Curr Infect Dis Rep (2016) 18: 16
DOI 10.1007/s11908-016-0523-z

Infection Prevention in the Hospital from Past to Present: Evolving Roles and Shifting Priorities

Michelle Doll[1] · **Angela L. Hewlett**[2] · **Gonzalo Bearman**[3]

Published online: 22 April 2016

Abstract Hospital epidemiologists are vital components of integrated health centers. This central place in the healthcare landscape has rapidly evolved over a half century. Early hospital epidemiologists possessed a visionary focus on patient safety many decades prior to the quality revolution of the 1990s. A systematic and scientific approach to infection prevention has facilitated the evolution of hospital epidemiology, along with advances in technology, and increasing public attention to infectious complications in the hospital. Currently, the growing expansion of tasks and moving regulatory targets strain existing resources. These challenges threaten to limit the effectiveness of some infection-prevention activities, while also providing important opportunities for improving care. It will be increasingly important to advocate for appropriate resources to address a diverse set of changing infection prevention priorities.

Keywords Hospital epidemiology · Healthcare-associated infection · Infection prevention · Infection preventionist · Infection control · Regulations

This article is part of the Topical Collection on *Healthcare Associated Infections*

✉ Michelle Doll
michelle.doll@vcuhealth.org

[1] Division of Infectious Disease, Virginia Commonwealth University Medical Center, 1300 East Marshall Street, P.O. Box 980019, Richmond, VA 23290-0019, USA

[2] Division of Infectious Diseases, University of Nebraska Medical Center, Omaha, NE 68198-3332, USA

[3] Division of Infectious Disease, Virginia Commonwealth University School of Medicine, Richmond, VA 23219, USA

Introduction: Evolution of the Hospital Epidemiologist

A multitude of factors have contributed over the last four decades to take us from the early days of formal infection prevention to the current model employed nationally today. The expanding role of infection prevention programs has been well documented in a variety of reports in terms of scope of activities, resource requirements, and accountability [1–3]. Extensive improvements in efficiency of surveillance, an increasing evidence base for infection prevention initiatives, and increased advanced training have facilitated the evolution of infection prevention activities over the years. The shift in paradigm from infection control to infection prevention reflects the increasingly proactive role programs are taking to meet institutional goals. Today's hospital epidemiologist faces a new set of challenges in the form of increasing reliance on information technology, regulatory expansion, implementation science, the business model for medical practice, as well as new responsibilities in emergency preparedness and antimicrobial stewardship (Table 1).

The Rise of Formal Infection Control Programs

Recommendations for formal infection control programs in the USA began after the 1958 National Conference on Staphylococcal Disease, convened to address a growing number of hospital-acquired staphylococcal outbreaks. The recommendations resulting from this meeting included the establishment of a multidisciplinary Hospital Infection Committee which would be responsible for surveillance and reporting of surveillance data, control of infection, and education regarding infection prevention [4]. However, scant infrastructure existed to implement these recommendations; as a result, a

Table 1 Expanding responsibilities of the hospital epidemiologist

Major issues	Responsibility description	Challenges	Opportunities
The science of infection prevention	Creating and interpreting the evidence base for infection prevention practices	Demonstrating benefit of overlapping interventions affecting relatively rare outcomes Limited research funding Limited time resources for scholarly pursuits	Cooperative spirit of hospital epidemiology conducive to research collaborations within and across institutions New areas of study that are expanding into the clinical setting (i.e., microbiome research) necessitating clinician participation
Implementation of best practices	Translating efficacy of reported interventions into effective provider practices	Human factors: social, behavioral aspects of the individual and the culture of an organization Practical work-flow obstacles	Unique perspective to provide expertise as clinician, infection expert, and administrator Implementation of new technologies to assist in infection prevention Development of bundled interventions and procedures specific to institutional needs
Mandatory reporting and regulations	Maintaining knowledge of and compliance with rules and regulations from various external sources	Regulations may have unintended consequences Regulations may not accomplish goals with greatest efficiency Efforts toward compliance may limit ability to accomplish other infection prevention goals	Increased overall attention to healthcare-associated infections Increased support for hospital epidemiology from healthcare center leadership in order to ensure regulatory compliance Potential for collaboration with governmental and regulatory bodies to assist in choosing appropriate target metrics
Emergency preparedness	Planning and implementing a program to prepare for potential infectious and non-infectious emergencies	Lack of dedicated resources to accomplish broad range of tasks	Hospital epidemiologist expertise is critical to the infection prevention aspects of the emergency plans, further adding value to the position Provides another rationale for demanding optimal baseline infection prevention practices
Antimicrobial stewardship	Promotion of appropriate usage of antimicrobials in order to improve patient safety and decrease drug resistant pathogens and *Clostridium difficile*	Absence of standardized comparative metrics Significant time commitment for prescription review and interventions	Opportunities for research and collaboration with other disciplines such as pharmacy and microbiology Potential to create new interest in infectious disease as a specialty
The business model of infection prevention	Performing multiple infection prevention-related services for the institution, providing staff and trainee education, while maintaining a financially productive clinical schedule	Relative value unit (RVU) system limits quality efforts by promoting volume over value, may potentially compete with work effort of non-reimbursed infection prevention activities	Hospital epidemiologists have the ability to self-advocate for additional resources for non-clinical tasks Potential for involvement in healthcare policy due to unique perspectives as clinician, educator, and administrator

minority of hospitals voluntarily set up programs of varying scope through the 1960s. Surveillance methods varied; some reported ward evaluation of each patient and others reviewed each positive microbiology result [5, 6••, 7, 8]. These labor-intensive activities were initially performed in the absence of published data to support a link between surveillance and decreased hospital-acquired infections. Although the National Nosocomial Infections Study was established by the Centers for Disease Control (CDC) in 1969, and had grown to include 80 hospitals by 1975 [9], the landmark Study on the Efficacy of Nosocomial Infection Control (SENIC) results were not published until a decade later in 1985. This report offered the first comprehensive estimate of the national burden of hospital-acquired infection and provided evidence supporting surveillance as key to prevention. The SENIC study compared 500 patient records from 1970 with 500 patient records from 1975 for hospital-acquired infections from all participating hospitals [6••]. The study team then compared infection rates to the level of infection prevention program that had been established at each institution between 1970 and 1975. SENIC found that those programs with essential components of a dedicated physician hospital

epidemiologist, one infection prevention nurse for every 250 beds, feedback of infection rates to surgeons, and organized surveillance and control activities reduced infection rates over the time period by 32 %; however, given that few hospitals had developed this level of program, the overall national estimate of prevented infections was only 6 %. Of note, those hospitals without any infection prevention activities saw an increase of 18 % in infection rates [10].

Surveillance Activities

Surveillance remains a core infection prevention activity, yet the manner in which it is performed has changed significantly. Early surveillance was characterized by individual patient chart review or individual microbiology lab specimen review [5]. In addition, many programs performed extensive environmental sampling [11]. In the early 1970s, routine environmental sampling was questioned and ultimately recommendations were made against this practice. The American Hospital Association's Committee on Infections Within Hospitals published a statement attempting to draw the focus back to patient data, citing "no evidence that routine environmental sampling is necessary to maintain good practices in the hospital, nor is there evidence that this type of routine sampling has contributed significantly to the prevention of nosocomial infection." They further argued that routine sampling, "done with no epidemiologic goal in mind is unnecessary and economically unjustifiable" [12]. A nationwide survey of infection prevention practices by the CDC in 1976 revealed a shift away from environmental culturing coupled with an increase in other surveillance activities [6••]. Yet even without culturing the environment, early infection prevention programs had plenty of recommended surveillance tasks to accomplish. In the early 1970s, the CDC was calling for infection control practitioners to conduct daily review of microbiology laboratory reports and chart review for positive cultures, daily ward rounds, and chart review for any patient with fever, antibiotics, isolation requirements, or "special treatments," and to consider additional activities such as review of autopsy reports, and follow up on discharged patients [13]. Meanwhile, a surveillance system based on patient risk factors and procedures was developed in Charlottesville, VA and expanded to be the first state-wide surveillance system by 1974 [14••]. The approach used in Virginia recognized early that chart by chart review in their 500-bed hospital would not be a feasible long-term enterprise. Instead, they developed a "Kardex System" in which a daily or weekly review of a card containing the nursing plan of care for each patient was reviewed for high-risk conditions or procedures. The Kardex contained patient diagnoses, procedures, and any special care needs. Patients found to be at risk due to specific diagnoses or procedures on the Kardex were the focus of surveillance efforts. In an arduous validation effort, the "Kardex System" was compared to the individual review of each chart and found to be >80 % accurate in detecting hospital infections. In addition, the risk-based method was more accurate in detecting infection compared to case detection by microbiology laboratory reports [15]. Eventually, a combination of risk-based and microbiology lab-based surveillance was adopted nationally and remains the model employed today for both internal audits and reporting to the National Healthcare Safety Network (NHSN).

Information Technology

The widespread use of electronic medical records and increasing sophistication of information technology has broadened the scope of infection prevention. One of the first hospitals to employ electronic surveillance for healthcare-associated infections (HAIs) was Latter Day Saints (LDS) Hospital in Utah. Computerized surveillance to capture cases based on microbiology reports was initiated at LDS in 1984, and found to be more effective and efficient than manual review of patient data [16]. In 2009, this group published an update of their 25-year experience with computerized surveillance. Central to their success has been a strong collaboration between medical informaticists with clinical knowledge, and clinical ownership of the electronic surveillance system by infection prevention. The authors highlight the need for periodic review and redesign of the system to meet evolving surveillance tasks and assert that every user of the system must understand where and how the data elements are saved [17].

In recognition of the growing dependence on technology support for infection prevention activities, the Society for Healthcare Epidemiology of America (SHEA) published a set of data requirements for electronic surveillance. In this report, they outlined the discrete elements required for NHSN-related surveillance. The authors support the push toward more and more automation not only for efficiency, but also for standardization of reporting, as manual chart review and individual judgment are subject to documentation variability and biases [18]. However, there are needs for clinical information beyond reporting requirements. In efforts to improve the processes of care that lead to HAI, a more in-depth review of patient records is often required. Thus, the tension between how much information could be useful to drive practice change and the costs of those efforts continues to challenge infection prevention programs.

Evidenced-Based Prevention

Once practical, useful surveillance methods were developed and enacted in hospitals in the 1970s and 1980s, the accumulated data began to inform specific prevention efforts.

Incidence, prevalence, and outbreak reports became the basis for risk-factor identification, and finally targeted interventions were explored to improve patient safety (personal communication, Richard Wenzel). Professional organizations and scientific journals focused on infection prevention played an important role in establishing an evidence-based field. In 1972, the Association for Practitioners in Infection Control (APIC) was the first professional organization to support early infection prevention programs. The organization was created to address a need voiced by participants at the CDC's infection prevention training courses for better communication and support of individual hospital programs. APIC's original mission was to "unite healthcare workers of all disciplines who share the common goal of improving patient care through infection control activities," seeking to achieve this through, "enhanced communication…education…and standardized techniques." [19] The organization published guidance in the form of a newsletter from 1973 to 1977, then as the APIC Journal from 1978 to 1981, and finally the American Journal of Infection Control since 1980 [20]. Similarly, the Society for Hospital Epidemiology of America (SHEA) was founded in 1980 by a group of physicians to achieve increased visibility and credibility for the fresh field of hospital epidemiology (personal communication, Richard Wenzel). SHEA also began publishing a journal titled Infection Control in 1980; this journal later became Infection Control and Hospital Epidemiology in 1987 [20].

Research in infection prevention has been heavily supported by industry over the years, a situation that produces both opportunity in the form of resource support and limitations in the quality and reliability of resulting studies. The body of early infection prevention literature is replete with single-center observational studies and outbreak investigations. More recently, there has been a call to improve infection prevention research with more robust study designs and multicenter collaborations. For example, an Agency for Healthcare Research and Quality (AHRQ) Systematic Review of process interventions to prevent several types of HAIs found the bulk of the data came from single-center, quasi-experimental studies; the authors expressed an "urgent" need for higher quality studies to inform infection prevention initiatives [21•]. However, delivering large-scale collaborative projects will remain a significant challenge for today's hospital epidemiologist given limited time for academic pursuits. Nevertheless, a growing global interest in healthcare quality and infection prevention may result in additional funds to spur well-organized collaborations into action. Data from the UK from 1997 to 2010 suggests a substantial increase in the amount of funding for HAI prevention. The majority of initial funding was dedicated to implementation projects. However, the authors noted a growing portion of preclinical studies sharing funds, particularly projects aimed at antimicrobial resistance and rapid diagnostics [22]. Furthermore, the field of microbiome research poises itself to expand outside of basic science and into clinical applications, such as infection prevention.

In the midst of an exciting era for infection prevention research, there is a growing realization that the evidence itself is not enough. Infection prevention has become an implementation science in which evaluation of interventions is paramount to sustainability of successful programs. Thus, implementation of evidence-based practices is a critical modern element of infection prevention programs. Hospital epidemiologists must provide expertise not only in relation to the evidence base, but also must be able to demonstrate an intricate knowledge of social behavioral determinants of institutional culture and the structural elements of an organization that will contribute to prevention failures or successes. Tools in the forms of checklists and bundles have been developed to consolidate multiple infection prevention techniques into a format easily practiced by providers. Application of implementation science to infection prevention will further infection prevention practice, and various regional, national, and international groups are already working to identify the fundamental components of successful implementation [23].

Regulatory Expansion

The past 10–15 years have witnessed a widespread expansion in the regulatory standards related to patient safety. Regulation of infection prevention in hospitals has evolved with infection prevention programs since the late 1960s [24]. Even before the effectiveness of surveillance and infection prevention programs in improving patient outcomes was established, the CDC and AHA were making recommendations on infection control program structure and practices [12, 13]. In contrast to the voluntary recommendations made by CDC and AHA, the Joint Commission on Accreditation of Hospitals (JCAH, now the Joint Commission on Accreditation of Healthcare Organizations, JCAHO) established requirements that had implications for Medicare participation. JCAH's initial standards for infection control were mostly structural requirements for the program that were meant to be minimum criteria feasible for all hospitals to meet [24]. However, in 1976, JCAH revised their infection prevention standards to include specific infection prevention tasks as well as the components that a comprehensive infection prevention program should have in order to complete these tasks [25].

Over the years, as more regulatory bodies took an interest in hospital-acquired infections, and as the data supporting specific practices accumulated, the quantity of regulatory requirements has increased in scope. In parallel, the tasks required of infection prevention professionals has greatly expanded. In the first Infection Control Practice Analysis performed by APIC in 1981, the number of discrete tasks reported by professionals

surveyed was 60; by 2009, this number had risen to 147 [2]. More recent versions of this survey incorporated a task list condensed by the investigators, rather than eliciting tasks directly from survey participants [26]. Hospital epidemiologists have experienced a similar explosion of tasks; in a 2013 survey of the SHEA Research Network, participants anticipated increasing program focus in a number of areas, particularly surveillance for multidrug-resistant gram-negative rods, antimicrobial stewardship, surgical site infection and related interventions, and environmental cleaning [27].

Guidelines, recommendations, and regulations have become a double-edged sword for hospital epidemiologists. On one hand, public attention, mandatory reporting, and reimbursement implications for HAIs have prompted healthcare administrators to devote resources to infection prevention in many institutions. Furthermore, evidence-based guidance to support decisions and implementation is paramount to maintaining the credibility of an infection prevention program. However, complications arise when there is an abundance of recommendations and regulations from stakeholders with differing underlying agendas. This is especially problematic when the infection prevention practice itself is controversial, as demonstrated by the debates surrounding mandated MRSA/VRE surveillance and isolation in 2007 [28–30].

Even mandates with good supporting evidence have the potential for adverse consequences; this is particularly a risk when regulators fail to anticipate the behavior of complex healthcare systems. An example is the controversy that surrounded time to antibiotic administration in the emergency room in the early 2000s. Patients with infections have better outcomes with timely antibiotic therapy, and delays in antibiotic administration have been documented to have mortality consequences [31]. However, when JCAHO and Centers for Medicare and Medicaid Services (CMS) set standards requiring antibiotic administration within 4 h of presentation to the emergency room in 2004, significant concerns regarding this standard leading to misdiagnosis and overuse of antibiotics surfaced [32]. What followed was a prolonged debate around antibiotic timing and eventual concessions on both sides that perhaps early antibiotic therapy, while essential for good patient care, is not the best quality measure for regulators to demand.

The ultimate goal of regulatory bodies as well as infection prevention programs is reducing the number of HAIs. Yet focusing directly on these outcome measures in regulatory attempts has also been controversial, similar to process measure regulations. Mandatory public reporting is one example. Starting with Illinois in 2003, mandatory state reporting of various HAIs has increased to include the majority of states [33]. Efforts to promote public transparency and to compel healthcare systems to improve HAI rates have resulted in availability of much of this data to the public. However, there is a lack of data to suggest that the collection and release of this information has improved HAI rates nationally [34, 35]. One reason may be a lack of resources for additional improvement efforts. In a 2011 survey of the SHEA Research Network, Linkin et al. found that there was no difference in perceived process measure improvement or infection rate outcomes between participants in states with and without public reporting. Participants also noted a perceived lack of time and resources for implementation of preventive measures [36]. In contrast, the multicenter Comprehensive Unit-based Safety Program for Central Line-Associated Blood Stream Infection (CUSP-BSI) found increased rates of participation and decreased rates of central line-associated blood stream infections (CLABSI) in ICUs from states with public reporting compared to those with no reporting requirements [37]. Perhaps the additional resources provided by that initiative to participant ICUs was a key element in an effective response to external pressures of reporting. In addition to resource considerations, public reporting benefits may be limited by an inability to use the provided information to improve consumer choices and safety. Many have noted flaws in public reporting's underlying assumptions including data accuracy and comparability, public ability to understand and use data, and limited public choice in where and when to receive healthcare [38]. These assumptions remain questionable in our current healthcare system.

Another example of regulatory focus on outcomes is the CMS's non-repayment policy for services complicated by certain HAIs. Although enacted in 2008, the effects of this policy on targeted HAI rates remain unclear, with some studies showing benefit [39] and others no benefit [40, 41]. Some of the discrepancy has been attributed to already declining rates for some HAIs such as CLABSI pre-policy enactment [40]. Financially punitive policies raise concerns regarding inappropriate changes in clinical practice to avoid penalties, such as both over-ordering tests to rule out infection on admission and under-ordering tests to avoid lab-documented infection during an admission [42]. Fortunately, data suggests that such "gaming" attempts are not widespread practices [43]. A more substantiated concern may be that focusing on a few conditions chosen by regulators may compromise other infection prevention opportunities [42, 44]. As one physician unit director and infection prevention champion observed during the course of an Infection Control Committee Meeting, "It's kind of like whacka-mole; the minute you have a handle on one issue, another one pops up" (Daniel Herr, oral communication). Infection prevention programs must maintain the flexibility to set priorities appropriate for the unique problems and cultural context of their respective institutions; too many imposed regulations threaten this ability to adapt in a complex healthcare system. Thus, an additional role for regional and national infection prevention professional organizations has become advocacy and policy, in efforts to ensure that regulatory decisions are based on the best evidence and advice possible.

Emergency Preparedness

Involvement of hospital epidemiologists in emergency preparedness represents an expansion outside of the healthcare system and into the realm of general public health. State and local health departments have traditionally been the groups charged with the public health aspects of emergency planning, receiving dedicated resources for these efforts [45]. However, the recognition that communicable disease emergencies would likely first seek treatment in a healthcare center and that hospitals would be charged with the safe and effective care of these patients has led to greater involvement of individual hospitals in preparedness efforts.

Emergency preparedness in the hospital is a multidisciplinary collaboration of extremely committed individuals attempting to plan for a wide array of scenarios involving both infectious and non-infectious causes. Infectious disease transmission remains a serious consideration in managing even non-infectious events due to the limited surge capacity of our already maximized healthcare systems [46]. Hospital epidemiologists and infection preventionists are an integral part of emergency preparedness teams due to their expertise in both infectious diseases and epidemiology. The expectation that all healthcare centers are somewhat prepared for infectious disease emergencies was put to the test during the Ebola outbreak in 2014, when it was widely recognized that there were many deficiencies in facility preparedness. This lack of preparedness is partly due to the discrepancy between the ambitious list of tasks [46] necessary to achieve preparedness and the resources provided to do so. Even after many tertiary care centers invested extensively in the facilities required to care for patients with highly infectious diseases like Ebola, the human resources to work in these environments is largely volunteer and not specifically compensated. This makes maintaining commitment to ongoing intensive training and program development a significant challenge. In addition, preparation for continuously shifting public health threats requires ongoing review and adaption of procedures and protocols, which is often an arduous task requiring a significant time commitment. The allotment of both financial and time support for individuals in Infection Control charged with these activities is imperative in order to facilitate the development and maintenance of effective hospital preparedness programs.

While presenting substantial challenges for hospital epidemiologists, emergency preparedness efforts also provide opportunities to stress the importance of a baseline infection prevention excellence. As noted by Ippolito et al., "All healthcare workers have the responsibility to ensure that their clinical practice prevents transmission of infection, and puts neither their own health, nor that of their patients, coworkers, or others at risk." They point out that complacency is problematic not only for general patient and staff safety but also leaves us more vulnerable to infectious disease emergency events [47]. Thus, in addition to specialized protocols for various emergency scenarios, emergency preparedness should include an ongoing assessment of readiness in terms of basic infection prevention procedures including standard and contact precautions, and staff proficiency in these areas should be an ongoing focus at the institution level.

Antimicrobial Stewardship: Old Problems and New Efforts

Multidrug-resistant organisms and antimicrobial overuse have been areas of interest for hospital epidemiologists from the beginning of formal infection prevention programs. Control of the spread of drug-resistant organisms is an obvious priority for infection prevention, and prevention efforts in the form of antimicrobial usage review and/or restriction are not new strategies [48, 49]. However, over the last two decades, the field of Antimicrobial Stewardship has exhibited explosive growth both nationally and internationally. Intensified efforts to standardize usage data and metrics for meaningful interventions are bringing the discipline closer to the ultimate goal of decreasing antimicrobial resistance within healthcare institutions. Antimicrobial stewardship programs are not necessarily housed within the infection prevention program, nor do the programs always involve hospital epidemiologists. However, hospital epidemiologists are uniquely suited to assist in the data collection and analysis necessary for antibiotic usage review. In addition, many of the skills required for providing tactful feedback and education to colleagues are similar to those practiced in other areas of infection prevention.

There are several parallels that can be drawn between early hospital-acquired infection surveillance and the antimicrobial usage reviews in operation today. Challenges of generalizability of data, comparability between institutions, and uncertainty regarding best metrics limit the evaluation of Antimicrobial Stewardship Programs to determine most effective practices. Furthermore, the lack of information technology infrastructure to accomplish tasks puts significant strains on healthcare institutions and the individuals charged with the operation of the Antimicrobial Stewardship Program. However, a shift has already been noted in the evidence base to support Antimicrobial Stewardship. When the Cochrane Collaboration initially systematically reviewed the effectiveness of antimicrobial stewardship programs in 2005 [50], they found a disappointing focus on process measures as opposed to patient-centered outcomes in most of the published literature. However, by 2013 when the group updated their review, they identified growing evidence of clinical benefits derived from Antimicrobial Stewardship interventions. Of note, their included, well-designed studies represented a minority of reports from a literature still dominated by studies of sub-optimal quality [51•]. Thus, there is opportunity along with the challenges in defining

optimal methods for reviewing, reporting, and changing provider prescribing practices. As governmental bodies are increasingly eager to mandate Antimicrobial Stewardship Programs in various healthcare settings [52–54], good evidence to inform program practices is urgently needed.

The Business of Medicine and Infection Prevention

The effects of applying a business model to medicine are long-reaching and have been lamented by medical professionals as well as health policy analysts. Relative value unit (RVU) systems of physician recognition and procedure based reimbursement puts financial incentives firmly on volume and at odds with quality. The Institute of Medicine published recommendations for restructuring of the healthcare system around quality, specifically calling for a more responsive healthcare system that provides patient access via phone or internet in addition to in-person visits, customized care and shared decision making, as well as communication and collaboration between physicians [55]. Yet all of these tasks, while loosely expected by a healthcare institution, depend on the provider's diligence to complete them in "spare time," after finishing with the long line of physically present (and billable) patients. Furthermore, the assembly line approach to patient care promotes error, discourages independent thought, and creates waste in the form of unnecessary tests and procedures.

Application of RVU systems to academic medicine resulted in a substantial culture shift: suddenly, focus was placed on just one of the many tasks academic physicians were charged to perform. While once thought to be integral to academic medicine, tasks such as teaching or scholarly activity became secondary considerations for providers who are neither compensated nor receiving "protected time" for these activities [56]. The long-term effects of this shift in valued activities have yet to be fully discerned, with the newer generations of providers training in a very different environment compared to their predecessors.

Hospital epidemiologists are specifically affected by the business model in a variety of ways. First, like the traditional academic physician, most hospital epidemiologists are responsible for a variety of job functions, and similar to academia in general, few of these tasks are actually compensated. For example, in a 2006 survey of SHEA members, only 65 % were compensated for providing general hospital infection prevention expertise. When asked about related tasks such as antimicrobial stewardship, employee health, emergency preparedness, and patient safety, the group receiving compensation for services fell to 25 % [1]. Secondly, the collaborative, safety focused environment essential to implementation of infection prevention and other patient safety initiatives is at odds with an RVU-based system. It becomes a significant imposition to even request meetings with colleagues for feedback and discussion of infection rates, much less depend on them for thorough case review and participation in performance improvement. Yet the commitment of frontline providers to shared infection prevention goals is essential. The ability of frontline staff to implement programs that produce sustained decreases in hospital-acquired bloodstream infections on a large scale was well documented by Pronovost et al. in their multi-ICU study partially funded by AHRQ. However, in this study, hospital administrators were not only committed to the initiative by declarations of support, they also allowed providers to devote 20 % of their time to project activities. The authors note that administrative decisions to continue in the program may have been impacted by insurer incentive payments for decreased bloodstream infections occurring simultaneously [57]. Adoption of this model may not be feasible in other settings; in fact, even in the study, several institutions declined participation in the longitudinal portion of the study that evaluated sustainability. Since implementation of infection prevention initiatives remains one of the biggest challenges faced by hospital epidemiologists and infection prevention programs, a careful re-evaluation of the business of medicine is required. If the work of hospital epidemiologists and infection preventionists is not assigned a concrete value, such as protected time, without significant expectation of RVU generation or financial and non-monetary program support resources, sustained commitment to infection prevention will be challenging. With the changing scope of hospital infection prevention programs, a critical reassessment of needed resources is long overdue. This includes defining the necessary monies and support for hospital epidemiologists, infection preventionists and related program elements such data collection, information technology, antimicrobial stewardship, emergency preparedness, mandatory public reporting, and responding to all relevant regulatory commitments.

Conclusion: Perpetual Challenges and Future Opportunities

Over the last four decades, hospital epidemiology has evolved significantly. There has been a shift from the descriptive and analytic approach of infection *control* toward a more proactive interventional approach in infection *prevention.* The evolution has been propelled by the increasing strength in the science to support infection prevention practices, which in turn has expanded the responsibilities for hospital epidemiologists. Implementation science is seen as increasingly important and relevant to infection prevention. Bundled approaches to infection prevention best practices have improved outcomes. Regulatory mandates have added to the scope of infection prevention programs, at times with questionable benefit.

Threats of multidrug-resistant organisms and public health emergencies have exposed the need for more robust

antimicrobial stewardship and collaborative emergency preparedness. While these threats are not new, the coordinated effort to effectively manage them at the national, regional, and institution level is a step beyond previous sporadic and isolated attention. Lastly, financial pressures such as RVU generation are likely to compete with the expanding roles and expectations of physician-epidemiologists thereby underscoring the need to formally protect the time and effort of infection prevention.

In facing the challenges of a changing healthcare landscape, there will also be great opportunities for hospital epidemiologists. The diversity of roles and skill sets required present a new standard for infection prevention, one that, when met with the appropriate resources, collaborations, and rigor, can significantly enhance and improve patient safety in the modern healthcare facility.

Compliance with Ethical Standards

Conflict of Interest Drs Doll, Hewlett, and Bearman declare they have no conflicts of interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Wright SB, Ostrowsky B, Fishman N, Deloney VM, Mermel L, Perl TM. Expanding roles of healthcare epidemiology and infection control in spite of limited resources and compensation. Infect Control Hosp Epidemiol. 2010;31:127–32.
2. Goldrick BA. The practice of infection control and applied epidemiology: a historical perspective. Am J Infect Control. 2005;33:493–500.
3. Sydnor ER, Perl TM. Hospital epidemiology and infection control in acute-care settings. Clin Microbiol Rev. 2011;24:141–73.
4. National Research Council, Communicable Diseases Center. Section II: summary and recommendations. In: Proceedings of the National Conference on Hospital-Acquired Staphylococcal Disease; Atlanta, Georgia; Sept 15–17, 1958.
5. Eickhoff TC, Brachman PW, Bennett JV, Brown JF. Surveillance of nosocomial infections in community hospitals. I. Surveillance methods, effectiveness, and initial results. J Infect Dis. 1969;120:305–17.
6. •• Haley RW, Shachtman RH. The emergence of infection surveillance and control programs in US hospitals: an assessment, 1976. Am J Epidemiol. 1980;111:574–91. **These are the historic SENIC results that provided evidence of the effectiveness of infection prevention programs in decreasing infection rates**.
7. McNamara MJ, Hill MC, Balows A, Tucker EB. A study of the bacteriologic patterns of hospital infections. Ann Intern Med. 1967;66:480–8.
8. Thoburn R, Fekety Jr FR, Cluff LE, Melvin VB. Infections acquired by hospitalized patients: an analysis of the overall problem. Arch Intern Med. 1968;121:1–10.
9. Center for Disease Control. National Nosocomial Infections Study Annual Summary, 1975. Atlanta, GA: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration; issued October, 1972. HSM 73–8181.
10. Haley RW, Culver DH, Emori TG, Hooton TM, White JW. Progress report on the evaluation of the efficacy of infection surveillance and control programs. Am J Med. 1981;70:971–5.
11. Thompson RL. Surveillance and reporting of nosocomial infections. In: Wenzel RP, editor. Prevention and control of nosocomial infections. 1st ed. Baltimore: Williams & Wilkins; 1987.
12. American Hospital Association Committee on Infections Within Hospitals. Infection control in the hospital. 3rd ed. Chicago: American Hospital Association; 1974.
13. Centers for Disease Control. Outline for surveillance and control of nosocomial infections. Atlanta, GA: CDC; 1972. http://stacks.cdc.gov/view/cdc/7697. Accessed February 16th, 2016.
14. •• Wenzel RP, Osterman CA, Townsend TR, et al. Development of a statewide program for surveillance and reporting of hospital-acquired infections. J Infect Dis. 1979;140:741–6. **This is one of the first descriptions of a feasible surveillance program done on a large scale**.
15. Wenzel RP, Osterman CA, Hunting KJ, Gwaltney Jr JM. Hospital-acquired infections. I. Surveillance in a university hospital. Am J Epidemiol. 1976;103:251–60.
16. Evans RS, Larsen RA, Burke JP, et al. Computer surveillance of hospital-acquired infections and antibiotic use. JAMA. 1986;256:1007–11.
17. Evans RS, Abouzelof RH, Taylor CW, et al. Computer surveillance of hospital-acquired infections: a 25 year update. AMIA Annu Symp Proc. 2009;2009:178–82.
18. Woeltje KF, Lin MY, Klompas M, Wright MO, Zuccotti G, Trick WE. Data requirements for electronic surveillance of healthcare-associated infections. Infect Control Hosp Epidemiol. 2014;35:1083–91.
19. Association for Practitioners in Infection Control Newsletter, Vol. 1, No. 1, March, 1973. APIC website. http://www.apic.org/Resource_/TinyMceFileManager/History/First_APIC_newsletter_1973.pdf. Accessed February 17, 2016.
20. Peterson RA. Using the literature. In: Wenzel RP, editor. Prevention and control of nosocomial infections. 1st ed. Baltimore: Williams & Wilkins; 1987.
21. • Ranji SR, Shetty K, Posley KA, Lewis R, Sundaram V, Galvin CM, et al. Prevention of healthcare-associated infections. In: Shojania KG, McDonald KM, Wachter RM, Owens DK, editors. Closing the quality gap: a critical analysis of quality improvement strategies. Rockville: Agency for Healthcare Research and Quality; 2007. **This is a review of the quality of research in the quality improvement and a call for more robust data; it is applicable to infection prevention research**.
22. Head MG, Fitchett JR, Holmes AH, Atun R. Funding healthcare-associated infection research: a systematic analysis of UK research investments, 1997–2010. J Hosp Infect. 2014;87:84–91.
23. Birgand G, Johansson A, Szilagyi E, Lucet JC. Overcoming the obstacles of implementing infection prevention and control guidelines. Clin Microbiol Infect. 2015;21:1067–71.
24. Lohr K, ed. Hospital Conditions of Participation in Medicare. In: Medicare: a strategy for quality assurance, volume 1. Washington, DC: National Academy Press; 1990. http://www.nap.edu/catalog/1547.html. Accessed February 18, 2016.
25. Eickhoff TC. Standards for hospital infection control. Ann Intern Med. 1978;89:829–31.

26. Feltovich F, Fabrey LJ. The current practice of infection prevention as demonstrated by the practice analysis survey of the Certification Board of Infection Control and Epidemiology, Inc. Am J Infect Control. 2010;38:784–8.
27. Morgan DJ, Deloney VM, Bartlett A, et al. The expanding role of the hospital epidemiologist in 2014: a survey of the Society for Hospital Epidemiology of America (SHEA) research network. Infect Control Hosp Epidemiol. 2015;36:605–8.
28. Weber SG, Huang SS, Oriola S, et al. Legislative mandates for use of active surveillance cultures to screen for methicillin-resistant Staphylococcus aureus and vancomycin-resistant enterococci: position statement from the joint SHEA and APIC task force. Infect Control Hosp Epidemiol. 2007;28:249–60.
29. Farr BM. Political versus epidemiological correctness. Infect Control Hosp Epidemiol. 2007;28:589–93.
30. Fraser V, Murphy D, Brennan PJ, et al. Politically incorrect: legislation must not mandate specific healthcare epidemiology and infection prevention and control practices. Infect Control Hosp Epidemiol. 2007;28:594–5.
31. Houck PM, Bratzler DW, Nsa W, Ma A, Bartlett JG. Timing of antibiotic administration and outcomes for Medicare patients hospitalized with community-acquired pneumonia. Arch Intern Med. 2004;164:637–44.
32. Kanwar M, Brar N, Khatib R, et al. Misdiagnosis of community-acquired pneumonia and inappropriate utilization of antibiotics: side effects of the 4-hour antibiotic administration rule. Chest. 2007;131:1865–9.
33. Herzig CT, Reagan J, Pogorzelska-Maziarz M, Srinath D, Stone PW. State-mandated reporting of health care-associated infections in the United States: trends over time. Am J Med Qual. 2015;30:417–24.
34. McKibben L, Fowler G, Horan T, Brennan PJ. Ensuring rational public reporting systems for health care-associated infections: systematic literature review and evaluation recommendations. Am J Infect Control. 2006;34:142–9.
35. Rinke ML, Bundy DG, Abdullah F, Colantuoni E, Zhang Y, Miller MR. State-mandated hospital infection reporting is not associated with decreased pediatric health care-associated infections. J Patient Saf. 2015;11:123–34.
36. Linkin DR, Fishman NO, Shea JA, Yang W, Cary MS, Lautenbach E. Public reporting of hospital-acquired infections is not associated with improved processes or outcomes. Infect Control Hosp Epidemiol. 2013;34:844–6.
37. Marsteller JA, Hsu YJ, Weeks K. Evaluating the impact of mandatory public reporting on participation and performance in a program to reduce central line-associated bloodstream infections: evidence from a national patient safety collaborative. Am J Infect Control. 2014;42:S209–15.
38. Edmond MB, Bearman GM. Mandatory public reporting in the USA: an example to follow? J Hosp Infect. 2007;65 Suppl 2:182–8.
39. Peasah SK, McKay NL, Harman JS, Al-Amin M, Cook RL. Medicare non-payment of hospital-acquired infections: infection rates three years post implementation. Medicare Medicaid Res Rev. 2013;3. doi:10.5600/mmrr.003.03.a08.
40. Lee GM, Kleinman K, Soumerai SB, et al. Effect of nonpayment for preventable infections in U.S. hospitals. N Engl J Med. 2012;367:1428–37.
41. Meddings JA, Reichert H, Rogers MAM, Saint S, Stephansky J, McMahon LF. Impact of non-payment for hospital-acquired catheter-associated urinary tract infection: a statewide analysis. Ann Intern Med. 2012;157:305–12.
42. Hartmann CW, Hoff T, Palmer JA, Wroe P, Dutta-Linn MM, Lee G. The Medicare policy of payment adjustment for health care-associated infections: perspectives on potential unintended consequences. Med Care Res Rev. 2012;69:45–61.
43. Morgan DJ, Meddings J, Saint S, et al. Does nonpayment for hospital-acquired catheter-associated urinary tract infections lead to overtesting and increased antimicrobial prescribing? Clin Infect Dis. 2012;55:923–9.
44. Lee GM, Hartmann CW, Graham D, et al. Perceived impact of the medicare policy to adjust payment for health care-associated infections. Am J Infect Control. 2012;40:314–9.
45. Iskander J, Strikas RA, Gensheimer KF, Cox NJ, Redd SC. Pandemic influenza planning, United States, 1978–2008. Emerg Infect Dis. 2013;19:879–85.
46. Rebmann T, 2008 APIC Emergency Preparedness Committee. APIC state-of-the-art report: the role of the infection preventionist in emergency management. Am J Infect Control. 2009;37:271–81.
47. Ippolito G, Puro V, Heptonstall J. Hospital preparedness to bioterrorism and other infectious disease emergencies. Cell Mol Life Sci. 2006;63:2213–22.
48. Ristuccia PA, Cunha BA. Microbiologic aspects of infection control. In: Wenzel RP, editor. Prevention and control of nosocomial infections. 1st ed. Baltimore: Williams & Wilkins; 1987.
49. Maki DG, Schuna AA. A study of antimicrobial misuse in a university hospital. Am J Med Sci. 1978;275:271–82.
50. Davey P, Brown E, Fenelon L, et al. Interventions to improve antibiotic prescribing practices for hospital inpatients. Cochrane Database Syst Rev. 2005;4:CD003543.
51.• Davey P, Brown E, Charani E, et al. Interventions to improve antibiotic prescribing practices for hospital inpatients. Cochrane Database Syst Rev. 2013;4:CD003543. **This describes the improving but still sub-optimal level of evidence to support antimicrobial stewardship programs and practices in hospitals**.
52. Office of the Press Secretary. The National Action Plan for combating antibiotic-resistant bacteria. The White House. March 27, 2015. Available at http://www.whitehouse.gov/the-press-office/2015/03/27/fact-sheet-obama-administration-releases-national-action-plan-combat-ant . Accessed November 11, 2015.
53. The President's Council of Advisors on Science and Technology. Report to the President on combating antibiotic resistance. Executive Office of the President. September 9, 2014. Available at http://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports. Accessed November 11, 2015.
54. Trivedi KK, Rosenberg J. The state of antimicrobial stewardship programs in California. Infect Control Hosp Epidemiol. 2013;34:379–84.
55. Institute of Medicine. Crossing the quality chasm: A new health system for the 21st Century. National Academies Press; 2001. http://www.nap.edu/read/10027/chapter/1. Accessed February 17, 2016.
56. Wenzel RP, Edmond MB. Academic I.D. in jeopardy: the erosion of time, professional values, and physician satisfaction. Infection. 2015;43:141–4.
57. Pronovost PJ, Goeschel CA, Colantuoni E, et al. Sustaining reductions in catheter related bloodstream infections in Michigan intensive care units: observational study. BMJ. 2010;340:c309.