospital visitors about the use of PPE (Manian & Ponzillo, 2007). Because many visitors actively provide care for their patients and frequently move around patients’ rooms and hospital clean areas, visitors who do not comply with hospital recommendations for isolation precautions may interfere with the prevention of HAIs in hospital settings. Furthermore, hospital visitors
should be protected from any HAI risk during their hospital visit. Thus, enhancing visitor’s compliance with isolation precautions through patients and visitor education may be an important area that hospitals should focus on, using an organizational approach rather than blaming individual compliance failures. Although the CDC recommends that visitors follow facilities’ visitor policies (CDC, 2011), there is no sufficient supporting evidence hospitals can use as a basis for determining optimal visitor policies for compliance with isolation precautions. To solve these challenges regarding visitor use of PPE, further studies are needed to inform hospital visitor policies for isolation precautions.

The strength of this survey study was the finding that regardless of hospital characteristics, there was substantial variation in hospital policies for visitor PPE use in North Carolina acute care hospitals. Regarding the related issue of visitor PPE use for isolation precautions, there were no descriptive differences in the survey responses, regardless of hospital size or teaching status.

Based on the narrative responses from frontline IPs who deal with everyday infection control issues in the hospitals, we developed a schema linking current difficulties to potential solutions for hospital visitor policies for isolation precautions (Figure 4.3). Taking the example of a visitor’s refusal to comply with isolation precautions and the hospital’s difficulty enforcing visitors’ compliance, potential solutions include clear standard guidelines from authorities (e.g., the CDC), hospital administration support to enforce this policy, education, and focusing on important aspects of isolation precautions.
As many IPs noted in our survey, the current problems associated with hospital visitor policies (e.g., low compliance rate, refusal to comply, and the use of different policies across departments or facilities) call for public awareness of the importance of visitors’ compliance with isolation precautions and for a standard guideline from authorities to back up each hospital’s efforts. In addition, further efforts are needed to address the lack of administrative support for the implementation of visitor policies and, in some hospitals, to eliminate the conflict between open visitation policy and isolation precautions.
REFERENCES


Feltovich, F., & Fabrey, L. J. (2010). The current practice of infection prevention as demonstrated by the practice analysis survey of the Certification Board of Infection


Appendix 4.1

Statewide Program in Infection Control and Epidemiology
Survey Questionnaire for Visitor Precautions Policy

Survey Introduction

Dear Infection Preventionists at NC Hospitals

Isolation precautions are recommended as an important intervention to prevent transmission of healthcare associated infections between patients and healthcare providers or others. However, the Centers for Disease Control and Prevention (CDC) guidelines regarding the use of personal protective equipment for visitors entering the room of a patient on isolation are unclear. The purpose of this survey is to learn about YOUR HOSPITAL’S current policy on management of visitors entering patient isolation rooms. We hope to gain a better understanding of the range of policies on visitor isolation being used across NC. For your information, this survey is part of a PhD dissertation under the mentorship of Dr. Barbara Mark at the School of Nursing, The University of North Carolina at Chapel Hill and Drs. William Rutala and David Weber at UNC Health Care.

Visitors are defined as non hospital persons visiting inpatients in their hospital rooms (e.g., family member, friend, and clergy).

Instructions: This survey will take less than 30 minutes. Please complete the survey to reflect your hospital policy and your experience/opinions as accurately as possible. Your response will be treated confidentially. This study has been approved by the UNC IRB. Please complete this survey by March 6, 2012.

If you have any question, please feel free to contact me at the address below.

Sincerely,
JaHyun Kang
BSN, MPH, CIC
PhD candidate, School of Nursing
314F Carrington Hall
Campus Box 7460
University of North Carolina at Chapel Hill
Chapel Hill, NC, 27599 7460
jhkang@email.unc.edu / 919 448 8484

PART A. Respondent Information

1. Name of person completing survey

2. Hospital role / Job title

3. Hospital name
4. Contact information
Telephone
Email

**PART B. Hospital Characteristics**

5. Number of licensed beds

6. Please check your hospital type (please check ALL that apply)
   - □ General/Acute care
   - □ Subspecialty (e.g., cancer, psychiatric)
   - □ Long term care
   - □ Other

7. Number of FULL TIME EQUIVALENT infection preventionists

8. Number of patients admitted to the hospital from January 1, 2011 to December 31, 2011.
   - ○ Do not know
   - ○ The number

**PART C. Isolation Room Characteristics**

9. Do you have inpatient airborne isolation room(s) (e.g., TB room)?
   - ○ Yes
   - ○ No
   - ○ Not applicable

10. Does your hospital post an isolation precautions sign on the door of isolation room?
    - ○ Yes (go to question 11)
    - ○ No (go to question 14)
    - ○ Not applicable (go to question 14)

11. What kind of isolation sign does your hospital have (please check ALL that apply)?
Airborne precautions (e.g., *Mycobacterium tuberculosis*)
Contact precautions (e.g., MRSA)
Droplet precautions (e.g., Influenza virus)
Enteric precautions (e.g., *Clostridium difficile*)
Immunocompromised precautions (e.g., neutropenic patient)
Other (please specify)

12. Do isolation precautions signs include instruction/information in English AND Spanish?
   ○ Yes
   ○ No
   ○ Not applicable

13. Do isolation precautions signs have visitor specific information included?
   ○ Yes
   ○ No
   ○ Not applicable

14. What other kind of infection control information for visitors, if any, does your hospital post (please check ALL that apply)?
   ○ Respiratory hygiene/cough etiquette (for cold symptoms)
   ○ Hand hygiene
   ○ None
   ○ Other (please specify)

15. Does your hospital provide education for visitors about isolation precautions?
   ○ No
   ○ Not applicable
   ○ Not sure
   ○ Yes (please describe)

16. If your hospital provides education for visitors, who usually teaches/provides that
information (please check ALL that apply)?

- Physician
- Nurse
- Infection preventionist
- Any of the above
- Not applicable

PART D. Hospital Policy for Visitors’ Isolation Precautions

17. Does your hospital have a policy for visitors entering patient isolation rooms?
   - Yes (go to question 19)
   - No (go to question 18)
   - Not applicable

18. Do you think a hospital should have policies to encourage visitors to comply with isolation precautions?
   - Yes
   - No
   - Not applicable

Why? (please provide your opinion)

19. Please check all categories for which your hospital has policies for visitors entering the 'AIRBORNE isolation room (e.g., Mycobacterium tuberculosis)'.

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No visitors under age of ( ) years
20. Please check all categories for which your hospital has policies for visitors entering the 'DROPLET isolation room (e.g., Influenza virus)'.

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<td>No visitors under age of ( ) years</td>
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21. Please check all categories for which your hospital has policies for visitors entering the 'CONTACT isolation room (e.g., MRSA, VRE)'.

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<td>No visitors under age of ( ) years</td>
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22. Please check all categories for which your hospital has policies for visitors entering the 'ENTERIC isolation room (e.g., C. difficile, norovirus)'.

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<td>N95 mask</td>
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<tr>
<td>No visitors under age of ( ) years</td>
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23. Does your hospital monitor compliance of visitors with isolation precautions?
   - ○ No
   - ○ Not applicable
   - ○ Yes (please provide the compliance rate (%) as measured in 2011)
24. Does your hospital have a different hospital policy on gowning or gloving for child visitors and adult visitors?
   ○ No
   ○ Not applicable
   ○ Yes (please describe)

25. Have you ever experienced any difficulty/issue/outbreak from visitors who entered the rooms of patients in isolation?
   ○ No
   ○ Not applicable
   ○ Yes (please share your experience)

26. How does your hospital handle non compliant visitors who are NOT guardians (e.g., parents of young children)? (please check ALL that apply)
   □ Discuss with nurse
   □ Discuss with infection preventionist
   □ Receive help from security team
   □ Excluded (don’t allow visiting)
   □ Other (please specify)

27. How does your hospital handle non compliant guardians (e.g., parent of young children)? (please check ALL that apply)
   □ Discuss with nurse
   □ Discuss with infection preventionist
   □ Receive help from security team
   □ Excluded (don’t allow visiting)
   □ Other (please specify)
28. What does your hospital do if a visitor is sick? (please check ALL that apply)

- [ ] Discuss with nurse
- [ ] Discuss with infection preventionist
- [ ] Receive help from security team
- [ ] Excluded (don't allow visiting)
- [ ] Other (please specify)

29. Do you have any ideas/suggestions to make an appropriate hospital policy for facilitating visitors' compliance with isolation precautions?

Thank you

Thank you for responding to this survey!
We will send you a copy of the results when available.
Appendix 4.2

Copy of the Survey Request Email (for the Main-Request Survey)

Subject line
Request for you to complete the SPICE Survey Questionnaire for Visitor Precautions Policy

Email content
Dear Infection Preventionists at NC Hospitals:

Could you please complete “the SPICE Survey Questionnaire for Visitor Precautions Policy” by March 6, 2012?

One response per facility will be enough. Duplicate response from the same facility will be fine.

You can access the survey at http://www.surveymonkey.com/s/ZJKYTRQ.

Isolation precautions are recommended as an important intervention to prevent transmission of healthcare-associated infections between patients and healthcare providers or others. However, the Centers for Disease Control and Prevention (CDC) guidelines regarding the use of personal protective equipment for visitors entering the room of a patient on isolation are unclear. The purpose of this survey is to learn about YOUR HOSPITAL’S current policy on management of visitors entering patient isolation rooms. We hope to gain a better understanding of the range of policies on visitor isolation being used across NC. For your information, this survey is part of PhD dissertation under the mentorship of Dr. Barbara Mark at the School of Nursing, The University of North Carolina at Chapel Hill and Drs. William Rutala and David Weber at UNC Health Care.
Visitors are defined as non-hospital persons visiting inpatients in their hospital rooms (e.g., family member, friend, and clergy).

**Instructions**: This survey will take less than 30 minutes. Please complete the survey to reflect your hospital policy and your experience/opinions as accurately as possible. Your response will be treated confidentially. This study has been approved by the UNC IRB. Please complete this survey by **March 6, 2012**.

If you have any question, please feel free to contact me at the address below.

Sincerely,

JaHyun Kang

BSN, MPH, CIC

PhD candidate, School of Nursing

314F Carrington Hall

Campus Box 7460

University of North Carolina at Chapel Hill

Chapel Hill, NC, 27599-7460

jhkang@email.unc.edu / 919-448-8484
CHAPTER 5

THE SYNTHESIS AND IMPLICATIONS OF STUDY FINDINGS:
HOSPITAL INFECTION CONTROL: A CONSTANT BATTLE AGAINST INVISIBLE HEALTHCARE-ASSOCIATED PATHOGENS

Background

As illustrated in Figure 1.2 in Chapter 1, healthcare-associated infections (HAIs) have multifactorial causes. HAIs result from multifactorial interactions (via transmission) between a healthcare-associated pathogen (the infectious agent) and a hospitalized patient (the susceptible host) within the hospital environment (Archibald, 2012; Ostrowsky, 2007). These three main components (transmission, infectious agent, and host), along with three additional components (reservoir, portal of exit and portal of entry) represent the “chain of HAIs” as illustrated in Figure 1.1 in Chapter 1 (Ostrowsky, 2007). Within hospital settings, exposure to a healthcare-associated pathogen, such as methicillin-resistant Staphylococcus aureus (MRSA), via a contaminated environment or a hospitalized patient serving as a reservoir is necessary, but is not enough to cause an HAI in a hospitalized patient who is a susceptible host (Archibald, 2012). HAIs cannot occur without complex interactions among additional contributing factors, including age, immune status, invasive device use, antibiotics usage, and multi-drug resistance (Archibald, 2012). Thus, some hospitalized patients develop HAIs and others do not, despite the same exposure to a hospital-associated pathogen, because the range of a patient’s (host’s) response can vary according to host defense mechanisms, such as specific immunity from vaccination or nonspecific immunity from such factors as bodily secretions and local inflammatory responses (Ostrowsky, 2007).
The hospital environment is very complicated and presents serious potential to cause harm, including the development of HAIs as adverse events (Nettleman et al., 2012). The delivery of healthcare is highly chaotic, in part because patient responses to therapeutic interventions are often unpredictable and because healthcare personnel (HCP) must multitask with frequent interruptions, creating the potential for such errors as skipping hand hygiene (Bartley & Olmsted, 2012). HAIs occur in almost every hospital setting. The more that HAI-contributing factors (e.g., aging patient population, severity of illness, invasive indwelling devices, and broad spectrum antibiotics) increase in hospital settings, the more hospitalized patients are at risk of acquiring HAIs (Nettleman et al., 2012). In addition, hospital infection control faces increasing demands from external sources, such as mandatory public reporting and financial constraints from third-party payers (e.g., the Centers for Medicare and Medicaid Services [CMS]’s non-reimbursement policy for hospital-acquired adverse events) to control HAIs. Given these complicated conditions in hospitals, effective infection control programs should include hospital-wide efforts and collaborations among multiple disciplines (Nettleman et al., 2012).

To assist hospitals in their efforts to prevent HAIs, the Centers for Disease Control and Prevention (CDC) and the Healthcare Infection Control Practices Advisory Committee (HICPAC) have published a variety of infection control guidelines based on scientific evidence (Umsheid et al., 2009). The most recent CDC/HICPAC isolation guidelines, the 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, recommend isolation precautions for HCPs in all healthcare settings (Siegel et al., 2007). Isolation precautions are a standard infection control practice that can simultaneously affect several components of the “chain of HAIs” and prevent the potential transmission of healthcare-
associated pathogens in hospital environments. The use of personal protective equipment (PPE), including such barrier precautions as gown, gloves, and mask, is an essential element of isolation precautions, as is the isolation of hospitalized patients who are infected with or colonized by a healthcare-associated pathogen. However, there is no scientific evidence to support isolation precaution guidelines, which are based on attacking a link in the “chain of HAIs” based on a known transmission route for pathogens (Nettleman et al., 2012). In addition, although active surveillance screening is recommended to identify patients who are infected with or colonized by important healthcare-associated pathogens (e.g., MRSA, vancomycin-resistant enterococci [VRE]) and contact precautions have been recommended, there is insufficient scientific evidence of a relationship between such recommendations and a decreased incidence of HAI by healthcare-associated pathogens (Pogorzelska, Stone, & Larson, 2012). Following the logic of isolation precautions, all persons who enter an isolated patient’s room should be required to comply with isolation precautions; however, no scientific evidence justifies extending isolation precautions to hospital visitors. In sum, infection control interventions should be logical, evidence-based approaches; however, sometimes consensus guidelines based on expert opinions have been used when there is no available scientific evidence to support the use of an intervention (Nettleman et al., 2012).

Information about the change in HAI incidence by pathogen through surveillance is useful because monitoring HAI incidence by pathogen may show that infection control measures (e.g., active surveillance screening upon hospital admission, isolation precautions) are effective (Allen-Bridson et al., 2012). In the case of HAIs, the identification of the healthcare-associated pathogen responsible for a patient’s HAI and an understanding of that pathogen’s characteristics (e.g., transmission mode, pathogenesis, and microbiology) are essential to implementing
appropriate infection control measures. Thus, this dissertation study aimed to examine three important HAI issues, including (Chapter 2) combined, extensive HAI incidence information by pathogen, by service, and by device-associated HAI based on hospital-wide surveillance data; (Chapter 3) a cost-effectiveness analysis comparing three alternative active surveillance screening strategies for MRSA (a healthcare-associated pathogen) using a modeling/simulation approach; and (Chapter 4) the range of hospitals policies governing visitors’ use of PPE when visiting patients on isolation precautions at the North Carolina state level.

Recapitulation of the Findings According to the Study Aims

Aim 1 (Chapter 2: The Changes in the Incidence of Healthcare-Associated Infections by pathogen at a University Hospital from 2005 to 2011)

Aim. This chapter aimed to examine the incidence of HAIs according to pathogen using hospital-wide surveillance data to describe the epidemiology of HAIs at a university hospital. Using the incidence density per 1,000 person-days (patient-days or device-days), the incidence change in HAIs by pathogen examined over time in the following categories: service (medicine, surgery, and pediatrics; intensive care units [ICU] vs. non-ICU); device-associated infections (central line-associated bloodstream infection [CLABSI], catheter-associated urinary tract infection [CAUTI], and ventilator-associated pneumonia [VAP]); and multidrug resistant (MDR) pathogens (MRSA, VRE, MDR Acinetobacter, and MDR Pseudomonas).

Findings. Over a 7-year period, 8,784 (87.2%) of the 10,070 HAIs at the hospital had at least 1 pathogen isolated. Because some of the HAIs had multiple pathogens, a total of 10,585 pathogens were isolated. Significant changes in the incidence rate of HAIs by healthcare-associated pathogen occurred from 2005 to 2011. However, among the top 10 pathogens, the
incidence of *Escherichia coli*, *Enterococcus* species, coagulase-negative staphylococci, *Candida* and other yeasts*, Enterobacter* species, and “other streptococci” decreased significantly, whereas the incidence of *Clostridium difficile* increased significantly per 1,000 patient-days. Overall, across all service categories, decreasing trends in the incidence rate of all pathogens except *C. difficile* were observed. All device-associated HAIs by pathogen, both overall and in each service category, showed significant decreases or no significant change in the incidence per 1,000 device-days. The incidence of specific pathogens decreased most in cases of CLABSI, less so for CAUTI, and least for VAP. Both overall HAIs and device-associated HAIs caused by the top 10 pathogens decreased over the study period, even though the number of patient-days increased significantly. Only *C. difficile* showed a significant increase in incidence, a finding that has also been reported in other recent HAI studies.

**Aim 2 (Chapter 3: Cost-Effectiveness Analysis of Active Surveillance Screening for Methicillin-Resistant Staphylococcus aureus in an Academic Hospital Setting)**

**Aim.** This chapter aimed to evaluate the cost-effectiveness of three alternative active screening strategies for MRSA in an academic hospital setting (from the hospital perspective) to detect MRSA-colonized patients who should be isolated with contact precautions upon hospital admission. The screening strategies were universal surveillance screening (USS) for all hospital admissions, targeted surveillance screening (TSS) for ICU admissions, and no surveillance screening (NSS). For academic hospitals with distinctive characteristics (e.g., acute care, more severely ill patients, and frequent transfer-ins from other facilities), a cost-effective analysis was conducted using a decision-tree model to determine the most cost-effective active surveillance screening strategy for MRSA. The issue of active surveillance screening for MRSA remains
controversial, as guidelines from the Society for Healthcare Epidemiology of America (SHEA) and HICPAC offer conflicting recommendations (Jackson, Jarvis, & Scheckler, 2004).

**Findings.** In the base-case, TSS was a dominant (i.e., less cost, better outcomes) strategy for preventing MRSA HAI. USS was associated with an incremental cost-effectiveness ratio of $14,955 per MRSA HAI. In the one-way sensitivity analysis, TSS was a dominant strategy across most ranges of parameters. Probabilistic sensitivity analysis also indicated that TSS was the most cost-effective strategy when willingness to pay to prevent a MRSA HAI was less than $94,750. Targeted active surveillance screening for MRSA is the most cost-effective screening strategy in an academic hospital setting. This finding supports current recommendations to use active surveillance to detect MRSA.

**Aim 3 (Chapter 4: Survey of North Carolina Hospital Policies Regarding Visitor Use of Personal Protective Equipment for Entering the Rooms of Patients on Isolation Precautions)**

**Aim.** Because there are no clear recommendations for hospital visitors, who could acquire healthcare-associated pathogens as susceptible hosts or could transmit these pathogens as reservoirs during their visit, this chapter explored the range of hospital policies for visitor use of personal protective equipment when entering the rooms of patients on isolation precautions because. Using an online survey of hospitals in North Carolina, we examined current hospital visitor policies related to isolation precautions and, based on lessons from infection preventionists (IPs)’ experience, suggested appropriate future policy directions, including difficulties with such policies and ideas for improving them.

**Findings.** Among 136 targeted hospitals, 93 hospitals (response rate: 68.4%) responded to our survey, and 82 acute care hospitals (60.3%) were included in the analyses (11 specialty
hospitals were excluded). Overall, 62% of the hospitals were small (<200 beds), and most (95%) were non-teaching facilities. Substantial variation was observed in the hospitals’ policies on visitors’ use of personal protective equipment when entering the rooms of patients on isolation precautions. However, there was no difference in hospitals’ visitor policies according to hospital size. Overall, 71% of the hospitals had a hospital visitor policy. Ninety-six percent of the responding IPs agreed that hospitals should have a visitor policy; however, only 14% of the hospitals monitored visitor compliance. The reported compliance rates varied from “very low” to 97%. Overall, 28% of the hospitals had experienced difficulties related to visitor compliance with isolation precautions, including hostility and refusal to comply. Our study results illuminated variations in hospitals’ policies regarding visitor isolation precautions. The current problems with hospital visitor policies (e.g., low compliance rates, refusal to comply, conflict with open visitation policies, lack of administrative support, and different policies across departments or facilities) call for a standard guideline and for increased public awareness of the importance of visitors’ compliance with isolation precautions.

**Strengths of the Dissertation**

This dissertation study has several strengths. Overall, it fills some gaps in HAI knowledge by examining HAIs on multiple levels, including healthcare-associated pathogens (the microscopic, infectious-agent level) to hospital infection control policy (the macroscopic, decision-making level) using three different types of studies: an epidemiologic study of the incidence change in HAIs by pathogen, a cost-effectiveness analysis (CEA) of active surveillance screening for MRSA, and a survey of hospital visitor policies for isolation precautions. Using a “chain of HAIs” conceptual model, this study examined HAIs from the
agent (the healthcare-associated pathogen) to the infection control measures that can interrupt the interactions (transmission) among agent, host, and environment at hospital level.

**Incidence study.** First, based on hospital-wide surveillance, this epidemiology study examined the incidence of HAIs by pathogen across the whole hospital and within several categories, including service-based and device-associated HAIs. Incidence studies usually address a single specific infection, such as CLABSI, within a specific hospital setting, such as the ICU, because most hospitals conduct target surveillance (e.g., ICU or surgical site infection [SSI]) based on their priorities within the limits of their infection control resources, such as the number of full-time equivalent IP. However, this study examined the incidence of HAIs by pathogen for each category of interest and provided many kinds of HAI incidence information across hospital categories. This study can be seen as a comprehensive summary of HAI incidences by pathogen. For example, CLABSI incidence information was provided for different service categories: overall, medicine, surgery, pediatrics, ICU, and non-ICU. This broad range of HAI incidence information (e.g., overall and for medicine, surgery, pediatrics, and non-ICU) was made available through hospital-wide surveillance; the ICU was selected for targeted surveillance because it had significantly more HAIs due to characteristics of its patients’ severity and need for intensive care.

Second, this incidence study provided HAI incidences broken down according to each pathogen group. We were able to examine the incidences of HAIs not just for the pathogens of greatest concern (e.g., MRSA, *C. difficile*), as is typically seen in publications, but also for every category and for all isolated healthcare-associated pathogens (e.g., *Escherichia coli*, *Enterobacter* species), information that is usually unavailable in the literature. Thus, this
incidence study is unique in that it provides pathogen-specific HAI incidence information across all ranges of healthcare-associated pathogens.

Third, this incidence study provided an adjusted incidence density using exact denominator information, such as patient-days and device-days (e.g., central-line days, Foley-catheter days, and ventilator days) for each analysis category (e.g., pediatrics, non-ICU) across hospital settings. Our results may be used as reference data for pathogen-categorized HAI incidence because, to our knowledge, very few studies have reported incidence density according to pathogen.

Fourth, this study provided information about both short-term incidence (e.g., 1 year) and changes in the incidence of HAIs by pathogen over the study periods (a 7-year analysis based on patient-days and a 6-year analysis based on device-days). This method allowed us to observe the increasing incidence of \textit{C. difficile}-associated HAIs and the significant decrease in the incidences of HAIs caused by other pathogens across analysis categories.

Fifth, to compare this incidence change with changes in the population at risk for HAIs, we also examined the trend in patient-days over the 7-year study period. Although the patient population at risk increased significantly during the study periods, we observed a decreasing trend in the incidence of HAIs caused by all pathogens except \textit{C. difficile}, as shown in Chapter 2, Table 2.1 and Figure 2.4.

Sixth, our incidence density study provided relative incidence difference information to help leaders understand the meaning of figures representing the estimated incidence changes in HAIs by pathogen per 1,000 person-days. Lastly, this study adds clinical support to recent HAI studies’ reports of a significant increase in \textit{C. difficile} and its emergence as a healthcare-associated pathogen in hospital settings.
Cost-effectiveness analysis. To our knowledge, this is the first cost-effectiveness study to compare alternative surveillance screening strategies (i.e., all hospitalized patients vs. ICU patients only vs. no screening) in the United States using a modeling approach. While expert groups disagree about whether MRSA control necessitates active surveillance screening (Jackson et al., 2004), our study provides evidence from a hospital perspective to support decisions about using an active surveillance strategy to screen patients for MRSA upon admission to academic hospital settings. In addition, this study compared three alternative strategies for active surveillance screening for MRSA using a modeling approach that included 1,000 simulations and a sensitivity analysis for variations in each input parameter. By adopting a modeling approach, we were able to avoid ethical concerns, such as negligence. If we had used an experimental study instead of modeling to obtain these data, we probably would have had to withhold active surveillance screening for patients in the control arm. Although active surveillance screening has not been proven to have a beneficial effect, it is assumed that it could reduce potential MRSA transmission to hospitalized patients.

Survey of hospital visitor policies. To our knowledge, this is the first study to examine hospital visitor policies related to implementing isolation precautions. This survey study found substantial variation in visitor PPE use policies among acute care hospitals in North Carolina. In addition, based on the narrative responses from frontline IPs, this study examined current problems with implementing isolation precaution policies for hospital visitors and provided IPs’ ideas and suggestions for solving current problems. In addition, by using the existing education and consultation program, the Statewide Program for Infection Control and Epidemiology (SPICE), we were able to achieve relatively high response rates (68.4%) to online surveys without providing incentives for responding.
Overall, this dissertation illustrated an infection-control connection. The study began with basic data-driven evidence based on an examination of the HAI incidence by each group of pathogen, then progressed to the proactive intervention of finding carriers upon their admission to the hospital and implementing immediate isolation precautions. The study then proceeded to examine further macroscopic hospital policy issues about PPE use for visitors of patients on isolation precautions under the current guidelines which do not require visitors to participate in isolation precautions. For example, MRSA has been the predominant pathogen of HAIs and has placed considerable burden on hospitals, including increasing mortality (Shorr, 2007). To prevent and control the transmission of MRSA, CDC guidelines recommend active surveillance screening of patients upon hospital admission and implementing contact precautions (Siegel et al., 2007). Although the incidence study (Chapter 2) and visitor policy survey (Chapter 4) examined MRSA as well as all other pathogens, the three topics of this dissertation study are connected via MRSA; they examine the incidence of HAIs by MRSA (Chapter 2), the use of active surveillance screening for MRSA carriers (Chapter 3), and hospital visitor policies for PPE use when visiting patients on contact precautions for MRSA (Chapter 4; Figure 5.1).
Figure 5.1 The connection of three chapters through MRSA. Note. HAI = Healthcare-associated infection; CEA = Cost-effectiveness analysis; MRSA = Methicillin-resistant Staphylococcus aureus; VRE = Vancomycin-resistant enterococci; MDR = Multidrug resistant.

Limitations of the Dissertation

Despite its many strengths, this study has some limitations.

**Incidence study.** First, the results of this study of HAI incidence by pathogen and the changes in HAI incidence may not be representative of all acute care university hospitals in the United States. Second, this incidence evidence is based on hospital-wide surveillance; therefore, it cannot be compared with incidence evidence from targeted surveillance (priority-based, usually site-directed [e.g., SSI] or unit-directed [e.g., ICU]), which is common at most hospitals, because surveillance studies that differ in their scope and approach cause variations in the sensitivity and specificity of HAI case findings (Allen-Bridson et al., 2012). For example,
targeted surveillance missed approximately 50% of HAIs that were found using hospital-wide surveillance (Weber et al., 2012). Third, although one of our study’s strengths was its ability to describe the magnitude of HAI incidence across hospital settings, we could not identify important HAI incidence differences that were caused by other factors, such as patient populations’ underlying diseases or changes in antimicrobial use. Lastly, we could not identify the exact infection control interventions that had decreased the incidence of HAI by most pathogens at the study hospital during the study period because the decrease in HAIs occurred across all study categories and throughout the hospital without any experimental trials of specific infection control measures.

**Cost-effectiveness study.** The main limitation of this study was the lack of reliable data for some key input parameters, such as the overall and relative effectiveness of active surveillance and isolation in either the ICU or non-ICU settings, and the relative prevalence difference of MRSA HAI between the ICU and non-ICU settings. Thus, we had to make assumptions based on clinical expertise; for example, the MRSA HAI rates in the non-ICU setting were lower than the rate in the ICU based on the fact that the likelihood of MRSA HAI is assumed to be higher among ICU patients. Therefore, the use of assumptions for key input parameters due to a lack of available data may limit the validity of the study results, as commonly occurs with model-based CEAs. In addition, the modeling techniques we used may limit the validity of the results. For example, we could not include MRSA mortality as our one of the end points of hospitalization in our decision tree model due to a lack of reliable MRSA HAI-attributable mortality data. This study also did not model transmission timing or transmission pathways because of the uncertain, complex transmission of MRSA from asymptomatic colonized patients. Lastly, these study results may not be applicable to small, community
hospital settings because active screening using polymerase chain reaction (PCR) is not feasible within small hospitals’ limited resources.

**Survey of hospital visitor policies.** This study has several limitations arising from the use of the questionnaire itself as a survey instrument. The length of the survey (29 questions estimated to take 10 to 30 minutes to complete) may have caused potential reporting bias, including nonresponse, given the substantial responsibilities of IPs, especially at small- to medium-sized hospitals. Online survey request by email could add reporting bias if the surveys are rejected by the security functions of institutional email accounts or are ignored by IPs due to their job demands. Second, we could not clearly separate PPE use for each category of isolation precautions in the survey questionnaire and had to provide multiple-choice options for many questions due to a lack of supporting evidence. Third, although we were able to report the IPs’ experience-based opinions about problems and possible solutions, we were unable to suggest specific recommendations supporting the need for visitors to use PPEs in the same way required of HCP due to a lack of sufficient scientific evidence indicating visitors’ behaviors and their role in the transmission of HAI pathogens in hospital settings.

**Implications for Research and Practice in Hospital Infection Control**

The findings of this study suggest several important implications for further research and for infection control practices in hospitals.

**The issue of the emerging healthcare-associated pathogen* Clostridium difficile***

We observed an increasing incidence of HAIs (gastrointestinal infections) by *C. difficile*, a finding that complemented similar reports from recent hospital epidemiology studies (Miller et al., 2011). *C. difficile* is becoming the most problematic healthcare-associated pathogen in
hospitals in the United States. Because *C. difficile* infection occurs with the disruption of normal intestinal microbiota after the use of broad spectrum antibiotics (e.g., clindamycin, cephalosporins, fluoroquinolones), antimicrobial restrictions to reduce exposure to antimicrobial therapy may be needed as more scientific supporting evidence emerges (Johnson & Gerding, 2012).

In addition, asymptomatic carriers (usually fecal excretors) of *C. difficile* can be a risk factor; therefore, further research on the role of active identification screening and immediate isolation for these carriers is required to control *C. difficile* in hospital settings. More research on environmental contamination by asymptomatic *C. difficile* carriers is also necessary because contamination of the room environment surfaces of patients infected with *C. difficile* (e.g., the bathroom, bed pans, and electronic thermometers) by *C. difficile* spores has been reported as a great source of risk for *C. difficile* transmission (Johnson & Gerding, 2012; Weber & Rutala, 2011). Nonetheless, much work is still needed to examine the role of asymptomatic carriers in *C. difficile* transmission and to establish more effective infection control recommendations (e.g., active surveillance screening upon hospital admission) in response to *C. difficile*’s emerging role as a major HAI pathogen.

In the current CDC guidelines, enteric precautions are not listed and all enteric pathogens including *C. difficile* should prompt use of contact precautions (Siegel et al., 2007). However, as our survey of hospital visitor policies showed, some hospitals have implemented enteric precautions to reinforce the use of contact precautions for *C. difficile*. Thus, further research is needed to determine the efficacy of enteric precautions instead of contact precautions, and the need for enteric precautions should be separated from contact precautions; for example, research
is needed to determine whether the use of enteric precautions can reduce the patient’s room contamination or the risk of HAI with *C. difficile* better than the use of contact precautions can.

**Active surveillance screening for important healthcare-associated pathogens**

In the Netherlands, a low incidence of MRSA was sustained for 5 years (2000-2004) using a thorough “search and destroy” policy (Vos et al., 2009). However, the implementation of active surveillance screening for MRSA in acute care hospitals in the United States is difficult because expert groups (SHEA and HICPAC) have provided different opinions about the need for screening, based on the fact that MRSA is already an endemic problem in hospitals (Shenoy, Walensky, Lee, Orcutt, & Hooper, 2012). Thus, more research is needed on other issues related to active surveillance screening that have not been clearly defined in the United States. Such issues include the identification of an appropriate target populations, the identification of microbiologic methods of active surveillance screening for MRSA, and the appropriate interval of active surveillance screening. In addition, although the CDC guideline includes decolonization recommendations for MRSA, the decolonization of MRSA in carriers’ nasal cavities using an antimicrobial agent (e.g., mupirocin) remains difficult to implement in hospital settings due to a lack of sufficient evidence to balance the emerging problem of a mupirocin-resistant MRSA strain with decontamination’s effects on reducing the transmission of MRSA (Siegel et al., 2007). Thus, further research should be conducted to solve these complicated problems related to preventing MRSA HAIs.

In fact, active surveillance screening is recommended for not only MRSA, but for other pathogens, such as VRE and MDR gram-negative bacilli (Siegel et al., 2007). However, there are significant variations in implementing screening methods for various MDR pathogens (Pogorzelska et al., 2012). Additionally, hospital infection control programs should have
adequate resources (e.g., financial support and staff to perform the screening) to implement active surveillance screening and to ensure that infection control measures are taken.

**The related issue of implementing isolation precautions**

Although CDC and HICPAC have provided guidelines for hospital infection control using isolation precautions, many unresolved issues remain and await further research. Implementing isolation precautions can reduce the transmission of not only one specific pathogen, but several pathogens that have the same transmission mode at the same time. However, the continuous implementation of isolation precautions does not always guarantee the prevention of transmission of healthcare-associated pathogens. In hospitals with a high prevalence of HAI, any intervention is likely to reduce HAI occurrences; however, the same intervention may be less effective in hospitals with a low prevalence of HAI. Therefore, the eradication of HAI may be more difficult or impossible in institutions with a low prevalence of HAI.

In addition, factors that contribute to individuals’ compliance with isolation precautions are not well studied. Although HCP are required to comply with isolation precautions, actual compliance rates in hospital settings are not high. According to a recent study, adherence to contact precautions in intensive care units (ICU) was significantly higher than it was in non-ICU settings, and adherence by patient care staff was better than adherence by other staff and visitors (Clock et al., 2010). The study reported the following adherence rates: for hand hygiene, 19.4% on room entry and 48.4% on room exit; 67.9% for wearing a gown and 77.1% for disposing of a gown; and 67.5% for wearing gloves and 63.5% for disposing of gloves (Clock et al., 2010). To examine factors underlying low compliance rates and to improve compliance with isolation precautions, further research on human behavior and environmental and organizational factors is
required. By extension, attention to the visitor’s role in the transmission and prevention of HAIs is needed because visitors can serve as facilitators or reservoirs of healthcare-associated pathogens.

In contrast, no recommendations are currently available for the discontinuation of isolation precautions (contact precautions). This lack of recommendations often presents a problem when hospitals must determine the timing of and standards for discontinuing isolation precautions without supporting guidelines or sufficient scientific evidence. According to a recent electronic survey of the Association for Professionals in Infection Control and Epidemiology (APIC) membership about hospital policy for discontinuing contact precautions, hospitals’ discontinuation policies vary in terms of the screening timing, method, intervals, sites sampled, number of samples, and off-antibiotics period prior to screening (Wright, 2012). In fact, a discontinuation policy is needed because hospitals maintain isolation precautions for the rehospitalization of patients with a previous history of isolation precautions, even though a substantial portion (e.g., 21%, according to a recent study) of patients no longer need contact precautions (Vikram et al., 2010). In addition, to reduce the unnecessary efforts and costs of contact precautions, further studies are needed to evaluate the economic outcomes of the duration of appropriate implementation of isolation precautions.

In sum, much more research is needed on issues related to isolation precautions, including cost issues, ethical issues, and practical issues related to the working conditions or characteristics of institutions (e.g., the organizational culture for patient safety and quality improvement), including behavioral discrepancies in acknowledging infection control principles and other human factors (e.g., getting lazy and forgetting) that underlie all kinds of medical errors.
Hospital-wide efforts for infection control

Many of the recommendations in the CDC’s infection control guidelines require a comprehensive approach at the organization level, including administrative involvement, to ensure that infection control measures are implemented and to prevent HAIs. Such an approach includes judicious use of antimicrobial agents, adequate nurse staffing, effective communication systems, and performance improvement efforts across hospital settings (Siegel et al., 2007).

Although we could not identify the exact infection control measures that might have induced the study hospital’s decreased incidence of HAIs by all pathogens except *C. difficile*, we could assume that these factors included a good long-term infection control program, continuous implementation of multiple infection control interventions, hospital-wide quality improvement initiatives based on the Six Sigma strategy, and an infection control liaison program across hospital settings. Further study is needed to provide data to support our speculation that these measures played a role in decreasing the incidence of HAIs. Although it seems strange to implement a production quality improvement concept that originated in manufacturing industries, the use of the Six Sigma concept in hospitals is aimed at creating a hospital culture of quality improvement at all levels. This quality improvement culture is achieved via purposely training healthcare teams to implement a rigorous Six Sigma methodology, which involves the steps of define, measure, analyze, improve, and control (Ruiz & Simón, 2012). In statistical terms, Six Sigma means only 3.4 defects per million; in other words, an error-free rate of 99.99966%, which is based on the concept that 99% error free with a 3.8 sigma level is not sufficient for patient safety in a hospital (Ruiz & Simón, 2012). For example, by adopting Six Sigma improvement process to identify possible causes of HAIs and change the problematic practices in the design of the infection control interventions, a recent study reported a significant reduction in
HAIs (CLABSI and VAP) and mortality rate in the pediatric ICU (Harris et al., 2011). Because effective communication is important in hospital infection control, infection control liaison nurses at each department can facilitate infection control practices in their departments by learning from IPs and taking away customized messages for specialized departmental infection control education needs (Hoffman & Clontz, 2012). Thus, adopting quality improvement concepts and a liaison program as additional approaches to enforce infection control measures at each department is expected to effectively prevent HAIs; however, this expectation needs to be supported with scientific evidence.

**New approaches for hospital infection control**

Of the HAI components that we examined through the “chain of HAIs” and related multifactorial interactions among agent, host, and hospital environment, many studies have examined pathogen-specific HAIs or environmental issues, such as outbreaks caused by the contamination of specific devices or environmental surfaces. It is true that those areas need more research because of their significance to HAIs and infection control. Although some research interests have focused on protecting HCP from acquiring HAIs through occupational exposure (e.g., hepatitis B infection after a sharps injury; Henderson & Beekman, 2012; Weber, Rutala, & Schaffner, 2010), relatively less attention has been paid to preventing HAIs by improving patients’ host defense mechanisms. Using another “see-saw model” concept of epidemiology for interactions between agent, host, and environment (see Figure 5.2), we may be able to prevent more HAIs by enhancing host defense mechanisms.
Some interventions to enhance the host defense mechanism and prevent HAIs can be found in the literature. Immunoprophylaxis, such as the intravenous administration of immunoglobulin, may help to reduce HAI incidence and provide an alternative approach to preventing HAIs in specific patient populations (e.g., surgical ICU patients), as some studies have reported (Black et al., 2012). As another example, selective decontamination to eradicate existing gram-negative pathogens in the digestive tract may serve as a prophylaxis for ventilator-associated pneumonia in ICU patients (Black et al., 2012). For the emerging problem of *C. difficile* as an HAI pathogen in hospital settings, fecal bacteriotherapy (also known as fecal transplantation) might help infection control efforts by facilitating the early termination of *C. difficile* infection. This treatment, which has no adverse effects and a high success rate, provides an effective intervention for *C. difficile*-associated diarrhea by restoring the normal intestinal microbiota (Guo, Harstall, Louie, Veldhuyzen van Zanten, & Dieleman, 2012). However, more...
research is needed to support the implementation of these interventions as a standard in clinical practice.

In the near future, economic evaluation and comparative effectiveness analysis may receive more attention in hospital epidemiology and infection control due to limited resources and the need to make comparisons among alternative infection control measures. To perform this economic analysis, more reliable data (e.g., incidence rate, mortality, and cost data) should be available for a range of HAIs and infection control issues. In general, hospital epidemiology researchers may not fully understand the policymaking process, and some researchers discourage the inclusion of policy recommendations in research reports without a supporting decision analysis that reflects complicated contexts or conditions (Abramson, 2012). However, without a frontline expert who understands the complex mechanism of HAI occurrence and infection control issues, economic evaluations would lose their value as decision-making tools for hospital infection control. Thus, more infection control professionals need to be trained in economic evaluation methods and comparative effectiveness research for the future of hospital infection control strategies.

**Conclusion**

This study examined three topics related to HAIs and infection control measures, ranging from HAI incidence to hospital policy. This study has several strengths and limitations, and it provides some important implications for research and clinical practice in hospital infection control.

As healthcare becomes more complicated with the use of increasingly advanced techniques involving invasive procedures, a more vulnerable patient population, and more
standards for high healthcare quality required by external factors (e.g., CMS’s non-reimbursement policy for hospital acquired adverse events, the Joint Commission [TJC]’s accreditation criteria), hospital infection control faces greater challenges. Although a zero-tolerance approach is desired for successful infection control interventions and some proportion of healthcare-associated infections is reasonably preventable, 100% HAI prevention is probably not achievable (Umscheid et al., 2011). As we reviewed, HAI causation is multifactorial; thus, some patients acquire HAIs during their hospitalization and some do not, depending on interactions among many factors related to the agent, transmission, and host. Every human has many endogenous microorganisms and any individual can be either a susceptible host or an intermediate transmission route of infectious agents as a reservoir. Thus, although we do our best to prevent 100% of HAIs in hospital settings, we may not be able to create the desired HAI-free hospital. However, the rigorous battle against invisible healthcare-associated pathogens should never stop. It is the duty of hospital infection control to protect patients from attacks by healthcare-associated pathogens by encouraging the collaboration of all HCP in the hospital.
REFERENCES


preventable and the related mortality and costs. *Infect Control Hosp Epidemiol*, 32(2), 101-114. doi: 10.1086/657912


Wright, P. J. (2012). *Contact precautions for MRSA/VRE: How and when should they be discontinued?* Paper presented at the APIC 39th Annual Educational Conference & International Meeting, San Antonio, TX.