Centers for Disease Control and Prevention

MMWR

Morbidity and Mortality Weekly Report

Early Release / Vol. 60

March 1, 2011

Vital Signs: Central Line–Associated Blood Stream Infections — United States, 2001, 2008, and 2009

Abstract

Background: Health-care–associated infections (HAIs) affect 5% of patients hospitalized in the United States each year. Central line–associated blood stream infections (CLABSIs) are important and deadly HAIs, with reported mortality of 12%–25%. This report provides national estimates of the number of CLABSIs among patients in intensive-care units (ICUs), inpatient wards, and outpatient hemodialysis facilities in 2008 and 2009 and compares ICU estimates with 2001 data.

Methods: To estimate the total number of CLABSIs among patients aged ≥1 year in the United States, CDC multiplied central-line utilization and CLABSI rates by estimates of the total number of patient-days in each of three settings: ICUs, inpatient wards, and outpatient hemodialysis facilities. CDC identified total inpatient-days from the Healthcare Cost and Utilization Project's National Inpatient Sample and from the Hospital Cost Report Information System. Central-line utilization and CLABSI rates were obtained from the National Nosocomial Infections Surveillance System for 2001 estimates (ICUs only) and from the National Healthcare Safety Network (NHSN) for 2009 estimates (ICUs and inpatient wards). CDC estimated the total number of outpatient hemodialysis patient-days in 2008 using the single-day number of maintenance hemodialysis patients from the U.S. Renal Data System. Outpatient hemodialysis central-line utilization was obtained from the Fistula First Breakthrough Initiative, and hemodialysis CLABSI rates were estimated from NHSN. Annual pathogen-specific CLABSI rates were calculated for 2001–2009.

Results: In 2001, an estimated 43,000 CLABSIs occurred among patients hospitalized in ICUs in the United States. In 2009, the estimated number of ICU CLABSIs had decreased to 18,000. Reductions in CLABSIs caused by *Staphylococcus aureus* were more marked than reductions in infections caused by gram-negative rods, *Candida* spp., and *Enterococcus* spp. In 2009, an estimated 23,000 CLABSIs occurred among patients in inpatient wards and, in 2008, an estimated 37,000 CLABSIs occurred among patients receiving outpatient hemodialysis.

Conclusions: In 2009 alone, an estimated 25,000 fewer CLABSIs occurred in U.S. ICUs than in 2001, a 58% reduction. This represents up to 6,000 lives saved and $414 million in potential excess health-care costs in 2009 and approximately $1.8 billion in cumulative excess health-care costs since 2001. A substantial number of CLABSIs continue to occur, especially in outpatient hemodialysis centers and inpatient wards.

Implications for Public Health Practice: Major reductions have occurred in the burden of CLABSIs in ICUs. State and federal efforts coordinated and supported by CDC, the Agency for Healthcare Research and Quality, and the Centers for Medicare & Medicaid Services and implemented by numerous health-care providers likely have helped drive these reductions. The substantial number of infections occurring in non-ICU settings, especially in outpatient hemodialysis centers, and the smaller decreases in non–*S. aureus* CLABSIs reveal important areas for expanded prevention efforts. Continued success in CLABSI prevention will require increased adherence to current CLABSI prevention recommendations, development and implementation of additional prevention strategies, and the ongoing collection and analysis of data, including specific microbiologic information. To prevent CLABSIs in hemodialysis patients, efforts to reduce central line use for hemodialysis and improve the maintenance of central lines should be expanded. The model of federal, state, facility, and health-care provider collaboration that has proven so successful in CLABSI prevention should be applied to other HAIs and other health-care–associated conditions.

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention

Introduction

Health-care–associated infections (HAIs) account for a substantial portion of health-care–acquired conditions (*1*) that harm patients receiving medical care. Nearly one in every 20 hospitalized patients in the United States each year acquires an HAI. Central line–associated blood-stream infections (CLABSIs) are one of the most deadly types of HAIs, with a mortality rate of 12%–25% (*2*). CDC defines a CLABSI as recovery of a pathogen from a blood culture (a single blood culture for organisms not commonly present on the skin and two or more blood cultures for organisms commonly present on the skin) in a patient who had a central line at the time of infection or within the 48-hour period before development of infection. The infection cannot be related to any other infection the patient might have and must not have been present or incubating when the patient was admitted to the facility.

In recent years, large-scale regional and statewide projects, such as the Pittsburgh Regional Healthcare Initiative and the Michigan Keystone Project, have demonstrated roughly 70% reductions in CLABSI rates in intensive-care units (ICUs) by increasing adherence to recommended best-practices for the insertion of central lines (*3,4*). Decreases in CLABSIs have been attributed to various factors, including increased financial and leadership support for CLABSI prevention, improved education and engagement of clinicians in prevention efforts, packaging of prevention recommendations into practice bundles, increased data monitoring and feedback on progress, improvement of the safety culture in health-care, and local and statewide collaborative prevention efforts.

In 2009, the U.S. Department of Health and Human Services set a national goal for a 50% reduction in CLABSIs by 2013 (*5*). CDC monitors progress toward this goal through the National Healthcare Safety Network (NHSN).* This report describes progress in CLABSI reductions in ICUs and estimates the numbers of CLABSIs occurring in non-ICU settings. CDC estimated the number of CLABSIs among hospitalized patients aged ≥1 years in 2009 and among patients receiving outpatient hemodialysis in 2008. CDC also compared the number of CLABSIs in ICUs and the pathogens causing inpatient CLABSIs in 2001 and 2009.

Methods

For each setting (ICU, inpatient ward, and hemodialysis facility) and period, CDC multiplied patient-day estimates by central-line utilization ratios to estimate the total number of central line-days nationally and then applied CLABSI rates to estimate the total number of infections. CDC estimated the total number of inpatient-days in United States hospitals by averaging estimates from the Healthcare Cost and Utilization Project's National Inpatient Sample (NIS) (*6*) and the Hospital Cost Report Information System (HCRIS) (*7*). Estimates were adjusted by the ratio of federal hospital patient-days to nonfederal hospital patient-days reported in the annual American Hospital Association survey in 2007 (*8*). The proportion of patient-days occurring in ICUs was estimated from the 2007 HCRIS. Information on pooled mean central-line utilization and CLABSI rates was obtained from the approximately 260 hospitals participating in the National Nosocomial Infections Surveillance System (NNIS) in 2001 (*9*) and the approximately 1,600 hospitals participating in NHSN in 2009. Surveillance data reported to NNIS and NHSN are collected by trained personnel using standard methodologies and definitions. These data were not available for inpatient wards for 2001. CDC applied a correction factor to NNIS data to account for a change in the CLABSI definition in 2008 (*10*).

CDC obtained the single-day number of maintenance hemodialysis patients in the Medicare End-Stage Renal Disease (ESRD) program for December 31, 2007, and December 31, 2008, from the U.S. Renal Data System (*11*) and multiplied the midpoint by 365 to obtain the estimated number of hemodialysis patient-days in 2008. CDC applied an adjustment factor to account for hemodialysis patients not covered by Medicare. The proportion of hemodialysis patients using a central line was obtained from the Fistula First Breakthrough Initiative (*12*) and applied to the number of hemodialysis patient-days. Pooled mean CLABSI rates were estimated from centers reporting event data to NHSN during 2007–2008. Because dialysis facilities use different definitions than hospitals, access-related bloodstream infection in dialysis patients with a central line was used to approximate CLABSI.

CDC also performed two sensitivity analyses: one in which CLABSI rates and central-line utilization were both underestimated by 25%, and one assuming both were overestimated by 25%. Information on the most common pathogens causing CLABSIs also was analyzed. CLABSIs with more than one pathogen could be reported in multiple categories. Relative changes were calculated by comparing the pathogen group–specific incidence in each year, and incidence rates were compared using a mid-P test with confidence intervals based on the Byar method (*13*).

Results

For the 2009 calculations, an estimated 168 million inpatient-days occurred in nonfederal acute-care hospitals in the United States. After adding approximately 4.9% to account for patient-days in federal hospitals, CDC allocated 12.5% of days to ICUs and 87.5% to inpatient wards, yielding 22.1 million ICU days and 154.3 million inpatient ward days (Tables 1 and 2).

* Additional information available at http://www.cdc.gov/nhsn.

TABLE 1. Data inputs for estimated number of central line–associated blood stream infections (CLABSIs) — United States, 2001, 2008, and 2009

Data inputs	Value	Source
Inpatient health-care utilization data		
Nonfederal hospital inpatient-days, 2007	168,113,488 patient-days	Average of values from the National Inpatient Sample and Hospital Cost Report Information System, 2007
Inflation factor to account for federal health-care facilities	0.049 additional patient-days per nonfederal hospital day	American Hospital Association Database, 2007
Proportion of inpatient-days that are in intensive-care units (ICUs), 2007	0.125	Hospital Cost Report Information System, 2007
Pooled mean ICU central-line utilization, 2001	0.53 central line-days per patient-day	National Nosocomial Infections Surveillance System, 1999–2003
Pooled mean ICU central-line utilization, 2009	0.50 central line-days per patient-day	National Healthcare Safety Network, 2009
Pooled mean inpatient ward central-line utilization, 2009	0.13 central line-days per patient-day	National Healthcare Safety Network, 2009
Inpatient CLABSI rate data		
Pooled mean ICU CLABSI rate adjusted for definition change, 2001	3.64 per 1,000 central line-days	National Nosocomial Infections Surveillance System, 1999–2003
Pooled mean ICU CLABSI rate, 2009	1.65 per 1,000 central line-days	National Healthcare Safety Network, 2009
Pooled mean inpatient ward CLABSI rate, 2009	1.14 per 1,000 central line-days	National Healthcare Safety Network, 2009
Hemodialysis health-care utilization data		
No. of prevalent maintenance hemodialysis end-stage renal disease patients on June 30, 2008	348,253 (equivalent to 127,112,345 patient-days)	Midpoint of U.S. Renal Data System estimates for December 31, 2007, and December 31, 2008
Proportion of hemodialysis patients dialyzed using a catheter, 2008	0.262	Midpoint of values from Fistula First Breakthrough Initiative for January–December 2006 and January–October 2010
Hemodialysis CLABSI rate data		
Pooled mean access-related bloodstream infection rate in hemodialysis patients with a central line, 2008	3.20 per 100 patient-months (equivalent to 1.05 per 1,000 central line-days)	National Healthcare Safety Network, 2007–2008

In 2001, the pooled mean central-line utilization ratio in ICUs was 0.53 central line-days per patient-day, which yielded 11.7 million central line-days. The CLABSI rate was multiplied by 0.817 to account for the change in definition, yielding a rate of 3.64 CLABSIs per 1,000 central line-days (Table 1). By applying this to ICU central line-days, CDC estimated that approximately 43,000 (sensitivity analysis range: 27,000–67,000) CLABSIs occurred in U.S. ICUs in 2001 (Table 2). In 2009, the pooled mean ICU central-line utilization ratio was 0.50, yielding an estimated 11.0 million central line-days (Table 1). Applying the pooled mean ICU CLABSI rate of 1.65 infections per 1,000 central line-days yielded an estimated 18,000 CLABSIs in ICUs in 2009 (sensitivity analysis range: 12,000–28,000) (Tables 1 and 2).

In inpatient wards in 2009, the pooled mean central-line utilization ratio was 0.13, yielding an estimated 20.1 million central line-days (Table 1). Applying the pooled mean inpatient ward CLABSI rate of 1.14 infections per 1,000 central line-days yielded an estimated 23,000 CLABSIs in U.S. inpatient wards in 2009 (sensitivity analysis range: 15,000–37,000) (Tables 1 and 2).

An estimated 127 million outpatient hemodialysis end-stage renal disease (ESRD) patient-days occurred in the United States in 2008. After adjustment for non-Medicare patients, CDC allocated 26.2% of patient-days to those in which a central line was used, based on Fistula First data, which yielded 34.9 million estimated central line-days (Table 1). Applying the pooled mean estimated CLABSI rate of 1.05 per 1,000 central-line days yielded an estimated 37,000 (sensitivity analysis range: 23,000–57,000) CLABSIs in hemodialysis patients in 2008 (Tables 1 and 2).

The reduction in CLABSI incidence in 2009 compared with 2001 was greatest for *Staphylococcus aureus* CLABSIs (73% reduction; rate ratio [RR] = 0.27; 95% confidence interval [CI] = 0.238–0.294) and more modest for gram-negative pathogens (*Klebsiella* spp., *Escherichia coli*, *Acinetobacter baumannii*, or *Pseudomonas aeuriginosa*) (37% reduction; RR = 0.63; CI = 0.568–0.692), *Candida* spp. (46% reduction; RR = 0.54; CI = 0.487–0.606), and *Enterococcus* spp. (55% reduction; RR = 0.45; CI = 0.408–0.491).

TABLE 2. Estimated annual number of central line–associated blood stream infections (CLABSIs), by health-care setting and year — United States, 2001, 2008, and 2009

Health-care setting	Year	No. of infections (upper and lower bound of sensitivity analysis)
Intensive-care units	2001	43,000 (27,000–67,000)
	2009	18,000 (12,000–28,000)
Inpatient wards	2009	23,000 (15,000–37,000)
Outpatient hemodialysis*	2008	37,000 (23,000–57,000)

* Case definitions approximate current definition of CLABSI according to the National Healthcare Safety Network.

Conclusions and Comment

In 2009, an estimated 25,000 fewer CLABSIs occurred among patients in ICUs in the United States than in 2001 (a 58% reduction). The cumulative number of CLABSIs prevented since 2001 is substantially higher because reductions have been occurring annually for the past decade (*14*). Given the reported mortality from CLABSIs, these reductions represent an estimated 3,000–6,000 lives saved and estimated excess health-care costs of $414 million (*15*) in ICUs in 2009 alone. Assuming that each CLABSI carries excess health-care costs of $16,550 and mortality of up to 25%, and that CLABSI reductions were steady during 2001–2009, the cumulative excess health-care costs of all CLABSIs prevented in ICUs could approach $1.8 billion, and the number of lives saved could be as high as 27,000. The majority of CLABSIs are now occurring outside of ICUs, many outside of hospitals altogether, especially in outpatient dialysis clinics. The data in this report indicate that CLABSIs attributed to *S. aureus* have decreased more than other pathogens. Reductions in CLABSIs in ICUs likely reflect the impact of a coordinated effort by state and federal agencies, professional societies, and health-care personnel to implement proven best practices for the insertion of central lines. Toward advancing this success further, CDC guidelines for CLABSI prevention (*2*) have been incorporated in regional, state, and national efforts to reduce CLABSIs, such as the Agency for Healthcare Research and Quality (AHRQ)–supported On the CUSP: Stop BSI campaign, which seeks to enroll facilities in every state[†] in CLABSI prevention efforts.

Because efforts to improve central line insertion might have limited impact in non-ICU settings, in which central lines are less frequently inserted, additional prevention strategies must be developed. For example, *S. aureus* more commonly inhabits the skin and thus might be a more common cause of insertion-related infections; therefore, the smaller reduction among other pathogens suggests a need for improved implementation of post-insertion line-maintenance practices and strategies to ensure prompt removal of unneeded central lines. In addition, reductions in *S. aureus* CLABSIs likely were enhanced by widespread efforts to interrupt transmission of methicillin-resistant *S. aureus*. Implementation of CDC-recommendations to maintain central lines, remove them promptly when they are no longer needed, and interrupt transmission of resistant bacteria (*16,17*) will reduce CLABSIs further. Focusing on antibiotic-resistant pathogens can be especially important given the increased risk for mortality associated with these pathogens (*18*). Slower declines in non–*S. aureus* CLABSIs also suggest the need to research methods for preventing infections that meet the surveillance definition for a CLABSI but clinically might be related to another cause (e.g., infections caused by translocation of bacteria from the intestine). The variation in reductions among different organisms underscores the importance of collecting pathogen and susceptibility information as part of CLABSI surveillance. Microbiologic information will be critical in helping direct future CLABSI prevention efforts at pathogens that have been reduced less markedly.

The substantial number of estimated CLABSIs among hemodialysis patients emphasizes another important prevention priority because these infections are a major cause of hospital admissions and mortality (*11*). A primary prevention measure is the avoidance of central lines in favor of arteriovenous fistulas or, in some instances, arteriovenous grafts. Currently, approximately 80% of ESRD patients in the United States initiate hemodialysis with a central line (*11*), a proportion that exceeded that of eight of 10 other developed countries and was nearly threefold higher than in Germany (23%) and Japan (29%) (*19*). Interventions to improve arteriovenous fistula placement, including increased access to pre-ESRD nephrology care, are needed to reduce catheter reliance (*11,20*). When catheters must be used, recommended interventions to improve central-line maintenance can reduce CLABSIs in hemodialysis patients and should be consistently implemented (*21*). Novel prevention strategies, such as measures to reduce central-line colonization in hemodialysis patients, also have shown promise and should be explored (*22*).

The findings in this report are subject to at least six limitations. First, estimates were calculated rather than measured directly and limitations in discharge datasets on the details of the types of ICUs and wards in which patient days occurred meant that the overall pooled means for all ICUs and all wards was applied to the aggregate number of patient days in each area. To account for some uncertainty in these estimates, CDC performed a sensitivity analysis. Second, substantial differences between facilities reporting and not reporting data to CDC might have affected the accuracy of these estimates. Third, difficulty exists in comparing these estimates with estimates that were not limited to CLABSIs (*23*) and might have used the pre-2008 definition. Fourth, for

[†] Additional information available at http://www.safercare.net/otcsbsi/home.html.

Key Points

- Central line–associated blood stream infections (CLABSIs) are serious but preventable infections.
- CLABSIs are largely preventable when health professionals use CDC's *Guidelines for the Prevention of Intravascular Catheter-Related Infections*.
- CLABSIs among patients in hospital intensive-care units were reduced by 58% in 2009 compared with 2001. Many CLABSIs still occur in other places in the hospital and in outpatient-care settings.
- In 2008, an estimated 37,000 CLABSIs occurred among outpatient hemodialysis patients.
- Hemodialysis-related CLABSIs can be reduced by avoiding the use of a central venous catheter in favor of an arteriovenous fistula or, in some cases, an arteriovenous graft, and by improving adherence to best practices for maintaining central lines in hemodialysis patients.
- Additional information is available at http://www.cdc.gov/vitalsigns.

hemodialysis-related CLABSI estimates, uncertainty is introduced because facilities report monthly (not daily) central-line utilization, they use a less specific bloodstream infection definition (compared with the NHSN inpatient definition), and <5% currently report data to NHSN. Fifth, the information provided to NNIS and NHSN is subject to reporting biases, although this is mitigated somewhat by the use of standard and common surveillance definitions and methodologies in both NNIS and NHSN. Finally, data are not available on CLABSIs that occur after patients have been discharged or among non-hemodialysis outpatients with central venous catheters. Hence, the CLABSI data described in this report do not include all patients affected by CLABSIs each year.

The successes of the Pittsburgh Regional Healthcare Initiative and Michigan Keystone Project demonstrate the impact of regional and state-based CLABSI prevention programs. State health departments are now building on these successes and working with state hospital associations and quality-improvement organizations to expand their roles in HAI prevention. As part of CLABSI prevention efforts, 22 states now require that inpatient facilities report CLABSI rates to NHSN, and one state (Colorado) also requires reporting from hemodialysis facilities. As of 2010, all 50 state health departments and the District of Columbia had developed state HAI prevention plans, based on the U.S. Department of Health and Human Services (HHS) *National Action Plan to Reduce Healthcare-Associated Infections* (*5*).

Federal agencies are working together to support state-based and facility level HAI prevention campaigns. AHRQ is expanding the highly successful CUSP CLABSI prevention campaigns into more health-care facilities and outside of ICUs, and expanding this same methodology to other HAIs. The Centers for Medicare & Medicaid Services (CMS) also is working with CDC to improve the monitoring and prevention of HAIs in all health-care settings. CDC will continue to serve as a national resource for technical expertise on HAIs, working on efforts to implement and expand prevention and to investigate new prevention and surveillance approaches. The growing involvement of state health departments in HAI prevention efforts will build on existing public health infrastructure and expertise. In 2009, through the American Recovery and Reinvestment Act, CDC provided $40 million to state health departments to promote HAI prevention. States are using these funds to establish and enhance HAI expertise; complement HAI prevention efforts of health-care facilities, hospital associations, and quality-improvement organizations; engage new partners in HAI prevention; improve the extent and accuracy of HAI reporting to NHSN; and implement specific prevention activities.[§]

Progress in reducing CLABSIs highlights the preventability of these infections and helps establish a prevention framework that can be applied to other HAIs and other hospital-acquired conditions. CDC, AHRQ, CMS, and HHS will continue to support HAI prevention in collaboration with state-based and facility partners. Success in this endeavor will require continued support for the implementation of current prevention best practices, the development of new prevention strategies (*24*), and an ongoing commitment to monitor progress in this endeavor. Further investments, especially in state health departments, will accelerate progress towards HAI elimination.

[§] Additional information available at http://www.cdc.gov/hai/recoveryact/map.html.

Reported by

A Srinivasan, MD, M Wise, PhD, M Bell, MD, D Cardo, MD, J Edwards, MS, S Fridkin, MD, J Jernigan, MD, A Kallen, MD, LC McDonald, MD, PR Patel, MD, D Pollock, MD, Div of Healthcare Quality Promotion, National Center for Emerging and Zoonotic Infectious Diseases, CDC.

References

1. Centers for Medicare & Medicaid Services. Hospital-acquired conditions. Baltimore, MD: US Department of Health and Human Services, Centers for Medicare & Medicaid Services; 2010. Available at https://www.cms.gov/hospitalacqcond/06_hospital-acquired_conditions.asp. Accessed February 3, 2011.
2. CDC. Guidelines for the prevention of intravascular catheter-related infections. MMWR 2002;51(No. RR-10).

3. CDC. Reduction in central line-associated bloodstream infections among patients in intensive care units—Pennsylvania, April 2001–March 2005. MMWR 2005;54:1013–6.
4. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. N Engl J Med 2006;355:2725–32.
5. US Department of Health and Human Services. National action plan to reduce healthcare-associated infections. Washington, DC: US Department of Health and Human Services; 2010. Available at http://www.hhs.gov/ash/initiatives/hai/actionplan/index.html. Accessed February 3, 2011.
6. Steiner C, Elixhauser A, Schnaier J. The healthcare cost and utilization project: an overview. Eff Clin Pract 2002;5:143–51.
7. Centers for Medicare & Medicaid Services. Hospital cost report. Baltimore, MD: US Department of Health and Human Services, Centers for Medicare & Medicaid Services; 2010. Available at http://www.cms.gov/costreports/02_hospitalcostreport.asp#topofpage. Accessed February 3, 2011.
8. American Hospital Association. Survey history & methodology. Chicago, IL: American Hospital Association. Available at http://www.ahadata.com/ahadata/html/historymethodology.html. Accessed February 3, 2011.
9. CDC. National Nosocomial Infections Surveillance (NNIS) system report, data summary from January 1992 through June 2004. Am J Infect Control 2004;32:470–85.
10. CDC. NHSN newsletter: revised LCBI definition. Atlanta, GA: US Department of Health and Human Services, CDC; 2007. Available at http://www.cdc.gov/nhsn/pdfs/newsletters/january2008.pdf. Accessed February 3, 2011.
11. US Renal Data System. Annual data report. Bethesda, MD: US Department of Health and Human Services, National Institutes of Health; 2010. Available at http://www.usrds.org/adr.htm. Accessed February 3, 2011.
12. Fistula First Breakthrough Initiative. Fistula First data: prevalent counts and rates. Lake Success, NY: Fistula First Breakthrough Initiative; 2009. Available at http://www.fistulafirst.org/aboutfistulafirst/ffbidata.aspx. Accessed February 3, 2011.
13. Rothman K, Boice J. Epidemiologic analysis with a programmable calculator. 2nd ed. Boston, MA: Epidemiology Resources; 1982.
14. Burton DC, Edwards JR, Horan TC, Jernigan JA, Fridkin SK. Methicillin-resistant Staphylococcus aureus central line-associated bloodstream infections in US intensive care units, 1997–2007. JAMA 2009;301:727–36.
15. Hu KK, Veenstra DL, Lipsky BA, Saint S. Use of maximal sterile barriers during central venous catheter insertion: clinical and economic outcomes. Clin Infect Dis 2004;39:1441–5.
16. CDC. Guidance for control of infections with carbapenem-resistant or carbapenemase-producing Enterobacteriaceae in acute care facilities. MMWR 2009;58:256–60.
17. Siegel JD, Rhinehart E, Jackson M, Chiarello L. Management of multidrug-resistant organisms in health care settings, 2006. Am J Infect Control 2007;35(10 Suppl 2):S165–93.
18. Patel G, Huprikar S, Factor SH, Jenkins SG, Calfee DP. Outcomes of carbapenem-resistant Klebsiella pneumoniae infection and the impact of antimicrobial and adjunctive therapies. Infect Control Hosp Epidemiol 2008;29:1099–106.
19. Ethier J, Mendelssohn DC, Elder SJ, et al. Vascular access use and outcomes: an international perspective from the Dialysis Outcomes and Practice Patterns Study. Nephrol Dial Transplant 2008;23:3219–26.
20. Allon M. Fistula First: recent progress and ongoing challenges. Am J Kidney Dis 2011;57:3–6.
21. Patel PR, Kallen AJ, Arduino MJ. Epidemiology, surveillance, and prevention of bloodstream infections in hemodialysis patients. Am J Kidney Dis 2010;56:566–77.
22. James MT, Conley J, Tonelli M, Manns BJ, MacRae J, Hemmelgarn BR. Meta-analysis: antibiotics for prophylaxis against hemodialysis catheter-related infections. Ann Intern Med 2008;148:596–605.
23. Klevens RM, Edwards JR, Richards CL Jr, et al. Estimating health care-associated infections and deaths in U.S. hospitals, 2002. Public Health Rep 2007;122:160–6.
24. Pronovost PJ, Cardo DM, Goeschel CA, Berenholtz SM, Saint S, Jernigan JA. A research framework for reducing preventable patient harm. Clin Infect Dis 2011 (in press).