Published in final edited form as:

Infect Control Hosp Epidemiol. 2010 June ; 31(6): 598–606. doi:10.1086/652524.

Universal Methicillin-Resistant *Staphylococcus aureus* (MRSA) Surveillance for Adults at Hospital Admission: An Economic Model and Analysis

Bruce Y. Lee, MD, MBA, Rachel R. Bailey, MPH, Kenneth J. Smith, MD, MS, Robert R. Muder, MD, Elsa S. Strotmeyer, PhD, G. Jonathan Lewis, DO, MPH, Paul J. Ufberg, DO, MBA, Yeohan Song, and Lee H. Harrison, MD

Section of Decision Sciences and Clinical Systems Modeling (B.Y.L., R.R.B., K.J.S., G.J.L., P.J.U., Y.S.), Department of Biomedical Informatics (B.J.L., R.R.B., G.J.L., P.J.U., Y.S.), Department of Epidemiology, Graduate School of Public Health (B.J.L., R.R.B., E.S.S., G.J.L., P.J.U., Y.S.), Division of Infectious Diseases (R.R.M.), Veterans Affairs Pittsburgh Health Care System, and Infectious Diseases Epidemiology Research Unit, School of Medicine and Graduate School of Public Health, University of Pittsburgh (L.H.H.), Pittsburgh, Pennsylvania

Abstract

BACKGROUND—Methicillin-resistant *Staphylococcus aureus* (MRSA) transmission and infections are a continuing problem in hospitals. Although some have recommended universal surveillance for MRSA at hospital admission to identify and to isolate MRSA-colonized patients, there is a need for formal economic studies to determine the cost-effectiveness of such a strategy.

METHODS—We developed a stochastic computer simulation model to determine the potential economic impact of performing MRSA surveillance (ie, single culture of an anterior nares specimen) for all hospital admissions at different MRSA prevalences and basic reproductive rate thresholds from the societal and third party–payor perspectives. Patients with positive surveillance culture results were placed under isolation precautions to prevent transmission by way of respiratory droplets. MRSA-colonized patients who were not isolated could transmit MRSA to other hospital patients.

RESULTS—The performance of universal MRSA surveillance was cost-effective (defined as an incremental cost-effectiveness ratio of less than \$50,000 per quality-adjusted life-year) when the basic reproductive rate was 0.25 or greater and the prevalence was 1% or greater. In fact, surveillance was the dominant strategy when the basic reproductive rate was 1.5 or greater and the prevalence was 15% or greater, the basic reproductive rate was 2.0 or greater and the prevalence was 10% or greater, and the basic reproductive rate was 2.5 or greater and the prevalence was 5% or greater.

CONCLUSIONS—Universal MRSA surveillance of adults at hospital admission appears to be cost-effective at a wide range of prevalence and basic reproductive rate values. Individual hospitals and healthcare systems could compare their prevailing conditions (eg, the prevalence of MRSA colonization and MRSA transmission dynamics) with the benchmarks in our model to help determine their optimal local strategies.

Methicillin-resistant *Staphylococcus aureus* (MRSA), an antibiotic-resistant bacterium, is a significant cause of nosocomial infection and a major public health problem in many countries, resulting in substantial morbidity and mortality.¹ Spread of MRSA from patient to patient can occur insidiously, because most patients colonized with MRSA are asymptomatic. Hospitals are prime locations for MRSA transmission. Therefore, many public health officials, policy makers, infection control personnel, and hospital administrators have considered different hospital-based strategies to mitigate the spread and impact of MRSA.²

Some people have suggested the implementation of universal, hospital-wide, active MRSA surveillance; that is, screening all patients on admission for MRSA colonization to identify which patients to place under contact precautions to prevent spread to others. Although some healthcare systems have adopted this policy, many have not. Surveillance programs can be costly, and the economic value of universal surveillance has not been well established.^{3–5}

To determine the potential economic value of universal MRSA surveillance, we developed a computer model that simulated the decision of whether to perform active surveillance for MRSA colonization for all adults admitted to an acute care health facility. Our simulation model incorporated dynamic transmission elements to represent the potential spread of MRSA from colonized patients to susceptible patients. Our goal was to map how the cost-effectiveness of universal surveillance may vary according to the MRSA prevalence and the basic reproductive rate. The results of our model may help guide policy making and the design of future epidemiological and clinical studies.

METHODS

Model Structure

Using TreeAge Pro 2008 (TreeAge Software), we developed a stochastic decision analytic computer simulation model with dynamic transmission elements that depicted the decision about whether to perform MRSA surveillance testing (ie, single culture of an anterior nares specimen) on all adult patients admitted to an acute care hospital. The model assumed both the societal and third party–payor perspectives and simulated the potential consequences of the decision.

Figure 1A depicts the general structure of the decision model. Each patient entering the model has a probability of being colonized with MRSA that is based on the MRSA prevalence. Each patient is then admitted to the hospital and either undergoes or does not undergo a single nares specimen surveillance culture for MRSA. Surveillance cultures can have positive or negative results, depending on whether the patient actually has MRSA and on the sensitivity and specificity of the test. Test sensitivity and specificity values were obtained from an extensive search of the literature. Patients with positive culture results then are placed under respiratory-droplet isolation precautions, regardless of whether they actually are colonized with MRSA (ie, even if the results are false-positive). Patients with negative test results are not isolated and may transmit MRSA if they are actually colonized with MRSA (ie, if the results are false-negative). Patients who are not tested are not isolated, regardless of their MRSA colonization status. The median age of a patient is 40 years. MRSA-colonized patients who are not isolated can transmit MRSA to other hospital patients, either directly or through healthcare personnel. The number of additional cases generated by each MRSA-colonized patient is determined by the basic reproductive rate. Each new case patient then enters an MRSA outcomes submodel.

Figure 2 shows the general structure of the MRSA outcomes model. Patients colonized with MRSA can remain asymptomatic or can develop different combinations of the following clinical syndromes: cellulitis, urinary tract infection, line infection, wound infection, abscess, pneumonia, osteomyelitis, septic shock, bacteremia, endocarditis, and cardiac surgery. For example, one patient traveling through the model may develop cellulitis. Another patient may have cellulitis, pneumonia, and endocarditis that requires cardiac surgery. Each clinical syndrome may require certain diagnostic and therapeutic procedures. Certain conditions, such as bacteremia, are prerequisites in the model for other conditions; for example, septic shock.

For each simulation run, we determined the incremental cost-effectiveness ratio (ICER) of MRSA testing, according to the following formula:

$$\text{ICER} = \frac{\text{Cost}_{\text{MRSA Surveillance}} - \text{Cost}_{\text{No Surveillance}}}{\text{Effectiveness}_{\text{MRSA Surveillance}} - \text{Effectiveness}_{\text{No Surveillance}}}$$

Data Inputs

Table 1 lists the input parameters for our model, divided into probabilities, costs, and utilities, as well as the distribution parameters for each variable. Appendix A (available online only) lists the data sources used for each variable. Probabilities assumed β distributions, except for the sensitivity and specificity of MRSA testing, the probability of development of an abscess, and the probability of development of osteomyelitis, which assumed triangular distributions. β Distributions frequently are used for clinical probability variables that are bounded by 0 and 1 and that approximate normal distributions.^{6,7} Also, the condition-specific mortality rates remained fixed. We used triangular distributions for all costs, except for the cost of death, which was a fixed \$5,000.⁸ Triangular distributions are typically used when a parameter distribution is asymmetric, sample data are limited, and only the lower limit, mode, and upper limit are known.⁹ Because our goal was to remain conservative about the benefits of surveillance and thus the costs associated with MRSA infection, the accrued cost of hospitalization was based on a patient's most expensive condition (eg, the cost of hospitalization for a patient with bacteremia, osteomyelitis, and a wound infection was equivalent to the cost of hospitalization for the most expensive condition, osteomyelitis). In other words, when a patient is hospitalized with multiple conditions, their true cost of hospitalization is usually somewhere between the cost of their most expensive condition and the sum of the costs of each condition. This has been seen in previous economic studies of patients hospitalized with multiple conditions, as well as in the Healthcare Utilization Project Nationwide Inpatient Sample.^{10–12} We chose the lowest value of this spectrum. All costs were in 2008 US dollars. A discount rate of 3% converted past and future costs into 2008 dollars.

Our model measured effectiveness in quality-adjusted life-years (QALYs). The probability distributions of life expectancy came from the Human Mortality Database.¹³ QALY decrements (Table 1) occurred from each respective medical condition.¹⁴ We assumed that the decrements persisted for the duration of each medical condition, which was for most cases 1 week.

Colonized patients had to have an active infection before they developed any complicating conditions. Additionally, patients with an MRSA urinary tract infection received a 3- to 5-day course of vancomycin, those with MRSA osteomyelitis received a 6-week course, and those with MRSA infective endocarditis received a 4- to 6-week course. Patients with all other types of MRSA infection received a 10- to 14-day course of vancomycin. The cost of vancomycin was a γ distribution with a mean of \$9.01 and a standard deviation of \$5.00.¹⁵

γ Distributions fit continuous variables that always have positive values and that have skewed distributions. Healthcare costs tend to have this distribution, with the majority of costs centered around the lower end of the cost range and a long narrow tail extending to the right that represents the small percentage of cases with very high costs.^{16,17}

To determine the probabilities of different clinical outcomes, we conducted a MEDLINE search with the key words “methicillin-resistant *Staphylococcus aureus*” and “MRSA,” with and without the key word “outcomes.” The search was limited to English language articles published since 2000, and it excluded surgical patient populations. Articles published prior to 2000 were excluded from the model because pre-2000 medical therapy may be inconsistent with current practices. Our literature review also excluded case reports and case series that did not contain patient populations large enough to permit determination of the probabilities of specified outcomes. For each probability parameter, we then abstracted all the probabilities from the identified studies from the literature search. The median value of these probabilities then became the mean for the distribution used in the model (eg, 0.26 was the median probability that an MRSA-colonized patient would develop an infection, based on the 8 studies identified by the literature search). The standard deviation or range of the values from the identified studies then generated the standard deviation or range for the distribution used in the model.

Sensitivity Analyses

Because MRSA prevalence may differ widely from hospital to hospital, we examined the effects of systematically varying the prevalence (ie, probability) of MRSA colonization from 1% to 9%. Moreover, as the actual basic reproductive rate of MRSA transmission has not been established and may vary depending on the hospital setting, we also systematically varied the basic reproductive rate from 0.25 to 3.0. In addition, probabilistic (Monte Carlo) sensitivity analyses simultaneously varied the values of each parameter through the ranges shown in Table 1.

Opportunity Cost of Lost Hospital Bed-Days

MRSA infections can extend a patient's length of stay (LOS); the patient occupies a hospital bed that could have been used by another patient and, in turn, this costs the hospital revenue. An alternative set of analyses involved rerunning our simulations by means of the Graves method to convert LOS increases that were attributable to MRSA infection to economic costs.^{18,19} LOS estimates for each clinical condition came from the National Inpatient Sample from the Healthcare Utilization Project.¹²

Scenarios Accounting for Preidentified MRSA Carriers

Hospitals with ongoing MRSA surveillance programs may maintain records of identified MRSA carriers who, when readmitted in the future, may immediately be placed under contact precautions (to preclude further transmission) and who might not undergo routine surveillance. A second version of the model accounted for this possibility and included additional branches, shown in Figure 1B, that shunted these preidentified MRSA carriers (who constituted a certain percentage of total hospital medical admissions) directly to contact precautions. Sensitivity analyses varied the proportion of MRSA carriers who were preidentified from 10% to 33%.

RESULTS

Baseline Model

Each simulation run consisted of 1,000 trials of 1,000 patients (for a total of 1,000,000 patients traveling through the model). Table 2 shows how the optimal choice of whether to

test for MRSA varies with the hospital prevalence of MRSA colonization and the basic reproductive rate both for our base case disease-cost method and for the lost hospital bed-days method. As Table 2 demonstrates, the 2 methods gave comparable results. Performing universal surveillance was the dominant strategy (less costly and more effective) at the following prevalence and basic reproductive rate combinations: when the basic reproductive rate was 1.5 or greater and the prevalence was 15% or greater, when the basic reproductive rate was 2.0 or greater and the prevalence was 10% or greater, and when the basic reproductive rate was 2.5 or greater and the prevalence was 5% or greater. Universal surveillance remained cost-effective (defined as an ICER of less than \$50,000/QALY) when the basic reproductive rate was 0.25 or greater and the prevalence was 1% or greater; that is, for all prevalence and basic reproductive rate combinations that we tested. In our model, MRSA infections resulted in a mean increase in patient LOS of 5.1 days, and each lost bed-day corresponded to \$1,412.29 in lost revenue.

Figure 3 presents the acceptability curves for different prevalence levels and a basic reproductive rate of 0.25. These curves display the percentage of patients in each 1,000,000-patient simulation for which surveillance was the cost-effective choice, compared with no surveillance, at different willingness-to-pay levels. For example, if the MRSA colonization prevalence is 1%, surveillance is the cost-effective selection for more than 50% of the simulated patients when the willingness-to-pay value is more than \$10,000.

Figure 4 shows the ICER of all trials in which there was no dominant strategy. As MRSA prevalence increases within a basic reproductive rate cohort, surveillance generally becomes more cost-effective. Moreover, at a given prevalence, as the basic reproductive rate increases, the ICER decreases. Even at an MRSA colonization prevalence of 1%, the ICER for surveillance is clearly less than \$10,000 per QALY for every basic reproductive rate level.

Model validation consisted of comparing the costs generated by our model with the costs reported by various studies in the literature. For example, our model generated a mean value of \$5,789 (range, \$4,904–\$6,674), which is consistent with the estimate of \$6,000–\$30,000 for the excess cost of antimicrobial-resistant infections reported by Maragakis et al.²⁰ Because we endeavored to remain conservative about the cost of MRSA infection and, in turn, the economic value of surveillance, our cost values were on the lower end of the reported range.^{21,22} Moreover, 2 different costing methodologies (the direct disease-attributable cost and the opportunity cost of lost bed-days) generated similar results and provided additional convergent validation.

Model Accounting for Preidentified MRSA Carriers

The model that accounted for preidentified MRSA carriers generated very similar results: surveillance remained cost-effective throughout the range of scenarios tested. For example, when the prevalence of MRSA colonization was as low as 1%, the basic reproductive rate was as low as 0.25, and 33% of carriers were already preidentified and immediately placed under contact precautions, then the ICER for performing universal surveillance was \$10,863 per QALY. As the prevalence increased, the ICER further decreased, until universal surveillance became economically dominant. Similarly, increasing the basic reproductive rate made surveillance even more economically favorable. At a prevalence of 1% and with 33% of carriers preidentified, a basic reproductive rate of 3.0 resulted in an ICER of \$683 per QALY. Moreover, decreasing the proportion of MRSA carriers who were pre-identified also enhanced the economic value of universal surveillance. When we held the prevalence at 1% and the basic reproductive rate at 0.25, decreasing the proportion of pre-identified MRSA carriers to 10% of MRSA carriers resulted in an ICER of \$8,936 per QALY. Then, increasing the basic reproductive rate to 3.0 decreased the ICER to \$470 per QALY.

Surveillance was the dominant strategy when the basic reproductive rate was 2.0 or greater and the prevalence was 10% or greater or the basic reproductive rate was 2.5 or greater and the prevalence was 5% or greater.

DISCUSSION

Although the Society for Healthcare Epidemiology of America has recommended active MRSA surveillance, to our knowledge this recommendation has not yet been supported by detailed cost-effectiveness studies.^{23,24} In fact, there have been calls for economic analyses to determine the value of MRSA surveillance.^{22,25} Although some studies have outlined the total costs associated with implementing MRSA surveillance in particular units and facilities, they did not include formal economic analyses that looked at whether the effectiveness of these interventions justified the costs.^{26,27} Moreover, results from one location are not necessarily generalizable to other locations and situations, where MRSA prevalence and incidence can vary geographically and temporally by a significant amount.²⁸ Additionally, the transmission dynamics of MRSA have not been well characterized. It remains unclear how many new MRSA cases an index case will create. Some epidemiological studies have shown that surveillance decreases the incidence of nosocomial infections, whereas others have shown no effect.^{4,29,30}

Our goal was not to make the decision about whether to implement universal surveillance but to provide information about the potential cost-effectiveness of surveillance for different ranges of prevalence and different basic reproductive rates. Such information may help physicians, infection control specialists, hospital administrators, and policy makers make decisions on the basis of their unique local situations and conditions. Our model suggested that universal surveillance may be cost-effective (and in many cases cost-dominant) at a very wide range of prevalence and basic reproductive rate values (a basic reproductive rate from 0.25 to 3.0 and a prevalence of 1% or greater).

By design, our model may have underestimated the benefits of surveillance. We endeavored to be conservative in our cost estimates, choosing the more expensive form of isolation (ie, respiratory-droplet precautions) and the less expensive potential procedures for each MRSA clinical condition. Moreover, aside from mortality, our model assumed no potential chronic disability from MRSA infection (eg, amputation because of severe soft-tissue infection or decreased exercise tolerance because of severe respiratory infection or cardiac surgery). We also did not consider possible benefits to the initially colonized patient, such as decolonization of MRSA-positive patients. Decolonization involves treating the MRSA-colonized patient with antibiotics or disinfectants to remove colonization. However, to date, studies have not clearly established the efficacy of decolonization, because many decolonized patients reacquire MRSA. Finally, surveillance may confer additional long-term benefits not represented by our model. Information from surveillance (eg, MRSA colonization prevalence and MRSA infection incidence) can help public health personnel, hospital administrators, and researchers track the spread of MRSA and the effectiveness of various system-wide interventions.

Limitations

Every computer model is a simplification of real life and cannot fully represent every single event and outcome that may occur when an MRSA-colonized patient enters the hospital. The model assumed that patients would be tested and that results would become available before the patient could transmit MRSA to others. Although clinical outcomes may be worse with patients who have significant comorbidities, we did not stratify patients into sociodemographic, clinical, or risk factor groups. Furthermore, our study assumed that no decolonization of MRSA-colonized patients would occur.

Conclusions and Future Directions

Universal MRSA surveillance of adult general medical patients at admission may be cost-effective for a wide range of MRSA prevalences and MRSA transmission dynamics. Individual hospitals and healthcare systems could compare their prevailing conditions with the benchmarks in our model to help determine their optimal local strategies. Future studies should explore how the combinations of prevalence and transmission dynamics may vary from hospital to hospital and how additional measures, such as decolonization, may alter the economic value of surveillance.

Acknowledgments

Financial support. National Institute of General Medical Sciences Models of Infectious Disease Agent Study (MIDAS) (grant 5U01GM070708–05).

References

1. Beretta AL, Trabasso P, Stucchi RB, Moretti ML. Use of molecular epidemiology to monitor the nosocomial dissemination of methicillin-resistant *Staphylococcus aureus* in a university hospital from 1991 to 2001. *Braz J Med Biol Res.* 2004; 37(9):1345–1351. [PubMed: 15334200]
2. Harbarth S, Sax H, Fankhauser-Rodriguez C, Schrenzel J, Agostinho A, Pittet D. Evaluating the probability of previously unknown carriage of MRSA at hospital admission. *Am J Med.* 2006; 119(3):275.e15–275.e23. [PubMed: 16490475]
3. Farr BM. What to think if the results of the National Institutes of Health randomized trial of methicillin-resistant *Staphylococcus aureus* and van-comycin-resistant *Enterococcus* control measures are negative (and other advice to young epidemiologists): a review and an au revoir. *Infect Control Hosp Epidemiol.* 2006; 27(10):1096–1106. [PubMed: 17006818]
4. Wernitz MH, Swidsinski S, Weist K, et al. Effectiveness of a hospital-wide selective screening programme for methicillin-resistant *Staphylococcus aureus* (MRSA) carriers at hospital admission to prevent hospital-acquired MRSA infections. *Clin Microbiol Infect.* 2005; 11(6):457–465. [PubMed: 15882195]
5. Hsu CC, Lin YE, Chen YS, Liu YC, Muder RR. Validation study of artificial neural network models for prediction of methicillin-resistant *Staphylococcus aureus* carriage. *Infect Control Hosp Epidemiol.* 2008; 29(7):607–614. [PubMed: 18549315]
6. Spiegelhalter, DJ.; Abrams, KR. *Bayesian Approaches to Clinical Trials and Healthcare Evaluation.* 1. Hoboken, NJ: Wiley; 2004.
7. Chin, R.; Lee, BY. *Principles and Practice of Clinical Trial Medicine.* 1. New York: Elsevier/Academic Press; 2008.
8. Smith KJ, Roberts MS. Cost-effectiveness of newer treatment strategies for influenza. *Am J Med.* 2002; 113(4):300–307. [PubMed: 12361816]
9. Evans, M.; Hastings, N.; Peacock, B. *Statistical Distributions.* 3. New York: Wiley; 2000. Triangular distribution; p. 187–188.
10. Friedman B, Jiang HJ, Elixhauser A. Costly hospital readmissions and complex chronic illness. *Inquiry.* 2008; 45(4):408–421. [PubMed: 19209836]
11. Hernandez C, Jansa M, Vidal M, et al. The burden of chronic disorders on hospital admissions prompts the need for new modalities of care: a cross-sectional analysis in a tertiary hospital. *QJM.* 2009; 102(3):193–202. [PubMed: 19147657]
12. Levit, K., Thomson Reuters; Stranges, E., Thomson Reuters; Ryan, K., Thomson Reuters; Elixhauser, A, AHRQ. *HCUP Facts and Figures, 2007: Statistics on Hospital-Based Care in the United States.* Rockville, MD: Agency for Healthcare Research and Quality; 2008.
13. Wilmoth, JR.; Shkolnikov, V. [Accessed January 21, 2008.] Human mortality database. <http://www.mortality.org>
14. Tengs TO, Wallace A. One thousand health-related quality-of-life estimates. *Med Care.* 2000; 38(6):583–637. [PubMed: 10843310]

15. Bounthavong M, Hsu DI, Okamoto MP. Cost-effectiveness analysis of linezolid vs vancomycin in treating methicillin-resistant *Staphylococcus aureus*-complicated skin and soft-tissue infections using a decision analytic model. *Int J Clin Pract*. 2009; 63(3):376–386. [PubMed: 19222624]
16. Thompson SG, Nixon RM. How sensitive are cost-effectiveness analyses to choice of parametric distributions? *Med Decis Making*. 2005; 25(4):416–423. [PubMed: 16061893]
17. Nixon RM, Thompson SG. Parametric modelling of cost data in medical studies. *Stat Med*. 2004; 23(8):1311–1331. [PubMed: 15083485]
18. Graves N. Economics and preventing hospital-acquired infection. *Emerg Infect Dis*. 2004; 10(4): 561–566. [PubMed: 15200842]
19. Graves N, Halton K, Lairson D. Economics and preventing hospital-acquired infection: broadening the perspective. *Infect Control Hosp Epidemiol*. 2007; 28(2):178–184. [PubMed: 17265399]
20. Maragakis LL, Perencevich EN, Cosgrove SE. Clinical and economic burden of antimicrobial resistance. *Expert Rev Anti Infect Ther*. 2008; 6(5):751–763. [PubMed: 18847410]
21. Ben-David D, Novikov I, Mermel LA. Are there differences in hospital cost between patients with nosocomial methicillin-resistant *Staphylococcus aureus* bloodstream infection and those with methicillin-susceptible *S. aureus* bloodstream infection? *Infect Control Hosp Epidemiol*. 2009; 30(5):453–460. [PubMed: 19344266]
22. Resch A, Wilke M, Fink C. The cost of resistance: incremental cost of methicillin-resistant *Staphylococcus aureus* (MRSA) in German hospitals. *Eur J Health Econ*. 2009; 10(3):287–297. [PubMed: 19015905]
23. Muto CA, Jernigan JA, Ostrowsky BE, et al. SHEA guideline for preventing nosocomial transmission of multidrug-resistant strains of *Staphylococcus aureus* and *Enterococcus*. *Infect Control Hosp Epidemiol*. 2003; 24(5):362–386. [PubMed: 12785411]
24. McGinagle KL, Gourlay ML, Buchanan IB. The use of active surveillance cultures in adult intensive care units to reduce methicillin-resistant *Staphylococcus aureus*-related morbidity, mortality, and costs: a systematic review. *Clin Infect Dis*. 2008; 46(11):1717–1725. [PubMed: 18494098]
25. Troillet N, Carmeli Y, Samore MH, et al. Carriage of methicillin-resistant *Staphylococcus aureus* at hospital admission. *Infect Control Hosp Epidemiol*. 1998; 19(3):181–185. [PubMed: 9552186]
26. Schultz ED, Tanaka DT, Goldberg RN, Benjamin DK, Smith PB. Effect of methicillin-resistant *Staphylococcus aureus* colonization in the neonatal intensive care unit on total hospital cost. *Infect Control Hosp Epidemiol*. 2009; 30(4):383–385. [PubMed: 19222371]
27. Goetghebuer M, Landry PA, Han D, Vicente C. Methicillin-resistant *Staphylococcus aureus*: a public health issue with economic consequences. *Can J Infect Dis Med Microbiol*. 2007; 18(1):27–34. [PubMed: 18923684]
28. Tiemersma EW, Bronzwaer SL, Lyytikäinen O, et al. Methicillin-resistant *Staphylococcus aureus* in Europe, 1999–2002. *Emerg Infect Dis*. 2004; 10(9):1627–1634. [PubMed: 15498166]
29. Tomic V, Svetina Sorli P, Trinkaus D, Sorli J, Widmer AF, Trampuz A. Comprehensive strategy to prevent nosocomial spread of methicillin-resistant *Staphylococcus aureus* in a highly endemic setting. *Arch Intern Med*. 2004; 164(18):2038–2043. [PubMed: 15477440]
30. Harbarth S, Fankhauser C, Schrenzel J, et al. Universal screening for methicillin-resistant *Staphylococcus aureus* at hospital admission and nos-ocomial infection in surgical patients. *JAMA*. 2008; 299(10):1149–1157. [PubMed: 18334690]

FIGURE 1.

A, Main model structure. *The original methicillin-resistant *Staphylococcus aureus* (MRSA) case generates new cases according to the basic reproductive rate. Each new case then enters the Infection versus No Infection Subtree. **B, Preidentified MRSA carrier submodel structure.** In this version of the model, each MRSA-colonized patient has a probability of being preidentified. Preidentified MRSA-positive patients are immediately placed under isolation precautions.

FIGURE 2.
Methicillin-resistant *Staphylococcus aureus* infection outcomes submodel.

FIGURE 3.

Graph of willingness-to-pay acceptability curves at different methicillin-resistant *Staphylococcus aureus* (MRSA) prevalences for the basic reproductive rate of 0.25.

FIGURE 4.

Graph of incremental cost-effectiveness ratio of performing surveillance at different methicillin-resistant *Staphylococcus aureus* (MRSA) prevalence and basic reproductive rate values.

TABLE 1

Data Inputs for Model Variables

Variable	Mean value (range)	Standard deviation
Cost, \$US		
Surveillance	9.95 (6.34–12.85)	...
Procedure		
Antibiotic spacer, joint replacement	481.72 (472.85–490.59)	...
Blood cultures, 2 sets	29.50 (19.47–39.53)	...
Cardiac surgery	1,204.31 (794.84–1,613.78)	...
Computerized tomography, chest	229.89 (151.73–308.05)	...
Echocardiogram, transesophageal	158.95 (104.91–212.99)	...
Echocardiogram, transthoracic	159.91 (105.54–214.28)	...
Incision and drainage	314.50 (207.57–421.43)	...
Magnetic resonance imaging, extremity	451.19 (297.79–604.59)	...
Orthopedic hardware replacement	1,676.74 (1,106.65–2,246.83)	...
Peripheral intravenous line insertion	141.99 (93.71–190.27)	...
Peripherally inserted central catheter insertion	273.46 (180.48–366.44)	...
Placing patient in contact isolation	6,500.00 (4,290.00–8,710.00)	...
Radiograph, extremity	28.13 (18.57–37.69)	...
Surgical removal of hardware	1,121.31 (740.06–1,502.56)	...
Surgical replacement of graft	1,224.46 (808.14–1,640.78)	...
Ultrasound, Doppler	120.46 (79.50–161.42)	...
Urinalysis	6.00 (3.96–8.04)	...
Urine culture	55.00 (41.25–68.75)	...
Wound culture	47.00 (39.50–54.50)	...
Wound debridement	67.81 (44.75–90.87)	...
Hospitalization		
Abscess	5,331.70 (3,895.26–6,768.14)	...
Bacteremia	9,548.21 (6,975.77–12,120.65)	...
Cardiac surgery	3,924.53 (2,867.20–4,981.86)	...
Cellulitis	5,331.70 (3,895.25–6,768.15)	...
Endocarditis	22,567.71 (16,487.61–28,647.81)	...
Line infection	11,716.92 (8,560.19–14,873.65)	...
Osteomyelitis	10,601.26 (7,745.11–13,457.42)	...
Pneumonia	6,160.74 (4,500.94–7,820.54)	...
Septic shock	9,481.25 (6,926.85–12,035.65)	...
Urinary tract infection	5,493.56 (4,013.51–6,973.61)	...
Wound infection	7,634.81 (5,577.87–9,691.75)	...
Utilities, QALYs		
Abscess	0.642 (...)	...
Bacteremia	0.530 (...)	...
Cardiac surgery	0.500 (...)	...

Variable	Mean value (range)	Standard deviation
Cellulitis	0.642 (...)	...
Endocarditis	0.530 (...)	...
Line infection	0.642 (...)	...
Osteomyelitis	0.530 (...)	...
Pneumonia	0.580 (...)	...
Septic shock	0.530 (...)	...
Urinary tract infection	0.730 (...)	...
Wound infection	0.642 (...)	...
Probability, %		
Surveillance sensitivity	92.6 (...)	63.0–97.0 ^a
Surveillance specificity	97.1 (...)	92.2–99.5 ^a
Condition, given MRSA colonization		
MRSA infection	26.00 (...)	17.65
Condition, given MRSA infection ^b		
Abscess	4.17 (...)	3.13–5.21 ^a
Bacteremia	27.70 (...)	31.42
Septic shock, given bacteremia	38.87 (...)	32.46
Cellulitis	37.04 (...)	32.62
Endocarditis	33.33 (...)	20.66
Cardiac surgery, given endocarditis	32.56 (...)	15.99
Line infection	38.15 (...)	30.83
Osteomyelitis	13.54 (...)	10.16–16.93 ^a
Pneumonia	22.70 (...)	10.05
Urinary tract infection	9.39 (...)	4.64
Wound infection	27.45 (...)	14.76
Mortality, by condition		
MRSA bacteremia	29.38 (...)	...
MRSA-infected cardiac surgery	17.91 (...)	...
MRSA endocarditis	40.71 (...)	...
MRSA pneumonia	31.38 (...)	...
MRSA septic shock	60.77 (...)	...

NOTE. Sources for each parameter value are available in Appendix A, online only. MRSA, methicillin-resistant *Staphylococcus aureus*; QALY, quality-adjusted life-year.

^aTriangular distributions with the indicated lower and upper limits.

^bProbability for these conditions is conditional on having an MRSA infection. Also, the probability of each clinical condition is independent. Patients may have various combinations of different conditions.

Incremental Cost-Effectiveness Ratio (ICER) of Performing Surveillance at Different Methicillin-Resistant *Staphylococcus aureus* Prevalence and Basic Reproductive Rate Values, according to 2 Cost Simulation Methods

TABLE 2

Method and prevalence, %	ICER, by basic reproductive rate							
	0.25	0.5	1.0	1.5	2.0	2.5	3.0	
Base case disease-cost								
1	7978.06	3807.71	1746.76	1127.48	740.89	502.04	362.31	
2.5	3962.57	1806.56	731.47	379.50	195.93	103.58	26.46	
5	2518.97	1114.13	370.86	146.90	22.99	Dominated	Dominated	
10	1757.68	735.32	195.78	26.43	Dominated	Dominated	Dominated	
15	1564.87	621.54	138.74	Dominated	Dominated	Dominated	Dominated	
20	1407.40	546.11	112.54	Dominated	Dominated	Dominated	Dominated	
25	1344.36	509.88	95.43	Dominated	Dominated	Dominated	Dominated	
30	1300.76	493.64	85.70	Dominated	Dominated	Dominated	Dominated	
40	1248.43	468.28	68.67	Dominated	Dominated	Dominated	Dominated	
50	1219.76	445.09	57.73	Dominated	Dominated	Dominated	Dominated	
75	1178.08	417.06	47.30	Dominated	Dominated	Dominated	Dominated	
90	1141.00	413.45	42.24	Dominated	Dominated	Dominated	Dominated	
Lost hospital bed-days								
1	8040.83	4167.57	1821.76	1081.03	689.67	534.46	365.75	
2.5	3785.71	1795.29	707.66	387.93	195.79	97.94	29.51	
5	2452.71	1081.31	381.28	144.50	Dominated	Dominated	Dominated	
10	1814.60	724.68	203.51	24.04	Dominated	Dominated	Dominated	
15	1560.70	613.55	143.81	Dominated	Dominated	Dominated	Dominated	
20	1444.94	548.24	118.13	Dominated	Dominated	Dominated	Dominated	
25	1332.11	504.91	91.49	Dominated	Dominated	Dominated	Dominated	
30	1326.93	492.61	84.70	Dominated	Dominated	Dominated	Dominated	
40	1248.32	462.10	66.35	Dominated	Dominated	Dominated	Dominated	
50	1194.50	437.45	58.37	Dominated	Dominated	Dominated	Dominated	
75	1189.40	419.18	46.84	Dominated	Dominated	Dominated	Dominated	
90	1170.84	417.05	44.12	Dominated	Dominated	Dominated	Dominated	

NOTE. Surveillance is the dominant strategy (ie, cost saving and utility saving).