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Major Article

The attributable cost of catheter-associated urinary tract infections in the United States: A systematic review

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Key Words:
Catheter-associated urinary tract infection
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Background: Catheter-associated urinary tract infections (CAUTIs) are the most common healthcare-acquired condition. The attributable cost of CAUTIs is frequently cited to be approximately $1,000. However, there is a paucity of recent literature that confirms this estimate. The purpose of this study was to perform a systematic review of the literature that estimates the attributable cost of CAUTIs in the United States.
Methods: A systematic review was conducted using Pubmed. Studies conducted between the years 2000 and 2017, conducted at a facility within the United States, and that used novel patient-level cost data were included. Attributable cost estimates were adjusted for inflation to 2016 U.S. dollars using the medical care component of the Consumer Price Index.
Results: Only 4 articles met our inclusion criteria. Adjusted to 2016 U.S. dollars, the attributable costs of a CAUTI as reported in these studies were: $876 (inpatient cost to the hospital for additional diagnostic tests and medications); $1,764 (inpatient cost to Medicare for non-intensive care unit [ICU] patients); $7,670 (inpatient and outpatient costs to Medicare); $8,398 (inpatient cost to the hospital for pediatric patients); and $10,197 (inpatient cost to Medicare for ICU patients).
Conclusions: The cost of a CAUTI ranges widely depending on population, patient acuity, and cost perspective. Attributable costs likely exceed $1,000. Additional research is needed to assess the full economic effect of CAUTIs.

Catheter-associated urinary tract infections (CAUTIs) are a common complication of indwelling catheters. In fact, CAUTIs are the most common healthcare-associated condition (HAC) in the United States.[1] Identifying the precise number of CAUTIs that occur in the United States is difficult. However, based on surveillance data reported to the Centers for Disease Control and Prevention (CDC) National Healthcare Safety Network (NHSN) in the year 2013, the incidence of CAUTIs ranged from 0.1 to 3.1 for adult inpatient floors, 1.2 to 5.3 for adult critical care units, and 1.4 to 3.4 for pediatric medical and critical care units (all were per 1,000 catheter days).[2] The incidence of CAUTIs in long-term care settings such as inpatient rehabilitation facilities and chronic care units ranged from 1.5 to 3.3 per 1,000 catheter days for adult and pediatric patients.[2]

There are several risk factors for CAUTIs, including older age, female sex, and diabetes.[3-5] The most important risk factor, however, is the use of an indwelling catheter, such as a Foley catheter. In fact, most CAUTI prevention interventions focus primarily on limiting the use and duration of urinary catheters.[6,7] Still, 15%-25% of all hospitalized patients receive urinary catheters,[8] and CAUTIs will likely remain a costly and preventable challenge for the foreseeable future.[9-11] A secondary bacteremia that develops from a CAUTI will add additional expense and should also be considered as contributing to the overall economic burden.

In 2008, Medicare ceased reimbursing hospitals for CAUTIs and other preventable HACs as part of the Hospital Acquired Conditions Reduction Program (HACRP), creating a financial incentive for prevention efforts. To appropriately respond to the financial incentive under the HACRP, hospitals need to know the full economic burden of CAUTIs. Currently, there is a paucity of studies available that provide an up-to-date and relevant perspective of the national economic burden of CAUTIs. An important part of estimating the national burden is first estimating the attributable costs of CAUTIs. Attributable costs of infections are excess costs—costs that are directly due to the infection. The purpose of this study was to perform a systematic review of the

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literature that estimates the attributable cost of CAUTIs in the United States.

METHODS

This study was a systematic review of the attributable costs of CAUTIs in the United States. PubMed was used to conduct an electronic search of the biomedical literature published from 2000 to 2017. To locate only studies conducted within the United States and studies that contained authentic patient-level cost data (versus meta-analyses), we chose PubMed as our sole database. Additionally, we assumed that databases that focus on specific diseases (eg, AIDS or cancer) would be unlikely to contain articles with a broad enough perspective. Thus, within PubMed, we searched for all studies that provided an estimate of the attributable costs of CAUTIs. The following search terms and combinations of search terms were used: "cauti," "ca-uti," "catheter-associated urinary tract infection," and "cost." The most recent search was performed on February 1, 2017.

Only studies in which cost data were collected as part of the study were included; systematic reviews, editorial articles, and studies that merely reported previous cost estimates were excluded. Cost studies were collected regardless of perspective (hospital, third-party payer, societal, etc.); however, studies that reported *charges* were excluded. Charges are the prices that providers set for their goods and services. However, providers do not expect to be paid full charges by most patients, because most patients are insured. Since hospital charges are often grossly inflated relative to actual cost, they do not accurately represent a cost from any relevant perspective (patients, providers, or payers). This fact has been well established in the literature.[12-14]

Because practice patterns and resource utilization regarding use of catheters can differ across countries, our review was further limited to only those studies performed in the United States and published in English-language journals. Studies were also excluded if they failed to use cost data and if they were published prior to 2000. Bibliographies of articles meeting our inclusion criteria were then reviewed to identify any additional studies missed in our electronic search.

Costs reported in the articles were adjusted for inflation to 2016 U.S. dollars using the medical care component of the Consumer Price Index, published by the Bureau of Labor Statistics.

RESULTS

Figure 1 presents a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram detailing the results

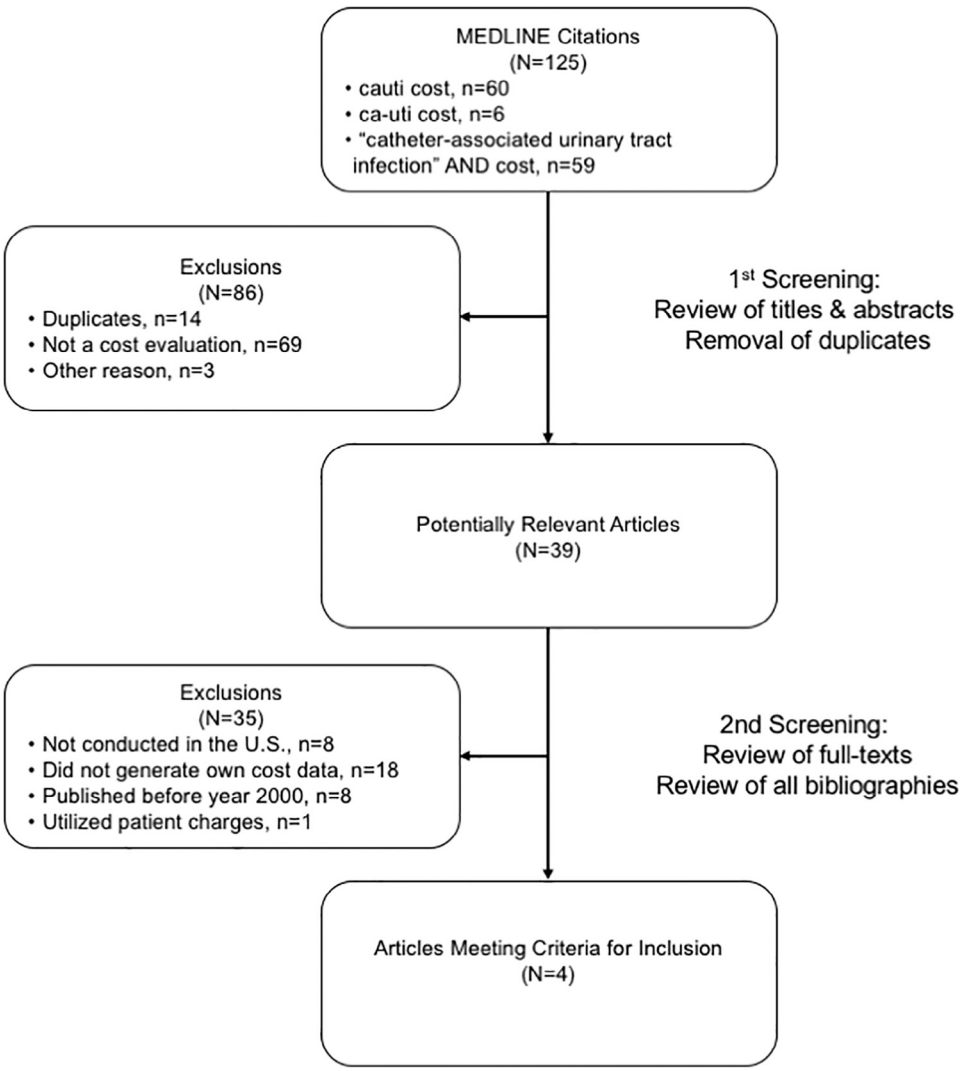

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of electronic literature search.

of our literature search and outlines how we arrived at our final collection of articles. Our initial electronic search yielded a total of 125 studies with potentially relevant data based on our search terms. Eighty-six articles were removed from consideration after excluding duplicate articles and articles that did not report attributable costs. After applying additional exclusion criteria, we were left with 4 articles that were retrieved and included in the study. No additional studies meeting inclusion criteria were found.

Table 1 gives an overview of the studies included in our analysis. Of the 4 studies reviewed, 2 adopted the cost perspective of the hospital, whereas the remaining 2 took the perspective of the cost to Medicare. Attributable cost estimates from the hospital perspective ranged from approximately $875 for diagnostic and medication costs only[15] to nearly $8,400 for pediatric patients.[16] From the Medicare perspective, attributable costs ranged from nearly $1,800 for non-intensive care unit (ICU) patients to approximately $10,200 for ICU patients.[17,18]

The Tambyah et al. study[15] reported only the excess costs for diagnostic tests and medications associated with CAUTIs. Their prospective study was conducted at a university hospital and included approximately 1,500 newly catheterized adult patients. Of these patients, 235 acquired a CAUTI, but only about half of these (n = 123) received treatment; the rest were asymptomatic and did not receive treatment. The finding was that the 123 CAUTI cases taken in aggregate were responsible for an additional $20,662 in diagnostic tests and $35,872 in medication costs, or an average cost of $589 (1998 U.S. dollars) per CAUTI. Adjusting for inflation, this equates to $876 per CAUTI in 2016 U.S. dollars.

Tambyah et al. also estimated costs as a function of infection etiology. CAUTIs caused by *Escherichia coli* had a lower cost than CAUTIs caused by other gram-negative bacteria or yeast ($363.3 for *E. coli*; $690.4 for other gram-negative bacteria; $821.2 for yeast—in 1998 U.S. dollars). In 2016 U.S. dollars, these costs are $540 for *E. coli*, $1,027 for other gram-negative bacteria, and $1,222 for yeasts.

Yi et al. studied the cost of CAUTIs from Medicare's perspective.[18] This study used data from Medicare inpatient claims, the NHSN, and the Medicare and Provider Analysis and Review (MedPAR). Medicare beneficiaries hospitalized in 2009 were stratified by whether a CAUTI had been reported to the NHSN for that beneficiary and also by whether their hospitalization involved an ICU admission. CAUTI patients were frequency matched to non-CAUTI patients in a 1:5 fashion according to ICU status and the Agency for Healthcare Research and Quality's Clinical Classifications Software system. Separate regression models were used to assess costs to Medicare for ICU patients versus non-ICU patients; CAUTI status was used as a covariate in each model to observe its effect on cost after controlling for patient- and hospital-level factors. The regression model for the ICU cohort revealed that having a CAUTI significantly increased the cost to Medicare by an additional $8,548 (2009 U.S. dollars) compared to not contracting a CAUTI while in the hospital ($P < .0001$). Likewise, the regression model for the non-ICU cohort revealed that having a CAUTI increased the cost to Medicare by an additional $1,479 (2009 U.S. dollars) compared to patients who did not contract a CAUTI ($P < .0001$). Adjusting these values for inflation, the Medicare costs increased to $10,197 for ICU patients and $1,764 for non-ICU patients (2016 U.S. dollars).

The study by Kandilov et al. also used Medicare inpatient claims data from MedPAR, as well as outpatient claims data from the Medicare Standard Analytic Files.[17] Medicare payments from a patient's index hospitalization, as well as all payments made for outpatient, physician, home health, and hospice care received during a 90-day follow-up period, were analyzed. Each CAUTI case was matched with 5 controls on the basis of diagnosis group, age, sex, and race. Total attributable costs to Medicare for CAUTIs were estimated using the matched sample and a log-linear regression model with hospital fixed effects. A statistically significant difference was observed in total Medicare payments between the CAUTI cases and their matched non-CAUTI controls of $6,429 ($P < .001$). Adjusted for inflation, this translates to $7,670 in 2016 U.S. dollars.

Goudie et al. investigated the attributable cost of CAUTIs in surgical pediatric patients (ages 1-17 years).[16] Data were collected from the Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS) and were limited to the years 2009-2011. Differences in a patient's clinical severity were controlled using propensity score analysis. Each CAUTI case was matched with 2 controls to account for the fact that medically complex patients are simply more expensive to manage overall. The study investigators converted the charges available in HCUP-NIS's database into costs using cost-to-charge ratios. The findings of this study were an incidence rate of 130 CAUTIs per 10,000 at-risk pediatric patient discharges and an attributable cost of $7,200 (2011 U.S. dollars) for a pediatric CAUTI. Adjusted for inflation, the attributable cost of a pediatric CAUTI is approximately $8,398 in 2016 U.S. dollars.

CONCLUSIONS

Our systematic review of the literature identified only 4 studies that produced original estimates of the attributable costs of CAUTIs in the United Statew since the year 2000. In 2016 U.S. dollars, the reported attributable costs of CAUTIs were $876 (inpatient costs to the hospital for additional diagnostic tests and medications); $1,764 (inpatient costs to Medicare for non-ICU patients); $7,670 (inpatient and outpatient costs to Medicare); $8,398 (inpatient costs to the hospital for pediatric patients); and $10,197 (inpatient costs to Medicare for ICU patients).

The costs reported in the 4 included studies should be interpreted and compared with caution. Since there was a mix of cost perspectives (hospital vs. Medicare) and patient populations (adult vs. pediatric), it is not feasible to compare them directly to one another. However, we can conclude that the prevailing notion of a CAUTI costing approximately $1,000 is an underestimate and an oversimplification of its true economic burden. Many factors can increase the attributable cost well above $1,000. These include patient population (adult or pediatric patients), setting (ICU or non-ICU), infection etiology (resistant gram-negative pathogens and yeasts), and cost perspective (Medicare as payer, hospital, societal), to name a few.

Complications of CAUTIs, such as a secondary bacteremia, were not considered in any of the 4 included studies. However, CAUTIs have historically been reported as the primary cause of secondary hospital-acquired bacteremias, with approximately 17% of blood stream infections arising from a urinary source.[19,20] Such serious complications will certainly have cost implications. These may include the cost of multiple blood cultures, additional days of parenteral antibiotics, and a longer length of stay in the hospital. Although the incidence of secondary bacteremia in the setting of a CAUTI itself is relatively low (1%-4%), 1 study reported that it could increase the total cost of treatment by nearly $3,000 (in 1998 U.S. dollars; by $4,400 in 2016 U.S. dollars).[21,22] The cost contribution of any resultant bloodstream infection should at least be considered when attempting to gain an accurate picture of the entire cost burden of CAUTIs.

An additional weakness of 3 of our 4 included studies is that they did not account for CAUTIs that developed after the patient was discharged. According to Infectious Diseases Society of America clinical practice guidelines for CAUTIs, a urinary tract infection that develops within 48 hours after catheter removal is still attributable to the catheter, even if that patient has already been discharged.[23] This likely represents a portion of the CAUTI patient population that has not been accounted for in cost estimations.

Table 1
Summary of studies reporting the attributable cost of CAUTIs in the United States

Author	Year of pub.	Patient population	Data source	Setting	Sample size (N)	Cost perspective	Study design	Costs collected	Attributable costs (reported)	Attributable costs (2016 U.S. dollars)	Additional statistics reported
Tambyah et al.	2002	Adults	University hospital	Inpatient	1,497 (123 CAUTIs)	Hospital	Prospective, observational	Laboratory and medication costs	$589	$876	Standard deviation: ± $1,265
Kandilov et al.	2014	Medicare beneficiaries	MedPAR, MSAF	Inpatient and outpatient	5,161 cases, 24,984 controls	Medicare	Retrospective case-control (1:5 matching)	Total Medicare program payments	$6,429	$7,670	$P < .001$ for costs of cases compared to controls. 17.5% difference (unadjusted). Multivariate analysis: 24.5% point estimate for cost difference; 95% CI: 20.6%-28.4%
Yi et al.	2014	Medicare beneficiaries (CO, IL, NH, NY, PA, SC, TN, VA)	NHSN, MedPAR, BASF	ICU vs. non-ICU (inpatient)	884 cases, 4,410 controls	Medicare	Retrospective case-control (1:5 matching)	Total Medicare program payments	ICU: $18,979 (unadjusted); $8,548 (adjusted) Non-ICU: $4,281 (unadjusted); $1,479 (adjusted).	ICU: $10,197 (adjusted value). Non-ICU: $1,764 (adjusted value)	$P<.0001$ for adjusted costs in both ICU and non-ICU cohorts 95% CIs: $6,062-$11,035 (ICU), $909-$2,050 (non-ICU)
Goudie et al.	2015	Pediatric	HCUP-NIS	Inpatient	1,513 cases, 3,026 controls	Hospital	Retrospective case-control (1:2 propensity score matching)	Total inpatient charges were converted to costs using cost-to-charge ratios	$7,200	$8,398	95% CI: $2,224-$12,176 Relative ratio (cases/controls): 1.44 (95% CI: 1.09-1.87)

Adjusted indicates results from a multivariable regression analysis.
BASF, Beneficiary Annual Summary File; *CAUTI*, catherter-associated urinary tract infection; *CI*, confidence interval; *HCUP*, Healthcare Cost and Utilization Project; *ICU*, intensive care unit; *MedPAR*, Medicare Provider Analysis and Review; *MSAF*, Medicare Standard Analytic Files; *NHSN*, National Healthcare Safety Network; *NIS*, National Inpatient Sample.

Several studies that discuss the cost of CAUTIs were not included in our review. Most of these studies were attempts to estimate the global burden of CAUTIs using estimates of prevalence combined with cost data either directly[14,24-26] or indirectly[27-30] from Tambyah et al. Other studies were excluded because they were performed outside of the United States, which makes cost comparisons difficult given differences in both practice patterns and healthcare financing.[31-36] Still other studies used cumulative incidence data and line-item costs to estimate attributable costs in place of actual patient cost data,[22] or they were quality improvement initiatives measuring cost reductions when antimicrobial catheters were used.[26-28,37-40] The attributable costs cited in these excluded articles and reviews were $676 (1998 U.S. dollars)[22]; $862 (2007 U.S. dollars)[14]; $1,007 (2007 U.S. dollars)[14]; $2,041 (1998 U.S. dollars)[38]; and $2,471-$3,391 (1999 U.S. dollars).[37]

The costs for CAUTIs summarized in a CDC report by Scott[14] have been frequently cited, but these costs are derived from other studies, including Tambyah et al.,[15] Anderson et al.[41] (who used costs from 2 foreign studies[36,42]), and Stone et al.[25,43] (who also used estimates from Tambyah et al.). Studies published before the year 2000 that addressed cost of CAUTIs were not included in our analysis because healthcare practices have changed substantially in the interim.[37,42,44-52]

In 2009, the CDC's NHSN suggested that the total economic burden of CAUTIs was $340 million in the United States. This was based on the assumption that the attributable cost of CAUTIs was $758 and the total number of CAUTIs per year was 449,334. If we assume 1) that admission trends have continued on their previous trajectory; 2) that 20% of critical care admissions require an ICU stay; and 3) that CAUTIs cost $10,197 in the ICU, $1,764 in non-ICU settings, and $8,398 for pediatric patients, then the total economic burden in 2016 dollars approaches $1.7 billion annually in the United States.

The study by Tambyah et al. has become a reference point for many researchers and infection control professionals, and it is frequently cited in other studies and reports, including the most recent CDC report on the status of healthcare-associated infections in U.S. hospitals and their direct medical costs.[53] However, a limitation of this study is that it included only diagnostic and medication costs that could be attributable to treating the CAUTI. Other cost drivers, such as increased hospital length of stay, were not included; therefore, even when the cost is adjusted for inflation, the cost reported is likely a substantial underestimate of the true total attributable cost.

An important and unique contribution of the Tambyah et al. study is that pathogen type may play a role in the cost to treat CAUTIs. Such a notion is reasonable when considering the treatment implications of multi-drug resistant organisms (MDROs). For MDROs, first-line empiric antimicrobials given to the patient before the urine culture and susceptibilities report are available will be largely ineffective. Thus, the patient will not begin to improve until broader-spectrum antibiotics or larger doses are administered. This delay in appropriate treatment could contribute to added costs by requiring more days of antibiotic therapy, requiring use of more costly antibiotics, and/or increasing the patient's length of hospital stay.

The increasing prevalence of multi-drug resistant pathogens isolated from CAUTIs is evident in the CDC's NHSN surveillance data.[54-56] Multi-drug resistant strains of *E. coli*, *Pseudomonas aeruginosa*, *Enterobacter* spp., *Klebsiella*, and *Enterococcus faecalis* have all shown increases from 2007 to 2014. MDROs can be especially prevalent in the setting of CAUTIs where bacteria tend to grow in biofilms on the inner surface of urinary catheter tubing.[21] Because bacteria growing in biofilms grow more slowly and can participate in unique cell signaling between one another, they can be particularly resistant to many antibiotics that would otherwise be effective for that pathogen.[21] Thus, MDROs in the setting of CAUTIs are likely to persist as barriers to treatment and affect costs now and well into the future.

The study by Yi et al. suggested that the overall clinical severity of a patient may influence costs to treat a CAUTI. One author has suggested that underlying diseases may be synergistic with hospital-acquired infections, especially MDRO infections.[57] Thus, sicker patients may experience a disproportionate decline in clinical severity compared to less clinically severe patients, even when infected with the same pathogen. Another possible explanation for Yi et al.'s findings are that ICU patients will of necessity remain on intravenous antibiotics for a longer period of time than their non-ICU counterparts, who can be switched to less expensive orals faster as their health state improves. Targeted prevention of CAUTIs in ICU patients may be warranted to yield substantial cost savings.

An important contribution of Kandilov et al. was that they considered all costs up to 90 days after discharge. Care for a CAUTI may continue after a patient leaves the hospital, either because the patient will finish a course of antibiotics outside the hospital or because the infection was not detected until after discharge. These factors affect CAUTIs' total economic burden and have largely been ignored by other studies.

The findings by Goudie et al. suggest that treating a CAUTI in a pediatric patient can be costlier compared to an adult patient.[16] Although it is unclear why this may be, a contributing factor could be a difference in drug therapy. Fluoroquinolones, for example, are often a treatment option for CAUTIs in adults; however, they are not necessarily the drug of choice in children, due to the risk of tendon rupture. The use of alternative therapies in children may contribute to increased costs. A major strength of the Goudie et al. study was its use of a propensity score matching algorithm to control for differences in clinical severity. Thus, matching a CAUTI patient to 1 or more non-CAUTI patients of similar clinical severity helped ensure that cost differences were representative of CAUTIs' attributable costs rather than the differences in medical complexity alone. Their use of a large national database instills further confidence in their results and conclusions.

A major limitation of our systematic review is that we could not perform a meta-analysis on the available cost estimates found in the literature. The varying study populations (adult, pediatric, Medicare beneficiaries, ICU, and non-ICU), as well as the differing study designs (case-control, cohort studies, etc.) and cost perspectives precluded a reliable pooling of the data. Another issue is that there are indirect implications for CAUTIs faced by hospitals that are not reflected in these estimates of the cost of CAUTIs. Although a higher rate of CAUTIs does not guarantee that a hospital will face penalties under the HACRP, it does place hospitals at greater risk of meeting the threshold for financial penalties. Thus, even these attributable costs likely underestimate the total burden to hospitals for CAUTIs.

Since the HACRP took effect in 2008, CAUTIs and other HACs are no longer reimbursable.[9-11] The goal of the legislation was to promote safer practices within all types of healthcare settings and to encourage improvement initiatives. As healthcare facilities consider their own best practices, it is instructive to have an accurate estimate of the attributable costs of CAUTIs. This provides the means to assess the economic value of new initiatives and guide decisions about the level of investment in prevention.

Additional research is needed to better understand the attributable cost of CAUTIs among non-Medicare patients, in all-payer inpatient settings, and among individuals residing in long-term care facilities. The work by Yi et al. and Goudie et al. both noted extended length of stays for patients with CAUTIs. However, this would be another facet of attributable costs worthy of further study due to its significant contribution to costs and in light of the current debate on how to value time-dependent bias. Such information will

help clinical decision-makers and hospital administrators better understand the implications of performance improvement and newer technologies that may prevent CAUTIs.

References

1. Stone PW. Economic burden of healthcare-associated infections: an American perspective. Expert Rev Pharmacoecon Outcomes Res 2009;9:417-22.
2. Dudeck MA, Edwards JR, Allen-Bridson K, Gross C, Malpiedi PJ, Peterson KD, et al. National Healthcare Safety Network report, data summary for 2013, Device-associated Module. Am J Infect Control 2015;43:206-21.
3. Platt R, Polk BF, Murdock B, Rosner B. Risk factors for nosocomial urinary tract infection. Am J Epidemiol 1986;124:977-85.
4. Wald HL, Ma A, Bratzler DW, Kramer AM. Indwelling urinary catheter use in the postoperative period: analysis of the national surgical infection prevention project data. Arch Surg 2008;143:551-7.
5. Kunin CM, McCormack RC. Prevention of catheter-induced urinary-tract infections by sterile closed drainage. N Engl J Med 1966;274:1155-61.
6. Lo E, Nicolle LE, Coffin SE, Gould C, Maragakis LL, Meddings J, et al. Strategies to prevent catheter-associated urinary tract infections in acute care hospitals: 2014 update. Infect Control Hosp Epidemiol 2014;35:464-79.
7. Riley DK, Classen DC, Stevens LE, Burke JP. A large randomized clinical trial of a silver-impregnated urinary catheter: lack of efficacy and staphylococcal superinfection. Am J Med 1995;98:349-56.
8. Centers for Disease Control and Prevention. Catheter-associated Urinary Tract Infections (CAUTI). Health-care associated infections; 2015. Available from: https://www.cdc.gov/hai/ca_uti/uti.html. Accessed February 27, 2017.
9. Federal Register. Volume 73, Issue 161 (August 19, 2008). 2008; Available from: https://www.gpo.gov/fdsys/pkg/FR-2008-08-19/pdf/FR-2008-08-19.pdf. Accessed 8 February, 2017.
10. Tatti P, Lehmann ED. A prospective randomised-controlled pilot study for evaluating the teaching utility of interactive educational diabetes simulators. Diabetes Nutr Metab 2003;16:7-23.
11. Tatti P, Lehmann ED. A randomised-controlled clinical trial methodology for evaluating the teaching utility of interactive educational diabetes simulators. Diabetes Nutr Metab 2001;14:1-17.
12. Dranove D. Pricing by non-profit institutions. The case of hospital cost-shifting. J Health Econ 1988;7:47-57.
13. Dor A, Farley DE. Payment source and the cost of hospital care: evidence from a multiproduct cost function with multiple payers. J Health Econ 1996;15:1-21.
14. Scott RD. The direct medical costs of healthcare-associated infections in U.S. hospitals and the benefits of prevention. Centers for Disease Control and Prevention; 2009.
15. Tambyah PA, Knasinski V, Maki DG. The direct costs of nosocomial catheter-associated urinary tract infection in the era of managed care. Infect Control Hosp Epidemiol 2002;23:27-31.
16. Goudie A, Dynan L, Brady PW, Fieldston E, Brilli RJ, Walsh KE. Costs of venous thromboembolism, catheter-associated urinary tract infection, and pressure ulcer. Pediatrics 2015;136:432-9.
17. Kandilov AM, Coomer NM, Dalton K. The impact of hospital-acquired conditions on Medicare program payments. Medicare Medicaid Res Rev 2014;4.
18. Yi SH, Baggs J, Gould CV, Scott RD 2nd, Jernigan JA. Medicare reimbursement attributable to catheter-associated urinary tract infection in the inpatient setting: a retrospective cohort analysis. Med Care 2014;52:469-78.
19. Weinstein MP, Towns ML, Quartey SM, Mirrett S, Reimer LG, Parmigiani G, et al. The clinical significance of positive blood cultures in the 1990s: a prospective comprehensive evaluation of the microbiology, epidemiology, and outcome of bacteremia and fungemia in adults. Clin Infect Dis 1997;24:584-602.
20. Gould C, Umscheid CA, Agarwal RK, Kuntz G, Pegues DA. Guideline for the Prevention of Catheter-Associated Urinary Tract Infections 2009. 2009. Available from: https://www.cdc.gov/infectioncontrol/guidelines/cauti/. Accessed October 6, 2017.
21. Saint S, Chenoweth CE. Biofilms and catheter-associated urinary tract infections. Infect Dis Clin North Am 2003;17:411-32.
22. Saint S. Clinical and economic consequences of nosocomial catheter-related bacteriuria. Am J Infect Control 2000;28:68-75.
23. Hooton TM, Bradley SF, Cardenas DD, Colgan R, Geerlings SE, Rice JC, et al. Diagnosis, prevention, and treatment of catheter-associated urinary tract infection in adults: 2009 International Clinical Practice Guidelines from the Infectious Diseases Society of America. Clin Infect Dis 2010;50:625-63.
24. Umscheid CA, Mitchell MD, Doshi JA, Agarwal R, Williams K, Brennan PJ. Estimating the proportion of healthcare-associated infections that are reasonably preventable and the related mortality and costs. Infect Control Hosp Epidemiol 2011;32:101-14.
25. Stone PW, Braccia D, Larson E. Systematic review of economic analyses of health care-associated infections. Am J Infect Control 2005;33:501-9.
26. Sutherland T, Beloff J, McGrath C, Liu X, Pimentel MT, Kachalia A, et al. A single-center multidisciplinary initiative to reduce catheter-associated urinary tract infection rates: quality and financial implications. Health Care Manag (Frederick) 2015;34:218-24.
27. Brilli RJ, McClead RE Jr, Crandall WV, Stoverock L, Berry JC, Wheeler TA, et al. A comprehensive patient safety program can significantly reduce preventable harm, associated costs, and hospital mortality. J Pediatr 2013;163:1638-45.
28. Clarke K, Tong D, Pan Y, Easley KA, Norrick B, Ko C, et al. Reduction in catheter-associated urinary tract infections by bundling interventions. Int J Qual Health Care 2013;25:43-9.
29. Zielinski MD, Kuntz MM, Polites SF, Boggust A, Nelson H, Khasawneh MA, et al. A prospective analysis of urinary tract infections among elderly trauma patients. J Trauma Acute Care Surg 2015;79:638-42.
30. Rhee C, Phelps ME, Meyer B, Reed WG. Viewing prevention of catheter-associated urinary tract infection as a system: using systems engineering and human factors engineering in a quality improvement project in an academic medical center. Jt Comm J Qual Patient Saf 2016;42:447-71.
31. Huang WC, Wann SR, Lin SL, Kunin CM, Kung MH, Lin CH, et al. Catheter-associated urinary tract infections in intensive care units can be reduced by prompting physicians to remove unnecessary catheters. Infect Control Hosp Epidemiol 2004;25:974-8.
32. Pickard R, Lam T, Maclennan G, Starr K, Kilonzo M, McPherson G, et al. Types of urethral catheter for reducing symptomatic urinary tract infections in hospitalised adults requiring short-term catheterisation: multicentre randomised controlled trial and economic evaluation of antimicrobial- and antiseptic-impregnated urethral catheters (the CATHETER trial). Health Technol Assess 2012;16:1-197.
33. Apisarnthanarak A, Rutjanawech S, Wichansawakun S, Ratanabunjerdkul H, Patthranitima P, Thongphubeth K, et al. Initial inappropriate urinary catheters use in a tertiary-care center: incidence, risk factors, and outcomes. Am J Infect Control 2007;35:594-9.
34. Chen YY, Chou YC, Chou P. Impact of nosocomial infection on cost of illness and length of stay in intensive care units. Infect Control Hosp Epidemiol 2005;26:281-7.
35. Chen YY, Wang FD, Liu CY, Chou P. Incidence rate and variable cost of nosocomial infections in different types of intensive care units. Infect Control Hosp Epidemiol 2009;30:39-46.
36. Moris de la Tassa J, Fernandez Munoz P, Antuna Egocheaga A, Gutierrez del Rio MC, Carton Sanchez JA. Estimating the costs associated with nosocomial urinary tract infection. A case-control study. Rev Clin Esp 2003;203:119-24.
37. Bologna RA, Tu LM, Polansky M, Fraimow HD, Gordon DA, Whitmore KE. Hydrogel/silver ion-coated urinary catheter reduces nosocomial urinary tract infection rates in intensive care unit patients: a multicenter study. Urology 1999;54:982-7.
38. Saint S, Veenstra DL, Sullivan SD, Chenoweth C, Fendrick AM. The potential clinical and economic benefits of silver alloy urinary catheters in preventing urinary tract infection. Arch Intern Med 2000;160:2670-5.
39. Cho HJ, Khalil S, Poeran J, Mazumdar M, Bravo N, Wallach F, et al. "Lose the tube": a choosing wisely initiative to reduce catheter-associated urinary tract infections in hospitalist-led inpatient units. Am J Infect Control 2017;45:333-5.
40. Seymour C. Audit of catheter-associated UTI using silver alloy-coated Foley catheters. Br J Nurs 2006;15:598-603.
41. Anderson DJ, Kirkland KB, Kaye KS, Thacker PA 2nd, Kanafani ZA, Auten G, et al. Underresourced hospital infection control and prevention programs: penny wise, pound foolish? Infect Control Hosp Epidemiol 2007;28:767-73.
42. Coello R, Glenister H, Fereres J, Bartlett C, Leigh D, Sedgwick J, et al. The cost of infection in surgical patients: a case-control study. J Hosp Infect 1993;25:239-50.
43. Stone PW, Larson E, Kawar LN. A systematic audit of economic evidence linking nosocomial infections and infection control interventions: 1990-2000. Am J Infect Control 2002;30:145-52.
44. French GL, Cheng AF. Measurement of the costs of hospital infection by prevalence surveys. J Hosp Infect 1991;18 Suppl A:65-72.
45. Girard R, Fabry J, Meynet R, Lambert DC, Sepetjan M. Costs of nosocomial infection in a neonatal unit. J Hosp Infect 1983;4:361-6.
46. Haley RW, Schaberg DR, Crossley KB, Von Allmen SD, McGowan JE Jr. Extra charges and prolongation of stay attributable to nosocomial infections: a prospective interhospital comparison. Am J Med 1981;70:51-8.
47. Jarvis WR. Selected aspects of the socioeconomic impact of nosocomial infections: morbidity, mortality, cost, and prevention. Infect Control Hosp Epidemiol 1996;17:552-7.
48. Platt R, Polk BF, Murdock B, Rosner B. Mortality associated with nosocomial urinary-tract infection. N Engl J Med 1982;307:637-42.
49. Platt R, Polk BF, Murdock B, Rosner B. Prevention of catheter-associated urinary tract infection: a cost-benefit analysis. Infect Control Hosp Epidemiol 1989;10:60-4.
50. Rubinstein E, Green M, Modan M, Amit P, Bernstein L, Rubinstein A. The effects of nosocomial infections on the length and costs of hospital stay. J Antimicrob Chemother 1982;9 Suppl A:93-100.
51. Vegas AA, Jodra VM, Garcia ML. Nosocomial infection in surgery wards: a controlled study of increased duration of hospital stays and direct cost of hospitalization. Eur J Epidemiol 1993;9:504-10.
52. Haley RW, White JW, Culver DH, Hughes JM. The financial incentive for hospitals to prevent nosocomial infections under the prospective payment system. An empirical determination from a nationally representative sample. JAMA 1987;257:1611-4.
53. Barnes ZJ, Mahabir RC. Catheter use and infection reduction in plastic surgery. Can J Plast Surg 2013;21:79-82.
54. Hidron AI, Edwards JR, Patel J, Horan TC, Sievert DM, Pollock DA, et al. NHSN annual update: antimicrobial-resistant pathogens associated with

healthcare-associated infections: annual summary of data reported to the National Healthcare Safety Network at the Centers for Disease Control and Prevention, 2006-2007. Infect Control Hosp Epidemiol 2008;29:996-1011.
55. Sievert DM, Ricks P, Edwards JR, Schneider A, Patel J, Srinivasan A, et al. Antimicrobial-resistant pathogens associated with healthcare-associated infections: summary of data reported to the National Healthcare Safety Network at the Centers for Disease Control and Prevention, 2009-2010. Infect Control Hosp Epidemiol 2013;34:1-14.
56. Weiner LM, Webb AK, Limbago B, Dudeck MA, Patel J, Kallen AJ, et al. Antimicrobial-resistant pathogens associated with healthcare-associated infections: summary of data reported to the National Healthcare Safety Network at the Centers for Disease Control and Prevention, 2011-2014. Infect Control Hosp Epidemiol 2016;37:1288-301.
57. Cosgrove SE. The relationship between antimicrobial resistance and patient outcomes: mortality, length of hospital stay, and health care costs. Clin Infect Dis 2006;42(Suppl 2):S82-9.