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The Economic Effect of Screening Orthopedic Surgery Patients Preoperatively for Methicillin-Resistant *Staphylococcus aureus*

Bruce Y. Lee, MD, MBA, **Ann E. Wiringa, MPH**, **Rachel R. Bailey, MPH**, **Vishal Goyal, MPH**, **Becky Tsui, MPH**, **G. Jonathan Lewis, DO, MPH**, **Robert R. Muder, MD**, and **Lee M. Harrison, MD**

Public Health Computational and Operations Research (PHICOR) (B.Y.L., A.E.W., R.R.B., V.G., B.T., G.J.L.), the Department of Biomedical Informatics (B.Y.L., A.E.W., R.R.B., V.G., B.T., G.J.L.), the Department of Epidemiology, Graduate School of Public Health (B.Y.L., A.E.W., R.R.B., V.G., B.T., G.J.L.), and the Infectious Disease Epidemiology Research Unit, School of Medicine and Graduate School of Public Health (L.M.H.), University of Pittsburgh, and the Division of Infectious Diseases, Veterans Affairs Pittsburgh Health System (R.R.M.), Pittsburgh, Pennsylvania.

Abstract

BACKGROUND AND OBJECTIVE—Patients undergoing orthopedic surgery are susceptible to methicillin-resistant *Staphylococcus aureus* (MRSA) infections, which can result in increased morbidity, hospital lengths of stay, and medical costs. We sought to estimate the economic value of routine preoperative MRSA screening and decolonization of orthopedic surgery patients.

METHODS—A stochastic decision-analytic computer simulation model was used to evaluate the economic value of implementing this strategy (compared with no preoperative screening or decolonization) among orthopedic surgery patients from both the third-party payer and hospital perspectives. Sensitivity analyses explored the effects of varying MRSA colonization prevalence, the cost of screening and decolonization, and the probability of decolonization success.

RESULTS—Preoperative MRSA screening and decolonization was strongly cost-effective (incremental cost-effectiveness ratio less than $6,000 per quality-adjusted life year) from the third-party payer perspective even when MRSA prevalence was as low as 1%, decolonization success was as low as 25%, and decolonization costs were as high as $300 per patient. In most scenarios this strategy was economically dominant (ie, less costly and more effective than no screening). From the hospital perspective, preoperative MRSA screening and decolonization was the economically dominant strategy for all scenarios explored.

CONCLUSIONS—Routine preoperative screening and decolonization of orthopedic surgery patients may under many circumstances save hospitals and third-party payers money while providing health benefits.

Patients who undergo orthopedic surgical procedures are at risk of developing infections attributable to methicillin-resistant *Staphylococcus aureus* (MRSA). Orthopedic procedures are generally invasive in nature; require prolonged operating time; introduce hardware, biomaterials, prostheses, and other foreign bodies; and may require postoperative

Address reprint requests to Bruce Y. Lee, MD, MBA, Public Health Computational, and Operations Research (PHICOR) Group, University of Pittsburgh, 200 Meyran Avenue, Suite 200, Pittsburgh, PA 15213 (byl1@pitt.edu).

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immobilization for extended periods of time. Postoperative MRSA infections tend to be associated with substantial morbidity and mortality.[1–6]

Preoperative MRSA screening and decolonization of orthopedic surgery patients who test positive for MRSA could help prevent postoperative MRSA infections and their sequelae, thereby improving patient outcomes.[7,8] Approximately 35% of the US population are chronic or intermittent carriers of *S. aureus,* and nasal MRSA colonization rates ranging from 0.4% to 20.6% have been reported.[7,9–12] Higher rates have been reported among populations and individuals with such risk factors as exposure to healthcare, older age, compromised immunity, and chronic health conditions, such as diabetes mellitus or hepatitis.[10,13,14] Nasal MRSA colonization has been associated with an increased risk of MRSA infection and poor outcomes.[7,9,15,16]

The implementation of routine surveillance and decolonization measures can be costly; previously published economic models have shown such a strategy to be cost-effective for patients undergoing vascular surgery but not for pregnant women.[17,18] As these divergent results have shown, routine MRSA surveillance may be worthwhile for some populations but not for others. Therefore, findings for one population (eg, vascular surgery patients) may not be applicable to other patient populations (eg, orthopedic surgery patients) who have different procedures, characteristics, and potential MRSA outcomes.

To date, no study has assessed the economic value of using such a strategy with orthopedic surgery patients; thus, we developed a computer simulation model to estimate the economic value of preoperative MRSA screening and decolonization for orthopedic surgery patients. Sensitivity analyses were used to assess how differences in MRSA colonization prevalence, the cost of testing and decolonization, and the probability of decolonization success affected the estimated economic value of universal preoperative surveillance. The findings from this study may help guide clinicians and infection control specialists, hospital administrators, and third-party payers to decide when and where to use an active preoperative MRSA screening and decolonization strategy with orthopedic surgery patients and guide the design of future epidemiological and clinical studies.

METHODS

The overall main structure (Figure 1) of our stochastic decision analytic computer simulation model, which was constructed using TreeAge Pro 2009 (TreeAge Software), used the same general elements as our previously published vascular surgery economic model.[18] As before, this model was used to compare 2 decision alternatives: the performance (by means of collecting a swab sample either from the anterior nares or from 2 body sites) or nonperformance of MRSA surveillance (this time, for an orthopedic surgery patient preparing to undergo a surgical procedure). The patient had a probability of being colonized with MRSA that was dependent on the local prevalence of MRSA and individual risk factors for colonization.[10,13,14] Surveillance culture outcomes were contingent on the sensitivity and specificity of the test and the presence of MRSA colonization. Each patient with a positive test result (either a true-positive or a false-positive result) underwent a decolonization attempt, and each patient with a negative test result (false-negative or true-negative result) did not undergo a decolonization attempt. Successful decolonization was assumed to confer protection against MRSA-attributable infections for the duration of the perioperative period.

The important and major differences between our orthopedic surgery model and our vascular surgery model were the risk of MRSA infection and the MRSA infection outcomes subtree. All patients who tested positive for colonization (whether or not decolonization had

already been attempted) entered this subtree, and probabilities of remaining asymptomatic or developing any of the following sequelae alone or in combination were calculated: surgical site infection, surgical revision, septic shock, arthrodesis, amputation, urinary tract infection, pneumonia, and death. Each complicating condition necessitated a distinct set of treatment procedures and attendant costs, as well as patient outcomes and utility decrements.

We conducted an extensive literature search in PubMed to determine the probabilities of various clinical outcomes of MRSA colonization and infection in the orthopedic surgery patient population. The search encompassed English-language articles published since 1999 that were returned by the following key words: "orthopedic," "orthopaedic," "orthopedic surgery," "orthopaedic surgery," "methicillin resistant *Staphylococcus aureus*," and "'MRSA." The authors reviewed all abstracts returned by this search to determine their appropriateness; excluded case reports, case series, and studies that did not clearly report their population denominators; and included only studies that clearly characterized study populations and reported on the full set of clinical outcomes from that population (ie, the numerators were properly defined). Parameter distributions in the model reflected the range of values identified from the literature search.

The median age of simulated patients was 65 years, consistent with the population of patients who undergo orthopedic surgery.[16,19] The cost, probability, and utility model inputs, as well as their respective distributions and source(s), are shown in Table 1. Effectiveness was measured in units of age-adjusted quality-adjusted life years (QALYs).[23,24,26] Each clinical condition resulted in a corresponding QALY decrement for the duration of the condition. Patients who did not survive lost QALYs on the basis of their projected life expectancy from the Human Mortality Database.[48] A discount rate of 3% was used to convert all cost and effectiveness measures into 2009 values.[49,50]

Each simulation run consisted of 1,000 hypothetical patients (each with a set of characteristics) preparing to undergo an orthopedic surgical procedure. Each patient traveled through the model 1,000 times, accruing a distinct set of costs, utilities, and outcomes each time, owing to the probabilistic nature of the input parameters. This process generated a total of 1 million patient outcomes for each simulation run.

Economic Outcomes

For each simulation run, the following formula determined the incremental cost-effectiveness ratio (ICER), expressed in US dollars per QALY, of implementing a screening strategy with or without decolonization:

$$\mathrm{ICER}=(\mathrm{cost}_{\text{MRSA screening}\pm\text{decolonization}}-\mathrm{cost}_{\text{no MRSA screening or decolonization}})\div(\mathrm{effectiveness}_{\text{MRSA screening}\pm\text{decolonization}}-\mathrm{effectiveness}_{\text{no MRSA screening or decolonization}}).$$

Although some debate exists about the ICER threshold below which an intervention is to be considered cost-effective, $50,000 per QALY is a commonly used cutoff point, and ICER values of less than $20,000 per QALY offer strong economic support for the adoption of an intervention.[51–53] A strategy that is both less costly and more effective than the alternative is deemed economically dominant.

Separate analyses were used to calculate the economic value of screening and decolonization from 2 perspectives:

1. Perspective of the third-party payer: this perspective accounted for the direct medical costs associated with each outcome.

2. Hospital perspective: using a method described by Graves,[54–56] this perspective estimates the opportunity cost of lost bed-days caused by the increased length of stay associated with each MRSA outcome.

Sensitivity Analyses

Sensitivity analyses varied the values of key input parameters and were used to evaluate the robustness of the model. Specific analyses systematically varied MRSA colonization prevalence from 1% to 30% to account for a range across geographic areas, individual patient risk factor profiles, and temporality. Decolonization success rates were varied from 25% to 100% to account for the varying efficacy of different treatment regimens, resistance to antimicrobial agents, and patient adherence to treatment regimens. To simulate the effect of testing samples from sites in addition to the anterior nares (eg, sampling the throat, axilla, or perineum) and of a variety of decolonization regimens, the cost was varied from $100 to $300 (because the maximum amount that the Centers for Medicare and Medicaid Services reimburses for *S. aureus,* methicillin resistant, amplified probe technique [polymerase chain reaction] is $50.27 and for bacterial culture of a swab sample of the anterior nares is $12.34;[57] decolonization regimens can vary widely, but a 10-day course of mupirocin costs $15.00, 1 L of 4%chlorhexidine gluconate costs $28.70, and a 10-day course of 300 mg of rifampin administered twice daily costs $57.83[58,59]). In addition, for each simulation run, probabilistic sensitivity analyses were performed that simultaneously varied all input parameters over the ranges listed in Table 1.

RESULTS

Table 2 shows, from the perspective of the third-party payer, how the ICER for MRSA surveillance varied with MRSA colonization prevalence and decolonization success rate when single-site and 2-site surveillance swab sampling were performed.

Third-Party Payer Perspective

Routine preoperative MRSA surveillance was either strongly cost-effective (ICER of less than $6,000 per QALY) or, in most situations, economically dominant for a wide variety of decolonization success rates and MRSA prevalence rates. For scenarios that used a single anterior nares swab sample ($100 cost of surveillance and decolonization), MRSA testing was economically dominant when decolonization was at least 50% successful and the prevalence of MRSA colonization was at least 2.5% or when decolonization was at least 25% successful and the prevalence of MRSA colonization was at least 5%. Routine MRSA surveillance remained strongly cost-effective (ie, ICER well below $20,000 per QALY) for all other scenarios examined when the prevalence of MRSA colonization was 2.5% or less.

The strategy remained cost-effective even when a second body site was sampled for surveillance. As Table 2 shows, the strategy was still economically dominant for most scenarios explored, ie, for a wide variety of MRSA colonization prevalences and decolonization at least 75% successful and for MRSA colonization prevalence at least 5% and decolonization at least 25% successful. MRSA surveillance and decolonization remained a cost-effective strategy for all other scenarios with a numeric value in the second and third blocks of Table 2.

Figure 2 shows the acceptability curves for different prevalences of MRSA colonization when the cost of decolonization was $200 and the probability of decolonization success was 25%, 50%, or 75%. These curves show the proportion of simulated patients for whom preoperative MRSA testing and decolonization was a cost-effective choice at different willingness-to-pay levels. The curves in Figure 2*A* indicate, for example, that when the

probability of decolonization success was 25%, MRSA colonization prevalence was 10%, and the maximum willingness to pay was $50,000, screening and decolonization for patients preparing to undergo orthopedic surgery was a cost-effective intervention approximately 65% of the time. As the prevalence of MRSA colonization increases, the same probability of surveillance being cost-effective (65%) is achieved at lower willingness-to-pay thresholds (approximately $20,000 for 20% MRSA prevalence and approximately $5,000 for 30% MRSA prevalence). In Figures 2*B* and 2*C*, the rate of decolonization success increases to 50% and 75%, respectively, and all of the curves shift upward. This is an indication that screening is more likely to be cost-effective at the same willingness-to-pay level when the probability of decolonization success is higher and cost is held constant.

Hospital Perspective

Universal MRSA surveillance and decolonization of culture-positive patients preparing to undergo orthopedic surgery was the dominant strategy for all scenarios in which the prevalence of MRSA colonization was at least 1% and the probability of decolonization success was at least 25% at costs of up to $200. The strategy had slightly more economic value from the hospital perspective than from the third-party payer perspective. In fact, from the hospital perspective, preoperative screening and decolonization was economically dominant in every scenario that we explored. By contrast, from the third-party payer perspective, the strategy was cost-effective but not economically dominant at lower MRSA colonization prevalence (5% or less). Table 3 outlines the median costs and number of invasive MRSA infections (with 95% confidence intervals) associated with 100 orthopedic surgical procedures with and without surveillance and preoperative decolonization for a $200 decolonization regimen, varying MRSA prevalence and decolonization success. In scenarios from the hospital's perspective, with the cost of decolonization no more than $200, MRSA prevalence at least 1%, and decolonization at least 50% successful, the median cost per invasive MRSA infection was a negative value, which indicates cost savings.

DISCUSSION

Our results suggest that routine preoperative MRSA screening and decolonization for orthopedic surgery patients would be a cost-effective and, in many circumstances, economically dominant strategy for a wide range of MRSA colonization prevalence (at least 1%) and decolonization success rates (at least 25%), from both the third-party payer and hospital perspectives. These findings may hold whether swab samples are obtained from 1 or 2 body sites, and they provide economic support for adopting such a strategy. The cost savings and health benefits of surveillance and decolonization seem to outweigh the cost of implementing such a strategy. In fact, the cost savings alone in many cases exceeds the cost of implementation. This is not a common finding, because most interventions require at least some net cost to realize health benefits.

Particularly compelling is the finding that decolonization does not have to be particularly effective for this strategy to be valuable. Short-term rates of decolonization success (long enough to cover the perioperative period) only have to be as high as 25% for the strategy to be cost-effective, substantially lower than many of the rates reported in the literature. A systematic review of MRSA eradication trials reported that a short course of mupirocin administered nasally was 90% effective 1 week after treatment and approximately 60% effective after a longer follow-up period, but additional studies are needed to ascertain the short-term effectiveness of assorted decolonization regimens.[60,61]

Combining this study with our previously published study of simulated vascular surgery patients, we have now revealed that routine preoperative surveillance and decolonization may provide substantial economic value in 2 different large populations of surgical

patients.[18,62] Although the vascular and orthopedic surgery populations are similar in many ways (eg, patients tend to be older, with a median age in the mid-60s, and have comorbid conditions; and many procedures are scheduled electively rather than emergently), there are important differences.[18] As may be expected, vascular insufficiency, which can predispose patients to develop postoperative infections, is more common among vascular surgery patients. Vascular surgical procedures create a direct route of entry to the bloodstream, potentially allowing bacterial contamination to rapidly lead to systemic complications, whereas orthopedic surgical procedures, although invasive, mainly involve soft tissue, osteochondral, and articular spaces in which bacterial contamination tends to remain more localized. The surgical materials and equipment are also quite different, with vascular procedures involving the use of catheters, grafts, and stents and orthopedic procedures involving the use of drills, saws, and hardware. Our model also reflected other key differences, such as the postoperative length of stay and the rate and type of surgical revisions.

The evidence does not yet suggest that MRSA screening should be applied to all preoperative surgical patient populations. Such a strategy may not be as advantageous for younger and healthier surgical patient populations (eg, cosmetic surgery) or for patients undergoing less invasive procedures (eg, ophthalmologic surgery). Researchers undertaking future studies may want to investigate the cost-effectiveness of MRSA screening and decolonization among surgical patient populations (eg, urological or gastrointestinal surgery) for which the economic value may be more equivocal.

Our analyses may underestimate the economic value of MRSA screening for several reasons. First, we endeavored to remain conservative about the benefits of MRSA surveillance when constructing the model. We deliberately elected to incorporate high screening and decolonization costs, to include only the most common complications of postoperative MRSA infections, and to use the least expensive diagnostic and treatment procedures for each clinical condition. Second, the model did not account for transmission of MRSA between carriers and noncarriers. Third, our model accounted only for infections caused by MRSA. Accounting for the additional health and financial outcomes due to infection by methicillin-susceptible strains of *S. aureus* would increase the economic value of surveillance. Fourth, decreasing the incidence of MRSA infections could reduce antibiotic use and decrease selection pressure for the evolvement of antibiotic resistance. Fifth, the model did not quantify the value of surveillance information (eg, colonization prevalence and infection incidence) gleaned from a structured MRSA surveillance and decolonization program.

Our findings were limited by the fact that all computer simulation models are simplifications of real life and cannot represent all possible MRSA colonization and infection outcomes in the highly heterogeneous orthopedic surgery patient population. The data inputs for our model came from different studies of varying quality but represent the best approximations of their respective values that were available to us. The findings of this model may not be applicable to patients undergoing emergency orthopedic surgery, because the urgency of treatment obviates screening.

In conclusion, the results of our model provide strong economic support for MRSA screening and decolonization in patients preparing to undergo orthopedic surgical procedures. Results were strongly cost-effective (ICER less than $10,000 per QALY) or dominant from both the third-party payer and hospital perspectives for a variety of MRSA colonization prevalence rates (1%–30%), testing and decolonization costs ($300 or less), and decolonization success rates (25%–100%). Preventing the substantial morbidity and mortality associated with MRSA infections can lead to improved patient outcomes and

decreased resource use. Clinical practitioners, infection control specialists, hospital administrators, third-party payers, and other decision makers can compare the inputs and assumptions of our model and the findings of our analyses with their local circumstances when deciding whether to implement routine preoperative MRSA testing for orthopedic surgical patients.

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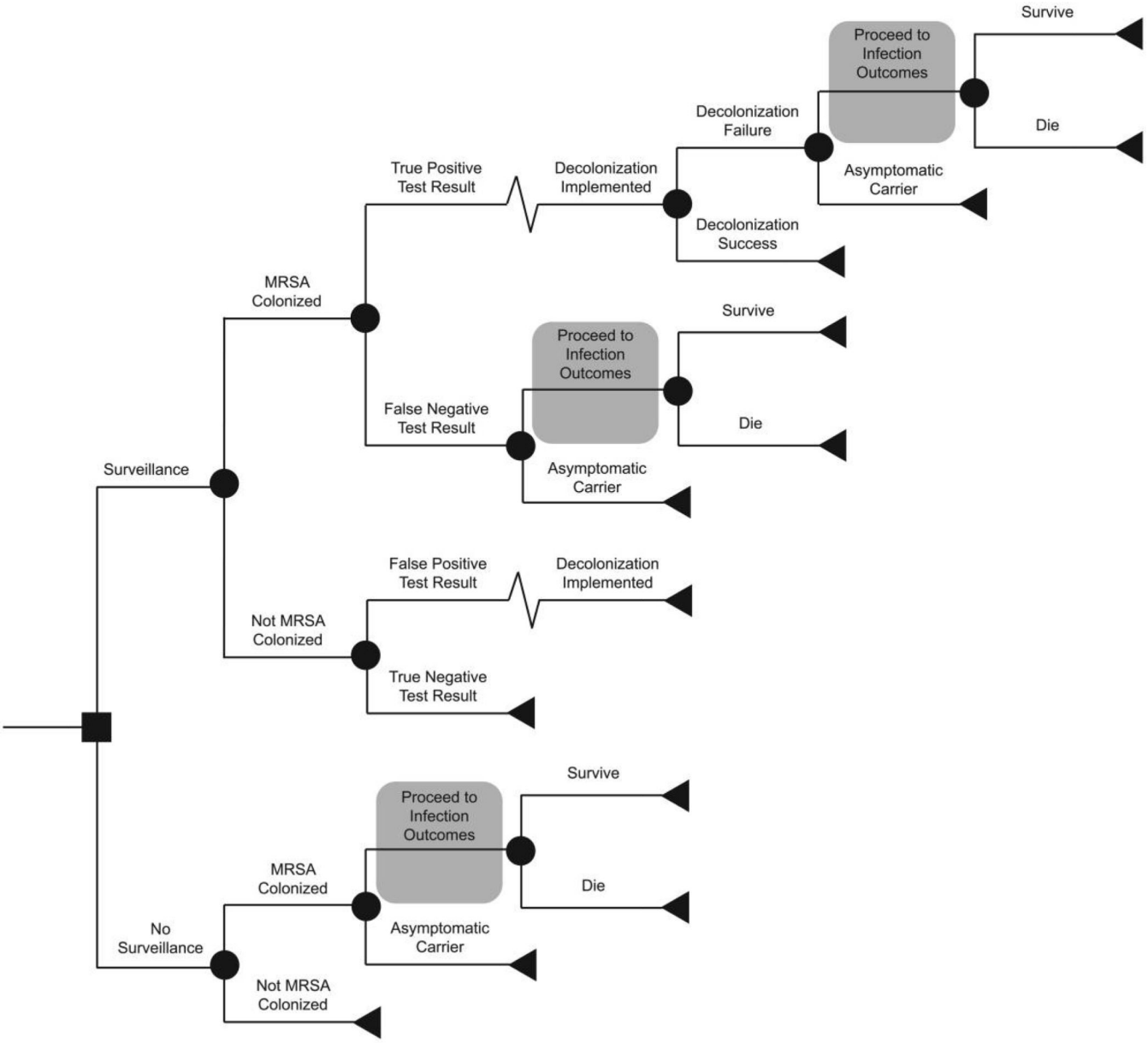

FIGURE 1.
General decision model structure comparing screening with not screening orthopedic surgery patients preoperatively for methicillin-resistant *Staphylococcus aureus.*

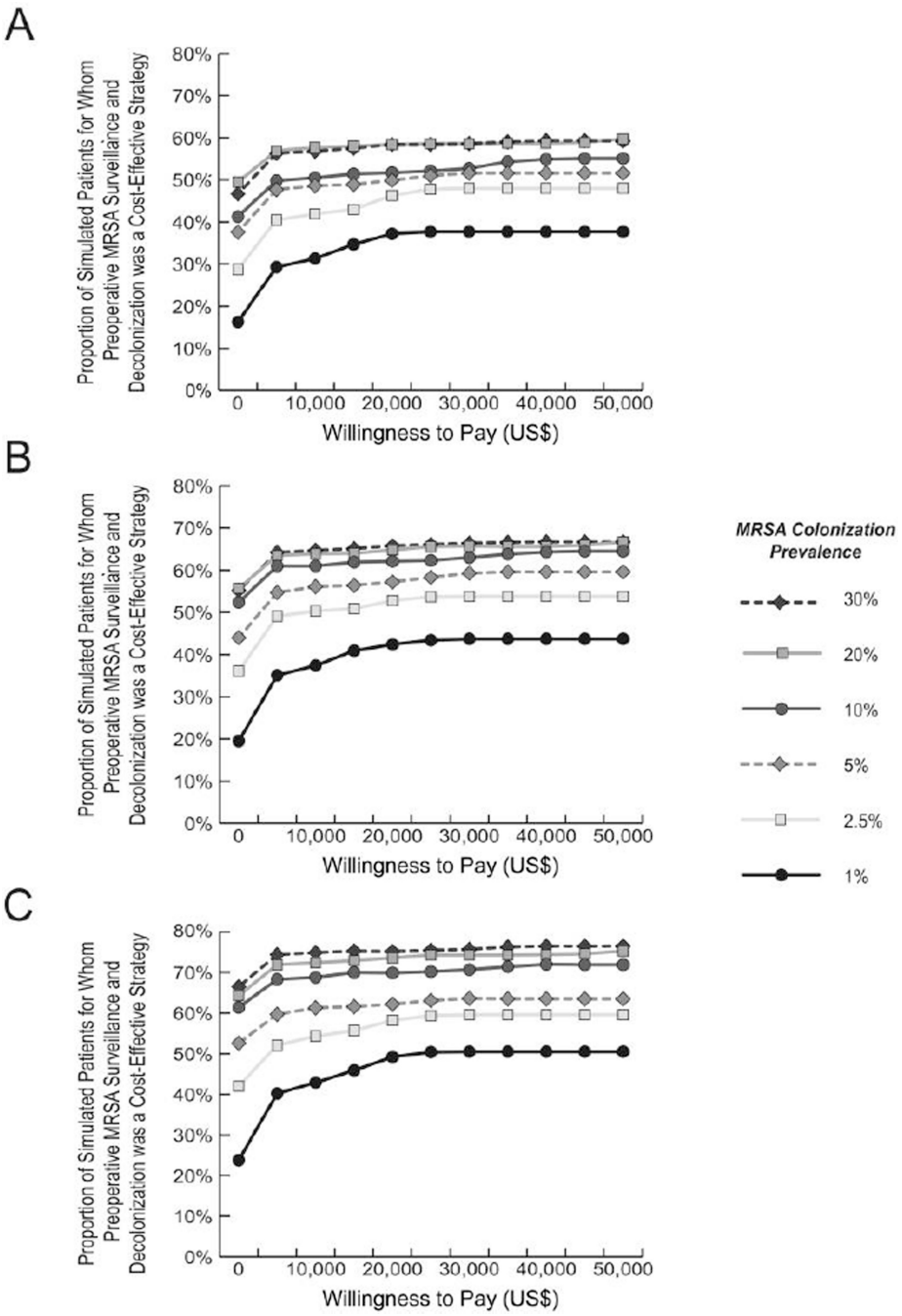

FIGURE 2.

Acceptability curves for different prevalences of methicillin-resistant *Staphylococcus aureus* when the cost of screening and decolonization is $200 and the probability of decolonization success is (*A*) 25%, (*B*) 50%, and (*C*) 75%.

TABLE 1

Data Inputs for Model Variables in a Computer Simulation Comparing Screening with Not Screening Orthopedic Surgery Patients Preoperatively for Methicillin-Resistant *Staphylococcus aureus* (MRSA)

Variable	Type of distribution	Value	Reference(s)
Costs, US$			
Surveillance, median (range)	Δ	6.34 (4.72–7.96)	R. Muder, MD, oral communication, August 3, 2009
Decolonization, median (range)	Δ	103.95 (68.61–139.29)	W. Pasculle, ScD, written communication, July 28, 2009
Vancomycin, per day, mean ± SD	γ	9.01 ± 5.00	20
Procedures, median (range)			
Amputation	Δ	851.14 (561.75–1,140.53)	21
Arthroscopy	Δ	1,533.91 (1,012.38–2,055.44)	21
Chest X-ray	Δ	25.75 (8.75–34.51)	22
PICC line insertion	Δ	281.66 (185.90–377.43)	22
Echocardiogram			
Transesophageal	Δ	163.72 (108.05–219.38)	22
Transthoracic	Δ	164.71 (108.70–220.71)	22
Surgical revision or prosthetic replacement	Δ	1,588.37 (1,048.32–2,128.42)	21
Hospitalization			
Amputation	…	17,239.95	22
Arthrodesis	…	11,938.04	22
Pneumonia	…	6,345.56	22
Septic shock	…	9,765.69	22
Surgical revision	…	17,614.76	22
Surgical site infection	…	6,619.74	22
Urinary tract infection	…	5,658.37	22
Utilities, QALYs			
Amputation	…	0.440	23
Arthrodesis	…	0.647	24
Pneumonia	…	0.580	23
Septic shock	…	0.530	25
Surgical revision	…	0.300	24
Surgical site infection	…	0.642	26
Urinary tract infection	…	0.730	23
Probability, %			
Surveillance sensitivity, median (range)	Δ	92.6 (63.0–97.0)	27
Surveillance specificity, median (range)	Δ	97.1 (92.2–99.5)	27
Probability, given MRSA colonization, of developing MRSA infection, mean ± SD	β	26.00 ± 17.65	9,15,28–33
Probability, given MRSA infection, mean ± SD			
Amputation	β	45.00 ± 15.30	34,35
Arthrodesis	β	5.00 ± 0.17	36

Variable	Type of distribution	Value	Reference(s)
Pneumonia	β	42.26 ± 14.37	37,38
Septic shock	β	1.67 ± 0.57	35
Surgical revision	β	6.67 ± 2.27	35
Surgical site infection	β	12.93 ± 28.26	3,4,35,37
Urinary tract infection	β	4.76 ± 1.62	37,38
Mortality under the following conditions			
MRSA pneumonia, mean ± SD	β	31.37 ± 15.20	39–47
MRSA septic shock	β	100.00	35

NOTE. PICC, peripherally inserted central catheter; QALY, quality-adjusted life year; SD, standard deviation.

TABLE 2

Incremental Cost-Effectiveness Ratio (ICER) from the Third-Party Payer Persective of Performing Surveillance and Decolonization for Different Cost, Methicillin-Resistant *Staphylococcus aureus* (MRSA) Colonization Prevalence, and Decolonization Success Rate Scenarios

	ICER, US$ per quality-adjusted life year				
Decolonization success rate, %	**1.0% MRSA prevalence**	**2.5% MRSA prevalence**	**5.0% MRSA prevalence**	**10.0% MRSA prevalence**	**15.0% MRSA prevalence**
Single-site surveillance and decolonization at $100 per patient					
25	3,626	716	Surveillance	Surveillance	Surveillance
50	1,058	Surveillance	Surveillance	Surveillance	Surveillance
75	691	Surveillance	Surveillance	Surveillance	Surveillance
100	233	Surveillance	Surveillance	Surveillance	Surveillance
2-site surveillance and decolonization at $200 per patient					
25	5,586	1,169	159	Surveillance	Surveillance
50	2,956	189	Surveillance	Surveillance	Surveillance
75	1,412	Surveillance	Surveillance	Surveillance	Surveillance
100	769	Surveillance	Surveillance	Surveillance	Surveillance
2-site surveillance and decolonization at $300 per patient					
25	7,025	2,808	1,079	Surveillance	Surveillance
50	4,641	1,317	363	Surveillance	Surveillance
75	3,555	744	Surveillance	Surveillance	Surveillance
100	2,460	476	Surveillance	Surveillance	Surveillance

NOTE. Cells labeled “Surveillance” indicate scenarios in which testing and decolonization dominates (ie, is less costly and more effective than) no testing or decolonization.

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TABLE 3

Hospital Perspective Median Costs and Numbers of Invasive Methicillin-Resistant *Staphylococcus aureus* (MRSA) Infections with and without Surveillance and Decolonization for Different Cost, MRSA Prevalence, and Decolonization Success Rate Scenarios

	Cost per 100 surgical procedures, US$		No. of invasive MRSA infections per 100 surgical procedures			
Decolonization success rate, %	**Without intervention**	**With intervention**	**Without intervention**	**With intervention**	**Net cost of intervention per 100 surgical procedures, US$**	**Net median cost per MRSA infection prevented, US$**
$200 cost of decolonization, 1% MRSA prevalence						
25	433 (0–1,779)	541 (119–1,917)	0.26 (0–0.80)	0.20 (0–0.80)	108 (119–138)	1,800
50	440 (0–1,712)	214 (117–1,492)	0.20 (0–0.80)	0 (0–0.60)	−226 (−220 to 117)	−1,130
75	442 (0–1,761)	193 (112–1,129)	0.20 (0–0.80)	0 (0–0.40)	−249 (−632 to 112)	−1,245
100	439 (0–1,776)	181 (110–717)	0.20 (0–0.80)	0 (0–0.20)	−258 (−1,059 to 110)	−1,290
$200 cost of decolonization, 10% MRSA prevalence						
25	5,519 (3,036–9,189)	3,672 (250–10,287)	2.6 (1.4–4.0)	1.6 (0–4.6)	−1,847 (−2,786 to 2,098)	−1,847
50	5,618 (4,301–7,092)	2,737 (419–7,416)	2.6 (2.0–3.2)	1.2 (0.1–3.3)	−2,881 (−3,882 to 324)	−2,058
75	5,624 (4,248–7,051)	1,848 (297–5,141)	2.6 (1.9–3.2)	0.8 (0.1–2.2)	−3,776 (−3,951 to −1,910)	−2,098
100	5,448 (2,739–8,938)	981 (122–3,341)	2.4 (1.2–4.0)	0.40 (0–1.4)	−4,467 (−5,597 to −2,617)	−2,234

NOTE. Quantities are median (95% confidence interval) unless otherwise indicated.

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