ORIGINAL ARTICLE

Sustained Reduction in the Clinical Incidence of Methicillin-Resistant *Staphylococcus aureus* Colonization or Infection Associated with a Multifaceted Infection Control Intervention

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OBJECTIVE. To assess the impact and sustainability of a multifaceted intervention to prevent methicillin-resistant *Staphylococcus aureus* (MRSA) transmission implemented in 3 chronologically overlapping phases at 1 hospital.

DESIGN. Interrupted time-series analyses.

SETTING. A Veterans Affairs hospital in the northeastern United States.

PATIENTS AND PARTICIPANTS. Individuals admitted to acute care units from October 1, 1999, through September 30, 2008. To calculate the monthly clinical incidence of MRSA colonization or infection, the number of MRSA-positive cultures obtained from a clinical site more than 48 hours after admission among patients with no MRSA-positive clinical cultures during the previous year was divided by patient-days at risk. Secondary outcomes included clinical incidence of methicillin-sensitive *S. aureus* colonization or infection and incidence of MRSA bloodstream infections.

INTERVENTIONS. The intervention—implemented in a surgical ward beginning October 2001, in a surgical intensive care unit beginning October 2003, and in all acute care units beginning July 2005—included systems and behavior change strategies to increase adherence to infection control precautions (eg, hand hygiene and active surveillance culturing for MRSA).

RESULTS. Hospital-wide, the clinical incidence of MRSA colonization or infection decreased after initiation of the intervention in 2001, compared with the period before intervention ($P = .002$), and decreased by 61% ($P < .001$) in the 7-year postintervention period. In the postintervention period, the hospital-wide incidence of MRSA bloodstream infection decreased by 50% ($P = .02$), and the proportion of *S. aureus* isolates that were methicillin resistant decreased by 30% ($P < .001$).

CONCLUSIONS. Sustained decreases in hospital-wide clinical incidence of MRSA colonization or infection, incidence of MRSA bloodstream infection, and proportion of *S. aureus* isolates resistant to methicillin followed implementation of a multifaceted prevention program at one Veterans Affairs hospital. Findings suggest that interventions designed to prevent transmission can impact endemic antimicrobial resistance problems.

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The Centers for Disease Control and Prevention has identified antimicrobial resistance in United States healthcare facilities as a major public health problem.[1] The Infectious Diseases Society of America has also recognized the critical need for response through its public policy information campaign initiated in 2004 entitled "Bad Bugs, No Drugs"[2] and, in 2008, by issuing a "call to action" for the medical community to take measures to minimize the transmission of resistant organisms.[3] Methicillin-resistant *Staphylococcus aureus* (MRSA) is among the most common multidrug-resistant organisms reported to the Centers for Disease Control and Prevention.[4] In most United States hospitals, MRSA is endemic and can cause substantial morbidity and mortality in patients who develop healthcare-associated (HA) MRSA infection.[5-7] In addition to increasing the total burden of *S. aureus* in hospitals, MRSA infections are associated with greater length of stay and cost than methicillin-susceptible *S. aureus* (MSSA) infections, and studies suggest that colonization with MRSA is associated with a higher risk of subsequent infection.[8-11] Outbreak investigations have suggested patient-to-patient transmission of MRSA on inpatient hospital units, and it is widely accepted that transient colonization of healthcare worker

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hands plays a large role in transmission.[12] Studies showing reductions in incident MRSA infections after aggressive infection control interventions suggest that MRSA transmission can be prevented by discrete changes in healthcare worker behavior and patient management.[13,14] It is unclear, however, whether reductions can be achieved on a large scale and sustained over time.

Infection control initiatives designed to prevent MRSA transmission in acute care settings have gained considerable support in the past decade. Two large studies in the United States demonstrated significant decreases in hospital-wide HA-MRSA infection; one intervention targeted intensive care unit (ICU) patients via active surveillance testing and isolation,[13] and the other targeted all patient-care areas in 3 hospitals with use of active surveillance testing and decolonization.[14] There are inherent challenges in conducting MRSA intervention studies in nonrandomized trial settings. For example, rates of MRSA bacteremia are decreasing in ICUs in the United States, which makes the impact of any one intervention difficult to isolate from existing temporal trends.[15] Also, interventions are often piloted in 1 or 2 patient-care areas before expanding hospital-wide, complicating intervention-impact analyses.

Our objective was to assess the impact of a multifaceted MRSA prevention intervention that was implemented in 3 chronologically overlapping phases at 1 Veterans Affairs hospital in the northeastern United States. This evaluation builds on an initial study performed in 2 patient-care units within the same hospitals that revealed significant reductions in HA-MRSA infection when comparing aggregate postintervention rates with aggregate preintervention rates.[16] The current study extends this work by fitting a more robust time-series model to the data, evaluating the impact of extending the intervention hospital-wide 4 years after the initial pilot study in a single unit, and evaluating the sustainability of the intervention 7 years after initial implementation.

METHODS

The University Drive Division of the Veterans Affairs Pittsburgh Healthcare System is a 146-bed, acute care hospital, which provides a full array of tertiary medical and surgical services for veterans. In October 2001, a multifaceted MRSA prevention intervention was initiated in a 36-bed non–intensive care surgical unit accounting for 20% of total hospital patient-days. In October 2003, the same intervention was introduced to an 11-bed surgical ICU, which accounted for 8% of total hospital patient-days. In July 2005, all remaining acute care hospital units began the intervention.

The MRSA prevention intervention consisted of the following 3 elements: (1) use of systems and behavioral change strategies to promote adherence to infection control protocol, (2) enhanced emphasis on hand hygiene and environmental disinfection, and (3) active surveillance testing of anterior nares and open wounds within 48 hours after admission to identify patients asymptomatically colonized with MRSA for prompt initiation of contact precautions. These 3 components were implemented in parallel and have been described in detail elsewhere.[16]

The hospital administration supported the implementation of the Toyota Production System (TPS) as the systems and behavior change component for the 2 units beginning the intervention in October 2001 and October 2003. The central principle of the TPS is that all processes can be highly specified with regard to content, sequence, timing, location, and expected outcome.[17] The strategy involves the continuous identification of problem processes (eg, inconveniently located sinks and personal protective equipment) and standardization of solutions (eg, placement and organization of supplies to optimize access). In July 2005, Positive Deviance (PD) was implemented as the systems and behavior change strategy, to ensure consistent and reliable adherence to hand hygiene, contact precautions, and environmental disinfection in the 2 pilot units, as well as the remainder of acute care areas. The central principles of PD are ownership and empowerment, and the approach is deliberately nonhierarchical.[18] All patients and hospital employees were encouraged to find solutions to the problem of MRSA transmission. When a particular individual or group made exceptional progress (eg, an unit consistently had extremely low rates of HA-MRSA, or a patient honed a creative technique for asking healthcare personnel to wash hands), these "positive deviants" were studied and the experiences were shared through "discovery and action dialogues."[19] Neither TPS nor PD implementation strategies required hiring additional healthcare personnel. The TPS strategy allowed staff to consult an industrial engineer as needed to identify the root causes of error, identify change strategies, implement strategies, and monitor effects; PD implementation involved several initial workshops and staff interviews conducted by PD consultants.

Outcomes

The primary outcome evaluated was clinical incidence of MRSA colonization or infection, which served as a proxy measure for MRSA transmission. Clinical incidence has been shown to be a reasonable marker for transmission in ICU settings, and similar measures have been advocated by the Society for Healthcare Epidemiology of America for quantifying MRSA acquisition in healthcare facilities.[20,21] Administrative and laboratory data were used to calculate clinical incidence for the 9-year period from October 1, 1999, through September 30, 2008. The definition of an incident case of MRSA colonization or infection was a positive, clinical (nonsurveillance) MRSA culture result obtained at least 48 hours after admission to an acute care unit or, if the patient was transferred, within 48 hours after transfer to another unit. Cases were excluded as "nonincident" if a positive clinical culture result could be identified anywhere in the laboratory information system within the previous year (including long-

TABLE 1. Summary of Unadjusted Pre- and Postintervention Estimates of Clinical Incidence of Methicillin-Resistant *Staphylococcus aureus* Colonization or Infection Presented for Each Hospital Unit and Hospital-wide

Area(s) of intervention	Intervention month and year	Predicted clinical incidence, cases per 1,000 patient-days at risk		Pre- to postintervention change	
		Preintervention	Postintervention	IRR (95% CI)	Percent change[a] (95% CI)
Non–intensive care surgical unit[b]	Oct 2001	2.28	1.48	0.650 (0.428–0.989)	−35.0 (−57.2 to −1.1)
Surgical ICU[b]	Oct 2003	3.73	2.17	0.582 (0.347–0.974)	−41.8 (−65.3 to −2.6)
Remaining acute care units[c]	Jul 2005	2.33	1.39	0.599 (0.493–0.729)	−40.1 (−50.7 to −27.1)
Hospital-wide[c]	Oct 2001	2.40	1.88	0.782 (0.663–0.922)	−21.8 (−33.7 to −8.8)

NOTE. $N = 109$ months. Model: $\ln(\lambda) = \beta_0 + \beta 1(I)$, where I is the dichotomous intervention effect (0 or 1). CI, confidence interval; IRR, incidence rate ratio.

[a] (IRR−1) × 100.

[b] Significant at the $\alpha = .05$ level.

[c] Significant at the $\alpha = .01$ level.

term care and outpatient settings). Cultures of nares and rectal swab samples were considered to be surveillance cultures and were thus ineligible. Clinical incidence was expressed as the number of incident cases per 1,000 patient-days at risk. Patient-days at risk were calculated from admission-discharge-transfer data for each patient stay. Patients were not considered to be "at risk" if they had a positive MRSA clinical culture result within the previous year. Patient-days were subtracted for any portion of the patient stay during which the patient was not "at risk." Additionally, patient-days accrued during the first 48 hours after admission were also excluded, because clinical incidence could not be identified during the first 48 hours after admission by definition.

Secondary outcomes included (1) monthly clinical incidence of MSSA colonization or infection, calculated using the methods described for MRSA; (2) quarterly incidence of MRSA bloodstream infection (BSI), calculated by dividing the number of new (first in 14 days) MRSA-positive blood cultures obtained at least 48 hours after admission by patient-days at risk; and (3) monthly proportion of all clinically incident *S. aureus* isolates that were resistant to methicillin. Prevalence at admission was also calculated to assess colonization pressure. Prevalent cases were defined by a positive clinical MRSA culture result within 1 year before admission or a positive clinical culture result from a sample obtained within 48 hours after admission.

Analysis

The clinical incidence of MRSA and MSSA colonization and infection and the proportion of *S. aureus* isolates resistant to methicillin were calculated per month; the incidence of MRSA BSI was calculated per calendar quarter. The unit of analysis was location-month for the clinical incidence of MRSA colonization or infection, clinical incidence of MSSA colonization or infection, and proportion of *S. aureus* isolates resistant to methicillin. Pre-post and interrupted time series (ITS) analytic approaches were used to assess the impact of the MRSA prevention intervention. For pre-post analyses, the clinical incidence of MRSA colonization or infection was modeled by entering a single dichotomous "intervention" predictor variable into the Poisson model (months before the intervention were assigned a "0," and months after the intervention were assigned a "1"). These pre-post analyses effectively compared aggregated rates before the intervention with aggregated rates after the intervention.

The ITS approach is more informative and rigorous than a pre-post design because it allows for comparison and quan-

TABLE 2. Incidence Rate Ratios (IRRs) and Associated Percent Changes for an Interrupted Time Series Analysis Model of Hospital-wide Clinical Incidence of Methicillin-Resistant *Staphylococcus aureus* Colonization or Infection

Parameter	Variable(s)	Coefficient(s)	IRR (95% CI)	Percent change[a] (95% CI)
Intercept	Constant	β_0	…	…
Preintervention trend[b]	T	β_1	1.022 (1.001–1.043)	2.2 (0.1 to 4.3)
Immediate intervention impact	I	β_2	0.964 (0.714–1.300)	−3.6 (−29.6 to 30.0)
Change in pre- to postintervention trends[c]	TSI	β_3	0.968 (0.948–0.988)	−3.2 (−5.2 to −1.2)
Persistence of trend in postintervention period[c]	T + TSI	$\beta_1 + \beta_3$	0.989 (0.985–0.992)	−1.1 (−1.5 to −0.8)

NOTE. $n = 109$ months. Model: $\ln(\lambda) = \beta_0 + \beta_1(T) + \beta_2(I) + \beta_3(TSI)$, where T is month, I is intervention (0 or 1), and TSI is months since intervention. CI, confidence interval.

[a] (IRR−1) × 100.

[b] Significant at the $\alpha = .05$ level.

[c] Significant at the $\alpha = .01$ level.

TABLE 3. Incidence Rate Ratios (IRRs) and Associated Percent Changes for a Modified Interrupted Time Series Analysis Model for Area-Specific, Clinically Incidence of Methicillin-Resistant *Staphylococcus aureus* Colonization or Infection

Parameter	Variable(s)	Coefficient(s)	IRR (95% CI)	Percent change[a] (95% CI)
Preintervention trend				
Non–intensive care surgical unit	T	β_1	1.031 (0.979–1.086)	3.1 (−2.1 to 8.6)
Surgical ICU	T	β_1	1.006 (0.983–1.030)	0.6 (−1.7 to 1.3)
All other acute care units	T	β_1	0.999 (0.994–1.004)	−0.1 (−0.6 to 0.4)
Pooled	T	β_1	0.999 (0.995–1.005)	−0.1 (−0.5 to 0.5)
Immediate intervention effect				
Non–intensive care surgical unit	I	β_2	0.775 (0.371–1.617)	−22.5 (−62.9 to 61.7)
Surgical ICU	I	β_2	0.913 (0.356–2.343)	−9.7 (−64.4 to 234.3)
All other acute care units[b]	I	β_2	0.656 (0.440–0.979)	−44.4 (−56.0 to −2.1)
Pooled[b]	I	β_2	0.708 (0.510–0.983)	−29.2 (−49.0 to −1.7)
Change in pre- to postintervention trends				
Non–intensive care surgical unit	TSI	β_3	0.958 (0.909–1.009)	−4.2 (−9.1 to 0.9)
Surgical ICU[c]	TSI	β_3	0.971 (0.938–1.004)	−2.9 (−6.2 to 0.4)
All other acute care units	TSI	β_3	0.998 (0.982–1.014)	−0.2 (−1.8 to 1.4)
Pooled	TSI	β_3	0.990 (0.976–1.004)	−1.0 (−2.4 to 0.4)
Persistence of trend in postintervention period				
Non–intensive care surgical unit[d]	T + TSI	$\beta_1 + \beta_3$	0.987 (0.978–0.996)	−1.3 (−2.2 to −0.4)
Surgical ICU[c]	T + TSI	$\beta_1 + \beta_3$	0.977 (0.952–1.005)	−2.3 (−4.8 to 0.3)
All other acute care units	T + TSI	$\beta_1 + \beta_3$	0.997 (0.982–1.012)	−0.3 (−1.8 to 1.2)
Pooled[d]	T + TSI	$\beta_1 + \beta_3$	0.989 (0.981–0.996)	−1.1 (−1.9 to −0.4)

NOTE. $n = 109$ months. Model: $\ln(\lambda) = \beta_0 + \beta_1(T) + \beta_2(I) + \beta_3(TSI)$, where T is month, I is intervention (0 or 1), and TSI is months since intervention. CI, confidence interval; ICU, intensive care unit.

[a] $(IRR-1) \times 100$.

[b] Significant at the $\alpha = .05$ level.

[c] Significant at the $\alpha = .10$ level.

[d] Significant at the $\alpha = .01$ level.

tification of pre- and postintervention trends (as opposed to a comparison of simple aggregated rates in the pre-post model).[22,23] Parameter estimates generated by the ITS model provide the following 4 key pieces of information: (1) preintervention trend (β_1); (2) the immediate intervention impact (β_2), which captures the difference in rates immediately after the intervention, compared with those immediately before; (3) the change in pre- and postintervention trends (β_3); and (4) postintervention change over time ($\beta_1 + \beta_3$), which effectively quantifies the persistence of the postintervention trend (see the notes of Tables 1–3 for models). Incidence rate ratios were calculated for each of these effects. Durban-Watson statistics were performed to examine serial autocorrelation.[24]

The hospital-wide ITS model for clinical incidence of MRSA colonization or infection was used to evaluate the impact of the intervention's initiation in October 2001 in all acute care areas. For area-specific ITS analyses, separate models were created for the non–intensive care surgical unit, the surgical ICU, and the remainder of acute care units, with interventions initiated in October 2001, October 2003, and July 2005, respectively. Estimates generated from each area-specific ITS model were then pooled; confidence intervals were calculated for the pooled estimates with use of inverse-variance weighting. Monthly MRSA prevalence was also entered into initial models to control for potential variation in colonization pressure over time.

Secondary outcomes (monthly clinical incidence of MSSA colonization or infection, quarterly MRSA BSI incidence, and monthly proportion of *S. aureus* isolates resistant to methicillin) were also modeled with ITS to determine hospital-wide impact. Because MRSA BSI was a rare outcome, MRSA BSI incidence was calculated and modeled on a quarterly basis. Clinical incidence of MSSA colonization or infection and quarterly MRSA BSI incidence were modeled using Poisson regression; monthly proportions of *S. aureus* isolates resistant to methicillin were modeled using logistic regression. All analyses were performed in SAS, version 9.1.2 (SAS Institute).

RESULTS

Clinical Incidence of MRSA Colonization or Infection

In pre-post analyses, overall hospital-wide clinical incidence of MRSA colonization or infection decreased by 21.8% (95% confidence interval, 8.8%–33.7%) following initiation of the intervention in October 2001, from 2.40 cases per 1,000 patient-days at risk in the preintervention period (months 1–24) to 1.88 cases per 1,000 patient-days at risk in the postintervention period (months 25–108) (Table 1). Pre-post

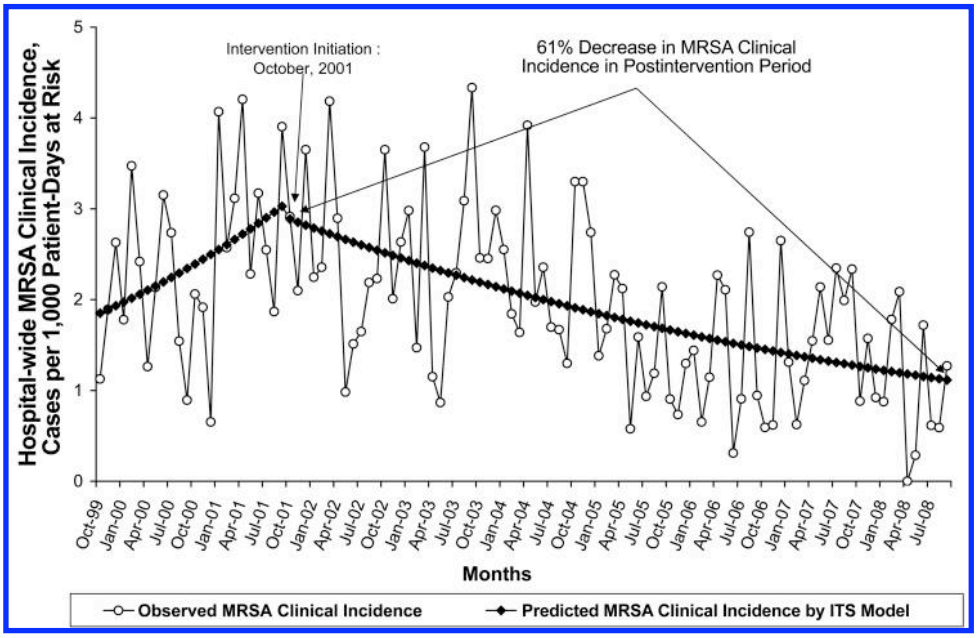

FIGURE 1. Observed hospital-wide clinical incidence of methicillin-resistant *Staphylococcus aureus* (MRSA) colonization or infection per 1,000 patient-days from October 1999 through September 2008 at 1 Veterans Affairs hospital, with superimposed predicted values generated by an interrupted time series (ITS) model.

analyses for each specific hospital unit also revealed significant decreases in clinical incidence associated with implementation of interventions in each unit.

The hospital-wide ITS analysis (Table 2) displays the incidence rate ratio and predicted percent change calculated from the incidence rate ratio for each of the model effects. Initial models included prevalence as a control variable. However, prevalence was not a significant predictor and did not impact the other parameter estimates or overall model fit. As a result, it was excluded from the final model shown. Although there was not an immediate impact (β_2) of the intervention on hospital-wide rates, there was a significant difference in the pre- and postintervention trends (β_3) ($P < .01$) and a significant postintervention decrease of 1.1% per month

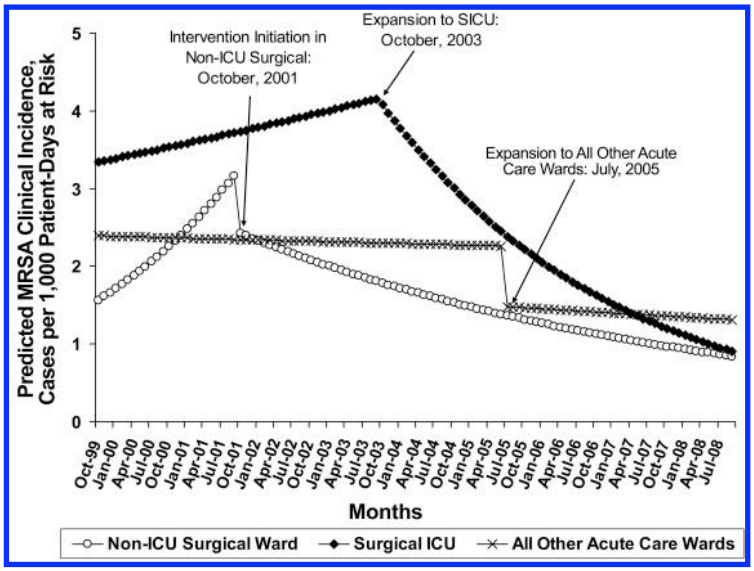

FIGURE 2. Predicted clinical incidence of methicillin-resistant *Staphylococcus aureus* (MRSA) colonization or infection per 1,000 patient-days at risk generated by an interrupted time series (ITS) model, stratified by hospital unit at 1 Veterans Affairs hospital. ICU, intensive care unit; SICU, surgical intensive care unit.

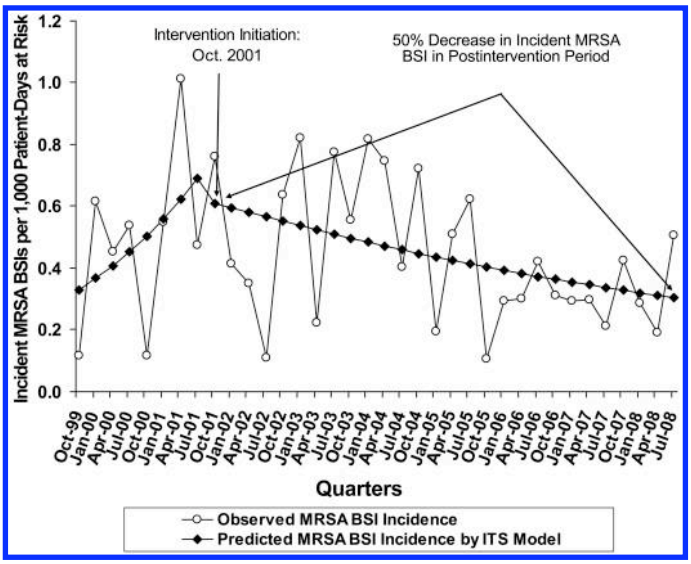

FIGURE 3. Incident methicillin-resistant *Staphylococcus aureus* (MRSA) bloodstream infections (BSIs) per quarter from October 1999 through September 2008, with superimposed predicted values generated by an interrupted time series (ITS) model.

for the 7 years following initiation of the intervention. Figure 1 shows the predicted (fitted) clinical incidence generated from the hospital-wide ITS model superimposed over the observed clinical incidence of MRSA colonization or infection. From the first postintervention fitted point and the last postintervention fitted point, there was a 61% decrease in clinical incidence during the 7-year postintervention period. When the identical hospital-wide model was applied to hospital-wide clinical incidence of MSSA colonization or infection, there was no difference between pre- and postintervention slopes, nor was there a significant postintervention decrease in clinical incidence of MSSA colonization or infection. Durban-Watson statistics were not significant for MRSA or MSSA models, indicating that there was no significant serial autocorrelation in either model.

Although there was no immediate intervention impact or change in pre-post trends for the proportion of *S. aureus* isolates resistant to methicillin, there was a significant postintervention reduction in resistant isolates (1.1% per month; $P < .001$); the proportion of resistant isolates decreased by 30% (from 73.6% resistant at the first postintervention predicted point to 51.5% resistant at the last postintervention predicted point). There was no change in the hospital-wide rates of clinical culturing (ie, the monthly number of clinical cultures obtained divided by patient-days) over the entire study period.

Area-specific and pooled ITS estimates of clinical incidence of MRSA colonization or infection are shown in Table 3, with predicted values displayed in Figure 2. In the non–intensive care surgical unit, which is the unit where the intervention was initiated, there was a significant decrease of 1.3% per month in the postintervention period (66% decrease overall in the total postintervention period). In the surgical ICU, there was a 2.3% monthly decrease (66% total decrease in the postintervention period); however, this decrease was not statistically significant. In the remainder of acute care units (which simultaneously initiated the intervention in 2005), there was a significant immediate intervention effect (β_2), with a 44.4% decrease in incidence (95% confidence interval, 2.1%–56.0%) immediately following the intervention.

Finally, the hospital-wide MRSA BSI analysis by quarter showed a statistically significant decrease (54%) in MRSA BSI incidence per 1,000 patient-days in the postintervention period (Figure 3) ($P = .02$).

DISCUSSION

This assessment demonstrates a significant and sustained intervention-associated reduction in hospital-wide MRSA transmission (defined by clinical incidence of MRSA colonization or infection) following implementation of a multifaceted intervention. Because of disproportionate reductions in the clinical incidence of MRSA relative to MSSA colonization or infection, there was a significant decrease over time in the proportion of clinical *S. aureus* isolates that were resistant to methicillin. In a supplemental analysis of quarterly MRSA BSI incidence, a 50% decrease in MRSA BSI incidence was noted in the 7-year postintervention period, suggesting decreases in transmission, as well as unambiguous clinical outcomes.

Regarding area-specific intervention impact, there was a relatively weak immediate impact on clinical incidence of MRSA colonization or infection, with subsequent decreases over time for the first 2 units initiating the intervention in October 2001 and October 2003, respectively. When the intervention was extended to the remainder of acute care units

in July 2005, however, there was a strong immediate effect with a relatively small subsequent decrease over time. The reasons for these area-specific differences in intervention impact are unclear. Implementation of the intervention in all acute care units corresponds temporally to a transition of the culture and behavior change strategy from TPS to PD, suggesting that implementation of PD may have fostered a more immediate effect. An alternative explanation is that there was a priming effect; knowledge and experience accrued in the initial phases may have enhanced motivation and more rapid implementation of the program in other areas of the hospital.

The impact of multifaceted MRSA prevention interventions has been variable, according to published reports. Although some studies have shown significant reductions in the number of MRSA infections,[13,14] a study published in 2008 showed no significant reduction in HA-MRSA infections after implementation of an active surveillance testing, decolonization, and isolation intervention in a Swiss hospital with endemic MRSA.[25] It is possible that innovative approaches to infection control that incorporated systems and behavior change strategies (eg, TPS or PD) contributed substantially to the success demonstrated in this study. Although it is impossible to disentangle the impact of TPS and PD activities from those of other intervention components, these systems and behavior change strategies likely heightened sensitivities of staff and patients to potential MRSA transmission pathways.

The discordance between the apparent intervention-associated impact on clinical incidence of MRSA colonization or infection, compared with MSSA, has been described in several other MRSA prevention studies.[13,14] There are several potential explanations for this observation. The additional use of contact precautions for asymptomatic MRSA carriers may have resulted in a greater reduction in transmission of MRSA, compared with MSSA. Alternatively, several lines of evidence suggest that even if the interventions reduced transmission of both MSSA and MRSA to similar degrees, the expected outcome would be a disproportionately greater effect on MRSA. These lines of evidence include the observation that the prevalence of MRSA carriage among healthcare-experienced patients is markedly higher than that among the general population; the same is not true for MSSA.[26-28] In addition, molecular fingerprinting evidence documents significantly greater homogeneity among HA-MRSA isolates, compared with HA-MSSA isolates,[29] which suggests intrahealthcare transmission of relatively few strains. Finally, mathematical models suggest that nonspecific interventions that reduce the transmission of all bacteria within a hospital will disproportionately reduce the prevalence of colonization with resistant bacteria.[30]

Our study is subject to several limitations. Both hospital-wide and area-specific modeling approaches have limitations. The hospital-wide models may mask the distinct relative contribution of the 3 area-specific intervention phases, making it difficult to assess the relative importance of each phase. Conversely, the area-specific models assume the intervention to have a completely independent effect in each hospital area and, therefore, are unable to detect "spill-over" effects between intervention and nonintervention areas of the hospital attributable to the movement of staff and patients throughout the hospital. Both models may be imperfect reflections of clinical reality, but interpreting them in parallel can provide the most complete understanding possible. Another limitation is that the clinical incidence metric used as a proxy for MRSA transmission does not distinguish between infection and colonization. There is, however, evidence from multicenter ICU studies that such measures correlate with transmission,[20] and similar metrics were recommended in late 2008 by the Society for Healthcare Epidemiology of America.[21] Unfortunately, such metrics, by focusing on acute care incidence alone, are unable to measure the "downstream" benefits that may result from preventing MRSA transmission during hospitalization, such as prevention of MRSA infections that occur after discharge and reduction in the reservoir for transmission (ie, fewer MRSA-colonized patients) during subsequent acute and long-term care admissions and other healthcare encounters. Modeling MRSA spread in the context of patient movement from the community to long-term care to acute care is an important area for future study.[31]

Another limitation of this study is that we did not systematically collect data on adherence to prevention measures, such as hand hygiene and contact precautions, and therefore, statistical relationships between specific intervention components and outcomes could not be assessed. However, hospital personnel who collected data for the purposes of quality improvement during the final 21 months of the study reported that adherence to hand hygiene on exit from the patient's room and adherence to contact precautions was more than 85% for most hospital units. Finally, we cannot rule out the possibility that contemporaneous infection control measures or the larger temporal trends in infection rates could have contributed to the observed reductions in clinical incidence of MRSA colonization or infection; these seem unlikely, however, to explain our major findings given the strong temporal relationship observed between the initiation of the intervention and the decreases in different units at different intervention times. There were no other major infection control efforts with an onset coinciding with the interventions.

In conclusion, a multifaceted MRSA prevention program implemented in a single hospital resulted in intervention-associated reductions in the clinical incidence of MRSA colonization or infection. In addition, significant postintervention reductions were demonstrated in the incidence of MRSA BSI and the proportion of *S. aureus* isolates resistant to methicillin. These findings contribute to the growing body of evidence suggesting that infection control interventions designed to prevent transmission can have significant impact on endemic healthcare-associated antimicrobial resistance problems and, therefore, should be emphasized as an important strategy for action, especially in the likely absence of near-

term help from the antibiotic development pipeline. The implications of our findings may extend beyond MRSA control; the principles underlying the intervention (ie, preventing patient-to-patient transmission of an epidemiologically significant, antimicrobial-resistant, healthcare-associated pathogen) can likely be applied successfully toward the control of any pathogen that is frequently transmitted from patient to patient in healthcare settings.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention and the Department of Veterans Affairs.

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