ORIGINAL ARTICLE

Implementation of an Industrial Systems-Engineering Approach to Reduce the Incidence of Methicillin-Resistant *Staphylococcus aureus* Infection

Robert R. Muder, MD; Candace Cunningham, RN; Ellesha McCray RN, MBA; Cheryl Squier, RN; Peter Perreiah, MBA; Rajiv Jain, MD; Ronda L. Sinkowitz-Cochran, MPH; John A. Jernigan, MD

OBJECTIVE. To measure the effectiveness of an industrial systems-engineering approach to a methicillin-resistant *Staphylococcus aureus* (MRSA) prevention program.

DESIGN. Before-after intervention study

SETTING. An intensive care unit (ICU) and a surgical unit that was not an ICU in the Pittsburgh Veterans Administration hospital

PATIENTS. All patients admitted to the study units

INTERVENTION. We implemented an MRSA infection control program that consisted of the following 4 elements: (1) the use of standard precautions for all patient contact, with emphasis on hand hygiene; (2) the use of contact precautions for interactions with patients known to be infected or colonized with MRSA; (3) the use of active surveillance cultures to identify patients who were asymptomatically colonized with MRSA; and (4) use of an industrial systems-engineering approach, the Toyota Production System, to facilitate consistent and reliable adherence to the infection control program.

RESULTS. The rate of healthcare-associated MRSA infection in the surgical unit decreased from 1.56 infections per 1,000 patient-days in the 2 years before the intervention to 0.63 infections per 1,000 patient-days in the 4 years after the intervention (a 60% reduction; $P = .003$). The rate of healthcare-associated MRSA infection in the ICU decreased from 5.45 infections per 1,000 patient-days in the 2 years before to the intervention to 1.35 infections per 1,000 patient-days in the 3 years after the intervention (a 75% reduction; $P = .001$). The combined estimate for reduction in the incidence of infection after the intervention in the 2 units was 68% (95% confidence interval, 50%–79%; $P < .001$).

CONCLUSIONS. Sustained reduction in the incidence of MRSA infection is possible in a setting where this pathogen is endemic. An industrial systems-engineering approach can be adapted to facilitate consistent and reliable adherence to MRSA infection prevention practices in healthcare facilities.

Infect Control Hosp Epidemiol 2008; 29:702–708

Infection with methicillin-resistant *Staphylococcus aureus* (MRSA) is endemic in most United States hospitals.[1] Among *S. aureus* isolates recovered from patients with healthcare-associated infection, the proportion resistant to methicillin has increased over the past 25 years; at present, MRSA causes over 50% of *S. aureus* infections that occur in intensive care units (ICUs) in the United States.[1] Healthcare-associated MRSA infections cause greater morbidity and mortality than do infections caused by methicillin-susceptible strains.[2-8] Among patients with healthcare-associated infections caused by *S. aureus,* infection due to a methicillin-resistant strain is associated with increased attributable cost.[4-9] the prevention and control of infection due to MRSA and other multidrug-resistant organisms has become a national public health priority.[10]

Recent guidelines from the Healthcare Infection Control Practices Advisory Committee call for US healthcare facilities to implement multifaceted control programs that result in a consistent decrease in the incidence of MRSA infection.[10] The guidelines emphasize the use of strategies to improve healthcare workers' adherence to each of the control program components. Traditional approaches to infection control that rely on education and reporting of infection rates often fail to ensure consistent and reliable adherence, as demonstrated by multiple studies showing low compliance with hand hygiene and other infection control practices in healthcare facilities.[11-14]

From the VA Pittsburgh Healthcare System (R.R.M., C.C., E.M., C.S., R.J.), Pittsburgh Regional Healthcare Initiative (R.R.M., R.J.), and the Department of Medicine, University of Pittsburgh School of Medicine (P.P.), Pittsburgh, Pennsylvania; and the Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention (R.S.-C., J.A.J.), Atlanta, Georgia.

Received September 17, 2007; accepted April 23, 2008; electronically published July 14, 2008.

 0899-823X/2008/2908-0004$15.00. DOI: 10.1086/589981

A possible explanation is that traditional infection control approaches frequently fail to address the barriers to adherence that are embedded in the complex systems of work common to healthcare facilities, and these approaches may not engage frontline healthcare workers in finding ways to overcome such barriers.

We postulated that an industrial systems-engineering approach designed to engage frontline workers in eliminating practice variation in complex work environments could be adapted to the healthcare industry. Further, we hypothesized that applying this approach specifically to an MRSA infection control program that includes the use of active surveillance cultures to detect colonized patients at admission, coupled with use of barrier isolation precautions, would lead to a sustained reduction in MRSA transmission and infection. Although the precise role of active surveillance in multifaceted MRSA infection prevention programs is the subject of debate, we chose to include it as part of the program on the basis of a number of observational studies suggesting that multifaceted prevention programs that include active surveillance have been effective in limiting the spread of MRSA on a unit or within a facility.[15-18] More information on the feasibility and long-term effect of multifaceted MRSA infection prevention strategies, with or without use of active surveillance cultures, is needed.

METHODS

The University Drive Division of the Veterans Affairs Pittsburgh Healthcare System is a 158-bed, acute care hospital that provides tertiary level medical and surgical services. MRSA is endemic in this hospital, and MRSA infection rates have been highest among surgical patients. During 2000–2001, 215 (63%) of 339 unique *S. aureus* patient isolates were MRSA. In October 2001, we initiated an intervention on a 36-bed surgical unit that was not an ICU (unit A) to implement an enhanced MRSA infection control program. Because of the initial success with MRSA infection prevention in unit A, we initiated the same program in an 11-bed surgical ICU (unit B) in October 2003. Both unit A and unit B housed patients who had been admitted to the general surgery and surgical subspecialty services. These 2 units house the vast majority of surgical patients in our facility.

The enhanced MRSA infection control program consisted of the following 4 elements: (1) the use of standard precautions, with an emphasis on hand hygiene before and after contact with patients and their environment; (2) the use of contact precautions for all interactions with patients infected or colonized with MRSA (we modified contact precautions to require the use of gowns and gloves on entering an area immediately surrounding the patient, demarcated by a red tape line on the floor in patient rooms); (3) the use of active surveillance cultures to identify patients who were asymptomatically colonized with MRSA; and (4) the use of the Toyota Production System (TPS), an industrial systems-engineering approach, to facilitate consistent and reliable application of elements 1–3.[19-20]

The central principle of the TPS is the expectation that all work processes are controlled experiments that are continuously improved upon by the people doing the work. The basic principles of the TPS have been summarized by Spear and Bowen as the following "rules in use."[21(p101)] (1) All work activity shall be highly specified as to content, sequence, timing, location, and expected outcome. (2) Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses. (3) The pathway for every product and service must be simple and direct, with no forks or loops. (4) Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the appropriate level of organization closest to the work.

To implement the TPS in our facility, a staff nurse from the unit was appointed to be team leader; her function was to identify obstacles to the identification and isolation of patients who were colonized or infected with MRSA and to engage staff in problem-solving aimed at improving processes relevant to infection control. An industrial engineer who had extensive familiarity with the TPS served as a teacher and consultant and provided assistance with data management. No additional nursing personnel were added to the units. The unit staff, with the guidance of the team leader and industrial engineer as needed, used the following sequence of actions to remove barriers to effective implementation of infection control procedures:

1. The specific need (for example, an adequate stock of isolation supplies) was identified
2. The team observed how the work was currently being done
3. The team identified the root causes of error
4. The team proposed the change of a single variable
5. The team then implemented the change
6. The effect of the change on correcting the condition was then tested

If the desired result did not occur, the process was repeated until all potential causes of error were identified and eliminated.

This sequence of actions was applied to multiple activities, which included the following:

1. Identification of patients known to be colonized with MRSA
2. Collection of swab samples for surveillance culture at admission and at discharge
3. Stocking of isolation supplies
4. Placement of alcohol-based hand sanitizer dispensers in appropriate locations
5. Redesign of the layout of isolation rooms to encourage compliance

6. Disinfection of shared equipment
7. Management of patient transfers

Staff participated in weekly unit briefings in which they were given up-to-date feedback on key metrics, which included the rate at which swab samples were being obtained at admission and discharge, the nosocomial MRSA infection rate, and the nosocomial MRSA transmission rate. The staff reviewed individual instances of MRSA infection or transmission to identify possible errors in practice and to formulate a plan of corrective action.

Study design. This was a quasi-experimental (before and after) study conducted on 2 units. The interventions occurred at 2 different times, separated by a period of 2 years.

Surveillance cultures. At admission and discharge, swab samples from the nares and wounds were obtained from patients admitted to the study units. Samples were obtained by using a Dacron-tipped swab (DuPont). For patients whose stay exceeded 48 hours, we attempted to obtain swab samples within 48 hours after admission and at the time of discharge. Standard precautions were used in interactions with patients who were not known to be colonized or infected with MRSA, pending availability of the surveillance culture results. Primary inoculation was onto mannitol salt agar, colistin–naladixic acid agar, and brain-heart infusion broth with 6.5% NaCl. *S. aureus* was identified by using standard microbiologic methods. Methicillin resistance was confirmed by growth on Mueller-Hinton agar supplemented with 4% NaCl and 6μg/mL oxacillin after incubation for 24 hours at 35°C. Identification of MRSA typically took 48 hours from the time the specimen was obtained. Patients were placed under contact precautions if they had a prior history of MRSA infection or colonization in the preceding 2 years and if surveillance or clinically indicated cultures were reported as positive for MRSA. If the first sample positive for MRSA was obtained more than 48 hours after admission, the pathogen was considered to have been hospital acquired (this criterion also applied to patients from whom surveillance culture swabs were not obtained at admission).

Identification of healthcare-associated infection. Healthcare-associated MRSA infections were identified by an experienced infection control nurse who used Centers for Disease Control and Prevention definitions.[22] The same individual used the same definitions before and after the intervention, for surveillance purposes. For both of the study units, we report MRSA infection rates beginning 2 years prior to the intervention and continuing through September 2006. Surgical site infections (SSIs) were attributed to the unit if they occurred in patients admitted within 30 days after their operation. Incidence rates were expressed as the number of MRSA infections per 1,000 patient-days.

Analysis. Infection incidence data (the number of MRSA infections per 1000 patient-days for each month) were analyzed by use of 2 methods. First, we examined trends in incidence by using locally weighted scatter plot smoothing (LOESS) regression, with a smoothing parameter of 0.6 and quadratic functions for local polynomials.[23] Next, for each unit, we developed separate segmented Poisson regression models to test the significance of changes in incidence after the intervention. The overall impact for both hospital units was estimated by pooling the individual model estimates, by use of the inverse variance-weighted method. Trends in the overall SSI rate (ie, the proportion of procedures that resulted in an SSI) were evaluated by using χ^2 trend analyses.

RESULTS

In unit A, the rate of healthcare-associated MRSA infection decreased from 1.56 infections per 1,000 patient-days in the 2 years before the intervention to 0.63 infections per 1,000 patient-days in the 4 years after the intervention (a 60% reduction); the rate in year 5 was 0.47 infections per 1,000 patient-days. The table shows the number of patient-days, the number of infections, and the infection rate for each unit, according to fiscal year. The LOESS regression plot for unit A is shown in Figure 1. A segmented Poisson regression model containing only the intercept and an intervention term indicated a significant decrease in the incidence of infection after the intervention ($P = .003$). The percentage of patients who had MRSA recovered from surveillance cultures of samples obtained at admission to unit A was 11.3% (128 of 1130) in fiscal year 2002. This gradually decreased to 8.9% (151 of 1697) by fiscal year 2006 ($P < .01$). The rate of MRSA acquisition by patients who were initially MRSA negative was 5.7% (20 of 353) during the first year of intervention; this gradually declined to 2.3% (9 of 384) by the end of the intervention period.

In unit B, the rate of healthcare-associated MRSA infection decreased from 5.45 infections per 1,000 patient-days in the 2 years before to the intervention to 1.35 infections per 1,000 patient-days in the 3 years after the intervention (a 75% reduction). The rate in year 3 was 0.32 infections per 1,000 patient-days (Table). The LOESS regression plot for unit B is shown in

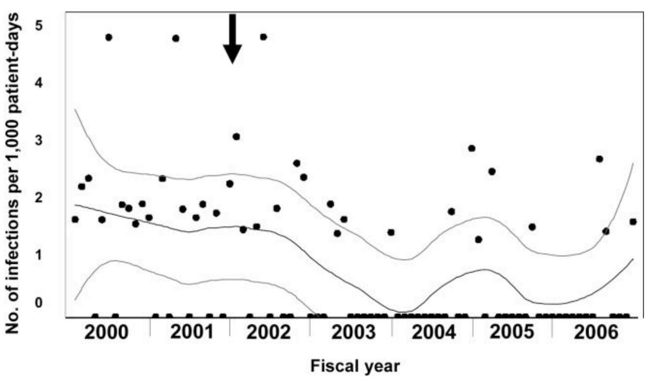

figure 1. Locally weighted scatter plot smoothing (LOESS) of monthly rates of methicillin-resistant *Staphylococcus aureus* (MRSA) infection in unit A. The lines represent the LOESS curve with its 95% confidence interval. *Arrow*, start of intervention.

TABLE 1. Rates of Methicillin-Resistant *Staphylococcus aureus* (MRSA) Infection in Study Units During the Study Period

Study unit, fiscal year	No. of patient-days	No. of MRSA infections: All	No. of MRSA infections: Surgical site infections	MRSA infection rate[a]
Unit A				
2000	6,691	12	9	1.79
2001	6,205	8	8	1.28
2002	6,794	10	8	1.47
2003	7,332	4	4	0.55
2004	7,882	3	3	0.38
2005	9,020	4	1	0.44
2006	8,494	4	2	0.47
Unit B				
2002	3,105	12	2	3.86
2003	3,131	22	6	7.03
2004	3,177	6	0	1.89
2005	3,325	6	1	1.80
2006	3,159	1	0	0.32

[a] No. of MRSA infections per 1,000 patient-days.

Figure 2. A segmented Poisson regression model containing only the intercept and an intervention term indicated a significant decrease in the incidence of infection following the intervention ($P = .001$). The percentage of patients who had MRSA identified in surveillance cultures of samples obtained at admission was 7.2%, with no significant trend over time.

When the parameter estimates from the individual models were pooled, the combined reduction in infection incidence in the 2 units was 68% (95% confidence interval [CI], 50%–79%; $P < .001$).

There were 2 infection control measures initiated during the intervention period that could have influenced the rate of MRSA infection: the institution of aggressive insulin infusion protocol and the discontinuation of perioperative antimicrobial prophylaxis 24 hours after surgery. On July 1, 2004, we initiated an aggressive insulin infusion protocol for unit B patients who underwent coronary artery bypass surgery. Two sternal wound infections due to MRSA occurred in fiscal year 2003, prior to the enhanced MRSA infection intervention, and only 1 occurred in fiscal year 2004, after the intervention and implementation of the insulin infusion protocol.

In 2003, a computerized standing order was initiated to automatically discontinue perioperative antimicrobial prophylaxis 24 hours after surgery. The percentage of surgical procedures for which perioperative antimicrobial prophylaxis was discontinued within 24 hours increased from 47% (185 of 390) in 2003 to 67% (261 of 386) in 2004. The appropriateness of the agents selected for perioperative antimicrobial prophylaxis did not change over the study period, and data regarding the timing of antimicrobial prophylaxis were unavailable.

To further adjust for any impact these interventions may have had on the MRSA infection rate, we repeated the regression analyses using models that included terms representing the initiation of the insulin infusion protocol intervention as well as the monthly rate of adherence to proper duration of perioperative antimicrobial prophylaxis. For unit B, the antimicrobial prophylaxis term was omitted because the intervention to improve this measure was initiated at the same time as the MRSA infection prevention program, making it impossible to differentiate between the impact of each of the 2 interventions simultaneously implemented in this unit. In these analyses, when the parameter estimates from the individual models were pooled, the combined reduction in infection incidence was not substantially changed (overall, a 55% reduction [95% CI, 22%–74%]; $P = .004$).

The overall rate of SSI following clean and clean-contaminated surgical procedures for the entire facility during the study period was 1.91%. This rate did not change significantly over time ($P = .60$, χ^2 for trend).

DISCUSSION

Our data indicate that a multifaceted prevention program that used an industrial-engineering approach to facilitate implementation of infection control practices, including the use of active surveillance cultures and contact precautions, was successful in reducing the rate of endemic MRSA infection in a continuous, sustained fashion. The intervention was introduced in 2 units at different times, and in each case there was a significant temporal association between the intervention and a decrease in the incidence of MRSA infection, suggesting that the observed results were highly unlikely to have been the result of random changes in infection rate or trends unrelated to the intervention. These findings add to the evidence suggesting that multifaceted prevention programs can reduce MRSA transmission and infection under conditions in which the organism is endemic.[16,18,24-28] More widespread implementation of similar programs (or alternative approaches that are similarly effective) in US hospitals has the potential to reverse the rising trend in MRSA infection rates that has been observed nationally over the past 25 years.[1]

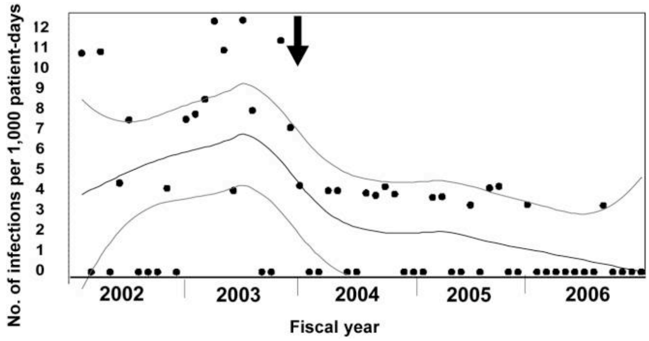

FIGURE 2. Locally weighted scatter plot smoothing (LOESS) of monthly rates of methicillin-resistant *Staphylococcus aureus* (MRSA) infection in unit B. The lines represent the LOESS curve with its 95% confidence interval. *Arrow*, start of intervention.

We applied an industrial-engineering approach, the TPS, to systematically identify and overcome barriers to implementation of the individual components of the MRSA infection control program. Each process of care was analyzed in conjunction with the unit personnel; a plan of remediation was formulated and tested if recommended processes of care were not followed. The analysis and remediation occurred as closely in time to the discovery of the problem as was practical. This process was repeated until each problem was solved. The staff members in each unit were aware of current rates of infection and transmission in approximately real time; each identified lapse in infection control was treated as a learning opportunity that could be used to improve the overall process. A key factor in the success of this effort was the commitment of the clinical and administrative leaders. They provided valuable assistance in enlisting the cooperation of multiple hospital departments, including, but not limited to, nursing, surgery, central supply, laboratory services, information management, and housekeeping.

This approach differs from that of traditional infection control practices. In a more traditional program, the rates of infection due to an organism of interest, such as MRSA, are characteristically tabulated over a period of time (eg, monthly or quarterly). Rates are commonly reported to the appropriate hospital body (eg, the infection control committee) and then disseminated to hospital leadership along with appropriate analysis and recommendations. Reformulation of policies, staff education, compliance monitoring, and reevaluation of infection rates are typical actions. What is often lacking under this model of infection control is real-time feedback of information to staff, real-time problem solving, involvement of frontline healthcare workers in devising countermeasures, and an effective means to ensure that the recommended countermeasures are consistently carried out. An additional flaw often seen in traditional infection control programs is the lack of recognition that appropriate support systems must be in place to ensure adherence. For example, identification and isolation of a patient carrying a multidrug-resistant organism is a complex process that can fail in multiple ways, such as failure to obtain samples for surveillance culture, delay in communication of laboratory results, delay in initiating contact precautions, or lack of the supplies necessary for adherence to contact precautions (eg, gowns, gloves, and/or alcohol-based hand rub). Successful implementation can only occur if the potential barriers to each step in the process are removed. The programs most likely to succeed are those that create a work environment in which identification and analysis of system failures is encouraged and creative problem solving by those closest to the work (ie, personnel who work on the unit on a daily basis) is fostered.

Of particular interest in our results is the observation that the number of SSIs due to MRSA decreased markedly in both units after the introduction of MRSA infection control measures, despite a lack of change in overall SSI rates over the same period. Most SSIs are thought to stem from intraoperative events. Current recommendations for preventing SSI (such as appropriate selection and timing of antibiotic prophylaxis, appropriate skin preparation, maintenance of sterile technique, and maintenance of normothermia) are aimed primarily at the preoperative and intraoperative periods.[29] However, a recent study hypothesized that postoperative factors could also play a role in the pathogenesis of SSI caused by MRSA.[30] Our observations are consistent with the hypothesis that some SSIs can be prevented by effective implementation of infection control measures in postoperative nursing units. Postoperative infection control measures are not currently emphasized in SSI prevention guidelines. Further study on this aspect of SSI prevention is warranted because MRSA is playing an increasingly important role in SSI.[31]

The improvement in adherence to proper duration of perioperative antimicrobial prophylaxis that occurred in 2004 could have contributed to the observed reduction in MRSA SSI rates. This seems unlikely to have been a major determinant because the improvements in the duration of antimicrobial prophylaxis were modest and consisted of a decrease in the duration of postoperative prophylaxis. In a multivariate model that adjusted for adherence to appropriate duration of postoperative prophylaxis in unit A, there was no substantial change in the results. Unfortunately, we could not control for this intervention in unit B because it was initiated simultaneously with the MRSA infection prevention program, making it impossible to differentiate between the impact of each of the 2 interventions simultaneously implemented in this unit. The constancy of overall SSI rates during the study periods is most likely because approximately 60% of surgical procedures in our facility are performed without admission to either of the study units, instead involving a brief stay in a same-day surgery unit. Thus, an improvement in hand hygiene and isolation practices in inpatient units would not have had any impact on the risk of SSI for the majority of patients.

The quasi-experimental nature of our study design introduces some limitations. First, the relative contribution of the individual intervention components cannot be assessed. It is possible that the same result could have been observed with only a subset of these intervention components. Second, we cannot rule out the possibility that contemporaneous infection control measures or the cyclical variation of infection rates could account for our major findings. This seems unlikely, however, given the strong temporal relationship observed between the initiation of the MRSA infection intervention and the decreases in infection rates for 2 different units at 2 different times. Hospitalwide programs to prevent catheter-associated bloodstream infections and ventilator-associated infections were implemented in the latter half of 2006, well after the major reduction in the incidence of MRSA infection was observed on the intervention units. The glucose-control intervention for cardiac surgery patients, although having the potential to influence MRSA infection rates, did not seem to explain our findings because only 2 cardiac surgical wound infections due to MRSA occurred prior to the intervention, and 1 occurred after; including terms for this intervention in our regression models did not change the results. We also note that the rate of MRSA infection in the surgical ICU had already decreased markedly prior to the institution of the insulin infusion protocol. Other limitations include uncertainty regarding the generalizability of these findings given that this is a single-center study, lack of standardized collection of data on adherence, and lack of data on unintended consequences of the intervention. Although no formal cost-effectiveness analysis was performed as part of this study, it is notable that the hospital administration perceived the cost-benefit ratio of the intervention to be favorable enough to warrant expansion of the intervention to the entire hospital in July 2005.

Our experience has important implications for the control of MRSA infection. First, we demonstrate that sustained reduction in MRSA infection is possible, even in a setting where the organism is endemic. Given that MRSA infection has significant adverse effects on both patient outcomes and expenditures, our findings support the current Centers for Disease Control and Prevention recommendations that US hospitals should implement multifaceted MRSA infection prevention programs that result in documentation of a sustained reduction in rates of endemic MRSA infection.[10] Second, we demonstrate that an industrial-engineering approach, in this case the TPS, can be adapted for use in a healthcare setting and can be applied successfully to promote the implementation of infection control programs. Strategies designed to engage frontline workers in changing institutional culture and the work environment could be critical to the success of programs preventing MRSA infection and other healthcare-associated infections.

ACKNOWLEDGMENTS

The authors thank Jane Muder for graphic design assistance.

Potential conflicts of interest. The authors report no conflicts of interest relevant to this article.

APPENDIX A

The Toyota Production System (TPS) is a systems approach to problem solving that requires the analysis of problems to identify their root causes. TPS operates through 4 major organizing principles called the "rules in use," as defined by Spears and Bowen[21] (these rules are listed in Methods). All of these rules require that activities, connections, pathways, and improvements have built-in tests to signal problems automatically.

The TPS applied to health care has 2 major principles: satisfying patient needs (including patient safety) and providing healthcare workers with meaningful work. A system can break down in the following ways:

1. Failing to support standardized work
2. Failing to have unambiguous connections between suppliers and customers
3. Failing to have clear pathways over which goods and services flow
4. Failing to have a consistent process by which system problems are identified and resolved

When the TPS is applied to health care, problems are identified and solved at the point of patient care by understanding how the system breaks down. The intended result is a redesigned system of work that improves health care, promotes job satisfaction, and eliminates wasted time. In addition, the TPS seeks to achieve cultural change by compelling healthcare workers to speak up to each other when recommended practices are ignored, making immediate recognition of these lapses as problems the central vehicle of cultural change. Healthcare workers are trained and encouraged to be engaged in the system and are provided mutual support in adhering to best practices.

The TPS was applied in this study specifically for the purpose of preventing MRSA transmission and infection. At the beginning of implementation, a staff nurse was appointed to be the team leader, with support from a TPS training consultant from the Pittsburgh Regional Healthcare Initiative; the consultant also acted as a teacher. The team leader was responsible for facilitating and leading other nurses and support staff in redesigning work to remove process variation. To understand the current condition of the work and how it might contribute to MRSA transmission, hundreds of detailed observations were collected. Several actions were taken to stabilize the work environment on these hospital units in order to maximize adherence to infection control practices. Furthermore, in an effort to make infection control procedures integral to the entire workplace, all staff were asked to attend weekly, 15-minute unit report meetings. The team leader, infection control staff, and members of the senior hospital management also attended. During these report meetings, feedback was used to provide staff with current rates of adherence to prevention measures as well as rates of nosocomial MRSA colonization and infection. The group then identified potential barriers to compliance with precautions and proposed countermeasures. Managers provided logistical support and encouraged interdepartmental cooperation. The specific countermeasures that were implemented are described in detail in Appendix B (available only in the online edition of the journal).

Address reprint requests to Robert R. Muder, MD Infectious Diseases Section, VA Pittsburgh Healthcare System, University Drive C, Pittsburgh, PA 15240 (Robert.Muder@va.gov).

REFERENCES

1. Klevens RM, Edwards JR, Tenover FC, McDonald LC, Horan T, Gaynes R. Changes in the epidemiology of methicillin-resistant *Staphylococcus aureus* in intensive care units in US hospitals, 1992–2003. *Clin Infect Dis* 2006;42:389–391.
2. Jernigan JA, Clemence MA, Stott GA, et al. Control of methicillin-resistant *Staphylococcus aureus* at a university hospital: one decade later. *Infect Control Hosp Epidemiol* 1995;16:686–696.
3. Cosgrove SE, Sakoulas G, Perencevich EN, Schwaber MJ, Karchmer AW, Carmeli Y. Comparison of mortality associated with methicillin-resistant and methicillin-susceptible *Staphylococcus aureus* bacteremia: a meta-analysis. *Clin Infect Dis* 2003;36:53–59.

4. Engemann JJ, Carmeli Y, Cosgrove SE, et al. Adverse clinical and economic outcomes attributable to methicillin resistance among patients with *Staphylococcus aureus* surgical site infection. *Clin Infect Dis* 2003;36:592–598.
5. Cosgrove SE, Qi Y, Kaye KS, Harbarth S, Karchmer AW, Carmeli Y. The impact of methicillin resistance in *Staphylococcus aureus* bacteremia on patient outcomes: mortality, length of stay, and hospital charges. *Infect Control Hosp Epidemiol* 2005;26:166–174.
6. Blot SI, Vandewoude KH, Hoste EA, Colardyn FA. Outcome and attributable mortality in critically ill patients with bacteremia involving methicillin-susceptible and methicillin-resistant *Staphylococcus aureus*. *Arch Intern Med* 2002;162:2229–2235.
7. Whitby M, McLaws ML, Berry G. Risk of death from methicillin-resistant *Staphylococcus aureus* bacteraemia: a meta-analysis. *Med J Aust* 2001;175:264–267.
8. Melzer M, Eykyn SJ, Gransden WR, Chinn S. Is methicillin-resistant *Staphylococcus aureus* more virulent than methicillin-susceptible *S. aureus?* A comparative cohort study of British patients with nosocomial infection and bacteremia. *Clin Infect Dis* 2003;37:1453–1460.
9. Abramson MA, Sexton DJ. Nosocomial methicillin-resistant and methicillin-susceptible *Staphylococcus aureus* primary bacteremia: at what costs? *Infect Control Hosp Epidemiol* 1999;20:408–411.
10. Siegel JD, Rhinehart E, Jackson M, et al. Management of multi-drug resistant organisms in healthcare settings, 2006. Available at: http://www.cdc.gov/ncidod/dhqp/pdf/ar/mdroGuideline2006.pdf. Accessed October 16, 2006.
11. Kim PW, Roghmann MC, Perencevich EN, Harris AD. Rates of hand disinfection associated with glove use, patient isolation, and changes between exposure to various body sites. *Am J Infect Control* 2003;31:97–103.
12. Pettinger A, Nettleman MD. Epidemiology of isolation precautions. *Infect Control Hosp Epidemiol* 1991;12:303–307.
13. Afif W, Huor P, Brassard P, Loo VG. Compliance with methicillin-resistant *Staphylococcus aureus* precautions in a teaching hospital. *Am J Infect Control* 2002;30:430–433.
14. Pittet D, Mourouga P, Perneger TV, Members of the Infection Control Program. Compliance with handwashing in a teaching hospital. *Ann Intern Med* 1999;130:126–130.
15. Jernigan JA, Titus MG, Groschel DH, Getchell-White S, Farr BM. Effectiveness of contact isolation during a hospital outbreak of methicillin-resistant *Staphylococcus aureus*. *Am J Epidemiol* 1996;143:496–504.
16. 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;24:362–386
17. Farr BM. Prevention and control of methicillin-resistant *Staphylococcus aureus* infections. *Curr Opin Infect Dis* 2004;17:317–322.
18. Cooper BS, Stone SP, Kibbler CC, et al. Isolation measures in the hospital management of methicillin resistant *Staphylococcus aureus* (MRSA): Systematic review of the literature. *BMJ* 2004;329:533.
19. Garner JS. Guideline for isolation precautions in hospitals. The Hospital Infection Control Practices Advisory Committee. *Infect Control Hosp Epidemiol* 1996;17:53–80.
20. Boyce JM, Pittet D. Guideline for hand hygiene in health-care settings: recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. *Infect Control Hosp Epidemiol* 2002;23(12 suppl):S3–S40.
21. Spear S, Bowen H. Decoding the DNA of the Toyota Production System. *Harvard Bus Rev* 1999;77:97–106.
22. Garner JS, Jarvis WR, Emori TG, Horan TC, Hughes JM. CDC definitions for nosocomial infections, 1988. *Am J Infect Control* 1988;16:128–140.
23. Cleveland W, Grosse E. Computational methods for local regression. *Statistics and Computing* 1991;1:47–62
24. Haley RW, Cushion NB, Tenover FC, et al. Eradication of endemic methicillin-resistant *Staphylococcus aureus* infections from a neonatal intensive care unit. *J Infect Dis* 1995;171:614–624.
25. Struelens MJ, Ronveaux O, Jans B, Mertens R. Methicillin-resistant *Staphylococcus aureus* epidemiology and control in Belgian hospitals, 1991 to 1995. Groupement pour le Depistage, l'Etude et la Prevention des Infections Hospitalieres. *Infect Control Hosp Epidemiol* 1996;17:503–508.
26. Murray-Leisure KA, Geib S, Graceley D, et al. Control of epidemic methicillin-resistant *Staphylococcus aureus*. *Infect Control Hosp Epidemiol* 1990;11:343–350.
27. Nicolle LE, Dyck B, Thompson G, et al. Regional dissemination and control of epidemic methicillin-resistant *Staphylococcus aureus*. Manitoba Chapter of CHICA-Canada. *Infect Control Hosp Epidemiol* 1999;20:202–205.
28. Kotilainen P, Routamaa M, Peltonen R, et al. Elimination of epidemic methicillin-resistant *Staphylococcus aureus* from a university hospital and district institutions, Finland. *Emerg Infect Dis* 2003;9:169–175.
29. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. Guideline for prevention of surgical site infection, 1999. Hospital Infection Control Practices Advisory Committee. *Infect Control Hosp Epidemiol* 1999;20:250–280.
30. Manian FA, Meyer PL, Setzer J, Senkel D. Surgical site infections associated with methicillin-resistant *Staphylococcus aureus:* do postoperative factors play a role? *Clin Infect Dis* 2003;36:863–868.
31. Jernigan JA. Is the burden of *Staphylococcus aureus* among patients with surgical-site infections growing? *Infect Control Hosp Epidemiol* 2004;25:457–460.

Appendix B: VAPHS Program for Getting to Zero on MRSA

I. Identification of MRSA Carriers
A. Use of electronic patient record
B. Use of Unit Lists of MRSA Carriers
C. Nasal swabbing on unit admission
D. Nasal swabbing of healthcare workers
II. Isolation of patients
A. Floor plan for isolation
B. Procedure for isolating patients
C. Single room preference
D. Cohorting rules
E. Moving patients identified as carriers
F. Signage at patient rooms
G. Patient movement outside rooms
H. Consult flagging
I. Visitor interactions with patients
III. Precaution compliance
A. Hand Hygiene
1. Alcohol foam hand rub
2. Antimicrobial soap
3. Skin lotion
B. Gloves
C. Gowns
D. Masks
IV. Supply systems supporting precautions
V. Equipment cleanliness
A. Dedicated equipment in rooms
B. Disinfecting wipes and holders
C. Clean and dirty equipment rooms
VI. Staff education
A. Nosocomial infection and MRSA awareness
B. Principles of MRSA transmission
C. Hand Hygiene
D. Precaution practices
E. Surveillance cultures
F. Use of contact precaution list
G. Case for cultural change
VII. Feedback measuring implementation and Connecting behavior with patient outcomes
A. Implementation metrics
B. Admission swabbing
C. Discharge swabbing
D. Soap and sanitizer monitoring
VIII. Countermeasure effectiveness
A. Nosocomial colonization rate per 1000 BDOC (Bed Days of Care)
B. Nosocomial infection rate per 1000 BDOC
C. Nosocomial transmission rate per 1000 MRSA BDOC
D. Nosocomial transmission rate index
IX. Real time problem solving
A. Followup on all transmissions
B. Setting up hypothesis testing
X. Managing patient transfers
XI. Visual environment
A. Gown lines on floor
B. Right to Clean Hands Sign in every room
C. Visual management boards for directing patient placement.

I. Identification of MRSA Carriers

Knowing who is a MRSA carrier is the first step in containing the reservoir to prevent spread.

A. Use of electronic patient record

The VA's Computerized Patient Record System (CPRS) provides a note in the upper right corner of the entry screen to each patient record. This note identifies the need for contact precautions under the *Crisis Warnings, Allergies and Advanced Directives (CWAD)*. Clicking on this note brings up instructions to maintain appropriate isolation precautions.

The CWAD note for contact precautions is activated by the Infection Control Practioner (ICP) based on laboratory culture results. Any patient with a prior positive MRSA culture has a warning placed on their CPRS record. This warning remains on the record and serves as a reminder to re-swab later to see if the patient has cleared.

The ICP also places CWAD's on all patients from healthcare facilities outside the Pittsburgh VA system whose cultures are tested as MRSA-positive MRSA by the University Drive Hospital lab. These warnings alert staff if these carriers ever visit University Drive in the future.

B. Use of Unit Lists of MRSA carriers

A consolidated list of all patients identified as MRSA carriers within the last two years is queued to automatically to print daily on every unit of the VA Pittsburgh Healthcare System (VAPHS). The unit Nurse Manager assigns someone to check against the list that all identified MRSA carriers are (i) isolated; (ii) have the correct precautions sign posted; and that isolation supplies like gowns, gloves and hand hygiene agents are immediately available to support staff compliance. A record of the isolation and stocking compliance rate is captured daily in the acute care facility and twice per week in the long-term care facility. This compliance data are reported to the Patient Safety Committee.

C. Nasal swabbing on unit admission

VAPHS has been performing 100% admission and discharge nares swabbing in the 4-West Inpatient Surgery since November 2001 and in the Surgical Intensive Care Unit (SICU) since December 2003. Swabbing for nasal and wound carriage is performed when indicated in other units.

VAPHS plans to implement 100% nares swabbing of patients on admission and discharge to its University Drive acute care hospital and its Heinz Long Term Care facility in Aspinwall. The intent of this comprehensive swabbing is to enable healthcare workers to know and isolate all MRSA carriers. Combining both entry and exit swabbing will also enable the VAPHS to determine its nosocomial colonization rate.

D. Nasal swabbing of healthcare workers

The VAPHS employee health office makes elective nares swabbing available to its employees to determine nares colonization when indicated. However, the VAPHS does not perform routine nares surveillance on its healthcare workers to identify carriers.

Other studies have shown the potential for transient nares colonization of healthcare workers, who may start their shift uncolonized, pick up the organism during patient care, go home, then return the next day having cleared the colonization.

At this point the VAPHS' position is that if precautions are adhered to tightly, then no pick up and transmission should occur. Thus potential transient colonization by healthcare workers is not a priority at this time.

II. Isolation of patients

Immediate isolation of known and suspected MRSA carriers is an effective way to minimize the risk of spread to non-carrier patients. The best isolation layout minimizes the placement of both MRSA carriers and non-carriers on the same nursing circuit.

A. Floor plan for isolation

Having a plan in advance as to which rooms will be targeted to receive MRSA carriers and non-carriers helps to avoid the rework of moving patients after a misplacement. Some long-term care units that care for many MRSA carriers have chosen to identify an entire hallway of the unit to receive MRSA carriers. The inpatient surgery unit has designated isolation rooms equipped with anterooms to be filled first with MRSA carriers, followed by standard rooms sharing the same hallway with the isolation rooms. Other open rooms are filled first before non-MRSA carriers are placed near MRSA carriers. Education of the nursing team and tight adherence to the placement plan can make isolation more effective and easier.

B. Procedure for isolating patients

Nurses who are receiving a patient for unit admission usually receive notification of a patient's need for contact precautions from the nursing report from the transferring unit. If no prior information on R/O status is provided, the cover sheet in the patient's computerized patient record can also be quickly reviewed to determine required precautions. The admitting nurse is accountable for placing the patient in the correct level of precautions.

C. Single room preference

At the University Drive acute care hospital, the VAPHS attempts to provide a patient in contact precautions for MRSA with a private room and bath.

D. Cohorting rules

Patients who are carrying the same pathogen may be cohorted in double or quad-rooms when single rooms are not available. Patients who are non-carriers should generally not be cohorted with MRSA carriers.

E. Moving patients after they become known carriers

Patients who are not known from their record to be MRSA carriers are currently placed in standard precaution (no isolation) rooms. If and when their MRSA nares swab result is determined to be positive at 48-72 hours, the patient will be placed in contact precautions. The patient is then usually moved to an isolation room, if available, or a more suitable room for contact precautions.

F. Signage at patient rooms

The placement procedure requires the admitting nurse to immediately place a sign in the sign holder outside the patient's room alerting entrants to the required precautions. The location of sign holders is standardized throughout VAPHS to provide clear identification of precautions before healthcare workers enter a patient room or care area.

G. Movement of patients outside of their assigned patient room

Patients may move about the VA outside of their assigned room, provided all wound drainage is contained. Patients who carry MRSA present some risk of transmission to other patients. However, the VAPHS has currently elected to focus on the risk of healthcare workers transferring MRSA from patient to patient. Nurses are instructed to educate patients identified as MRSA carriers to perform hand hygiene regularly.

H. Consult flagging

All consults on patients with MRSA are flagged in the CPRS alerting therapists and doctors that the patient they are about to treat requires contact precautions. These consult flags appear on the CPRS cover screen through which the consultant must pass to access the patient record.

I. Interaction between visitors and patients in patient rooms

Healthcare workers are instructed to encourage families and visitors to perform hand hygiene at least on entry and exit to their visit in the patient room. Families and other visitors are typically not required to gown and glove when visiting the patient. The only exception is when family or visitors assist with patient care requiring intensive contact like bathing or dressing changes. If a family member or visitor is having intensive physical contact with the patient, gowning and gloving is required and should be guided by the RN. Family and visitors are encouraged throughout their visit to perform hand hygiene when entering and exiting patient rooms.

III. Precaution Compliance

A. Hand hygiene

Achieving high compliance with hand hygiene is the first step in eliminating pathogen transmission and is thus a common element in all precautions. The VAPHS goes further than the CDC which recommends hand hygiene after all contact with the patient or the patient's environment. The VAPHS expects hand hygiene on entry and exit from a patient care area (e.g. a patient room), between patients in the same room and between procedures on the same patient. Hand hygiene should always be done prior to donning gloves to prevent contamination of the gloves. Finally, hand hygiene performed on exit from a room may count toward entry hand hygiene to the next patient care area, if the healthcare provider proceeds immediately to the next area and has no hand contact with other patients, staff or the environment.

1. Alcohol foam hand rub

Alcohol foam hand rub is the first line of defense against the spread of pathogens by hands. Since alcohol is more effective at reducing the bacteria count on hands than anti-microbial soap, and alcohol's anti-microbial effect persists longer, the VA encourages the predominant use of alcohol hand rub over soap and water. The probability that hand hygiene will occur at all before, during or after a patient encounter increases when healthcare workers have a habit of using alcohol hand rub. Thus the VA has mounted alcohol hand rub dispensers at the entrance to every patient room and care area. The VAPHS uses EcoLab's *Quick-Care Hand Foam* alcohol rub from Huntington Laboratories.

2. Antimicrobial Soap

When hands become soiled, anti-microbial soap must be used for at least 15 seconds of washing to remove the dirt and oils. Antimicrobial soap washing in place of alcohol hand rub is also required for hand hygiene after working with patients with *Clostridium difficile*.

The use of *anti-microbial* soap instead of regular soap has been mandated by the VA central office for hand washing. Every patient room or care area provides ready access to anti-microbial soap (with Triclosan) and hand washing facilities. Again, the use of alcohol hand rub is encouraged as the best method of hand hygiene whenever hands are not soiled. The VAPHS uses Steris' *Medicated Lotion Soap* as for its general purpose antimicrobial hand wash.

3. Skin Lotion

Steris Lotion Soft® Skin Conditioner is made available for healthcare worker skin maintenance. Bottles of the conditioner (15oz) are placed in mounted holders at defined locations in the units. Both the alcohol hand rub foam and the anti-microbial soap have hand lotion integrated into their formulas to condition skin while it disinfects.

B. Gloves

Powder-free latex gloves are provided in two sizes, medium and large, in all rooms. Work has been done in the inpatient medical and surgical units to relocate glove boxes to the optimal location where they are clearly visible on entry to the room. Glove boxes are marked to ensure that the right size gloves are replenished to the boxes. In addition to one box of medium and large gloves, intensive care units also have boxes for small, extra large sizes as well as a second medium box of gloves.

Powdered latex gloves are intentionally not provided because the powder can irritate the skin, contributing to dermatitis and higher bacteria colonization of the hands. Again, hand hygiene is stressed *before* putting on gloves to prevent contamination of the gloves.

Latex-free and nitrile gloves are also available to staff who have special needs.

C. Gowns

Gowning is one of the distinguishing features of Contact Precautions. Sheer, yellow, fluid-resistant gowns are provided at the VAPHS for routine work in areas under contact precautions when no fluid exposure risk is expected. These fluid-resistant gowns are designed to prevent the incidental pick up and deposit of pathogens from contact during a patient encounter.

Blue, fluid-impermeable gowns are worn whenever a fluid exposure risk is anticipated. Note that these fluid-impermeable gowns are required in both Standard Precautions and Contact Precautions *whenever a fluid exposure risk exists*.

Since putting on a gown requires several extra seconds, it is one step in Contact Precautions that is most neglected. Continuous engagement in attacking gown compliance at the VA has uncovered the following factors for successful gown compliance:

1. Immediate availability on entry—Any delay involving hunting for gowns will cause a significant decrease in gowning. Supply reliability is important to prevent the creation of individual work-arounds, such as having partial bags of gowns stashed throughout the work area -just in case.

2. Immediate visibility at the point of entry—Where ante rooms are available, cabinets containing gowns are clearly labeled inside and out. For isolation in rooms without ante-rooms, a yellow, four-drawer cabinet is placed beside the entrance of the patient room. The outside of the drawers are labeled with pictures of the supplies contained. The Heinz long-term care facility is installing clear Plexiglas boxes to hold gowns that will be visible from the room entry.

3. Fit—Prior to deploying the sheer yellow gowns, the VA supplied heavy green cloth gowns that came in one size and fit no one. Floor nurses managed the evaluation of alternative disposable fluid-resistant gowns to improve the fit. The current yellow gowns come medium and larges sizes, though only the large size is stocked to the units. These large-sized fluid resistant gowns have proved to be adaptable at supporting coverage on a variety of body sizes.

4. Appropriate use—Believe it or not, some healthcare workers don gowns backwards like a coat, leaving their front side open. Others neglect to tie the neck and let the gown fall to mid-chest. Continuous training and awareness about the potential for pathogen pick up on an unprotected front side has reduced these forms of noncompliance.

5. Understanding the clinical case for gowns—There are convincing clinical studies that show MRSA transmission cannot be eliminated without using gowns to prevent healthcare workers' clothing from becoming vectors for transmission. Beyond the scientific studies our experience suggests the presentation of a few photographs of culture dishes that show the pathogen pickup can occur on the lab coats of some prominent clinicians has been highly effective at communicating the need to gown.

D. Masks

Masks are used in Contact Precautions by some US hospitals to prevent colonization of the nares and subsequent transmission from the nares to non-carriers. Healthcare workers with runny noses are obviously at greatest risk for pick up and transmission of pathogens through this pathway. The VAPHS recommends the elective use of masks when a healthcare worker has a runny nose or is otherwise inclined to have frequent contact between the hand and nose. Masking is elective but, not required as a part of Contact Precautions at this time at the VAPHS.

Note: Under both Contact and Standard precautions, personal protective equipment (eye protection, masks or face shields) is required if any risk of splashing of body fluids is anticipated.

IV. Supply systems to support contact precaution requirements

Reliability of supply at the point of need has been a key enabler of improved precaution compliance. The clear goal is that nurses, doctors and other healthcare workers should never have to interrupt their patient care routine to hunt for precaution supplies. If supplies temporarily stock out at some point in the system, it should be immediately clear what should be done next and who has accountability for the system that may have stocked out.

The glove supply system is a case study in the application of these principles. Until January of 2002, it was not uncommon to enter a room on 4-West and find one or more of the wall-mounted glove boxes empty. There might have been multiple open boxes of gloves scattered throughout the room on countertops, inside cabinets or on sills. The problem was that the simple task of gloving involved a distracting hunt for gloves at best, and at worst a frustrating search for floor staff to obtain gloves from the central stock room. Accountability for restocking the gloves belonged to "everybody", but no one owned the process.

The solution to stabilizing the glove supply system consisted of fixing several systems problems. First *store* and *safety* stock quantities were estimated from observations of healthcare worker-patient encounters. It was determined that stocking could reasonably take place once per day and that one box of each size of glove (medium and large) should be sufficient to cover routine glove needs and additional needs if the supply system broke down. These store and safety stock glove boxes of both medium and large gloves were set up in the cabinets of every patient room. The wall mounted dispensers were clearly labeled that, if empty, gloves could be found in a designated cabinet. The cabinet doors were also labeled to lead healthcare workers and stockers to the stores. All labels were color-coded to correspond to the service (in this case escort) that was accountable for maintaining that part of the system. After several weeks of trials the system was determined that the initial assignment of replenishment could not be reliably fulfilled by the environmental services and the restocking was assigned to the current escort service. The escort now reliably restocks gloves every 24 hours to every room and gloves are always available.

V. Equipment cleanliness

Equipment that contacts patients or their environment has the potential to become a vector for transmission. RN's and other healthcare workers tend to be aware of this risk, but are often frustrated by the lack of convenient cleaning supplies to disinfect equipment between patient use.

A. Dedicated equipment in rooms:

One solution identified by the RN's was to reduce the sharing of equipment between carriers and non-carriers.

1. Bright Red Stethoscopes are placed in isolation rooms for use by the staff on the resident patient. These stethoscopes are of relatively high quality so there is no need for a healthcare professional to use a personal stethoscope. After a patient is discharged, the red stethoscopes are bagged and sent to sterile processing for cleaning, then return by the central supply group. The distinct red color is intended to help the staff remember not to remove the stethoscope from the room.

2. Ivac thermometers are also dedicated in each of the isolation rooms to prevent circulation. We have removed the rectal probes from these thermometers to prevent rectal use in infected patients. RN's have also candy-striped a roll-around Dynamap vitals machine to identify its dedicated use on isolated patients.

3. Disposable blood pressure cuffs which cost about $2.50 are available in all of the isolation rooms. This eliminates the need to soak the woven fabric of blood pressure cuffs to remove dirt.

B. Disinfecting wipes & holders

Are available throughout the unit and on temporary isolation carts. Nurses and other healthcare workers report that the convenience of a readily available, disposable wipe is critical to supporting the constant disinfect of equipment before it is stored for reuse. We had trouble preventing mold grow on the inside of the lids of the first product we deployed, Kimberly Clark's Wet Task. We have since switched to PDI Wipes that come in a disposable container that is discarded after the wipes are consumed. Importantly, both Kimberly Clark and PDI supply free wall mounting holders for their wipe containers. We found it was critical to mount the wipes, so that everyone knew the reliable locations to obtain a wipe.

C. Clean & Dirty Equipment Rooms that actually work.

A 5S exercise was conducted on the Clean and Dirty utility rooms on the unit to improve the efficiency of accessing equipment. Nurses decided that the standard of equipment handling would be to place equipment in the Clean equipment room only after it had been cleaned. The Clean equipment room is lined with simple signs on the walls displaying a picture of the equipment that is to be stowed below it. The status of this equipment (e.g. "plugged in to recharge batteries", oriented for easy pickup, etc) is also indicated on the equipment signs. The principle here is that whenever RN's need equipment from the room, they can rest assured that it is clean and ready for use.

VI. Staff education

Education of staff on infection control practices continues to be conducted as a part of employee orientation sessions by the local Infection Control Professional (ICP). Observational studies and conversations with healthcare workers revealed a gap in understanding the severity of the antibiotic resistant organism problem and in following prescribed precautions.

For healthcare workers in the 4-West Inpatient Surgery Unit and the 3-West SICU we teach a separate module on resistant organisms (R/O) that explains the following:

A. Nosocomial Infection and MRSA awareness

Most healthcare workers in this training are surprised at the magnitude of the problem of hospital-acquired infections. We review the size of the nosocomial infection problem in the United States, its costs and the implications for patient outcomes. We also discuss the rise of MRSA as a leading pathogen in the US.

B. Principles of MRSA transmission

The most common misconception we encounter is that MRSA is a result of the overuse of antibiotics on individual patients. In fact, the hands and clothes of healthcare workers are the more likely primary vectors in R/O transmission. Another misconception is that just isolating patients with MRSA infections will prevent the spread of MRSA. Patients who are colonized with MRSA actually outnumber infected patients more than 5 to 1 and present a significant risk of further MRSA transmission. Finally, there is often an attitude that "Well this patient has a lot of medical problems and containing him/her as a MRSA reservoir is not a priority." Our bottom line has been that we have to identify and contain all MRSA carriers if we hope to shutdown transmission.

C. Hand hygiene

Most healthcare workers are aware of the importance of hand hygiene, yet few take a systematic approach to cleaning their hands. Hand washing has been the dominant mode of hand hygiene. Our training module presents data from studies that confirm, for unsoiled hands, alcohol hand rub is more effective than antimicrobial soap, which is in turn more effective than regular soap at disinfecting hands. Specifically, alcohol hand rub kills more germs and its effect lasts longer than antimicrobial or regular soap.

Our initial observational studies showed our staff to be on par with national averages for hand hygiene (typically 10-30%). We have found that healthcare workers who have a strong habit of using alcohol hand rub when appropriate are much more likely to perform hand hygiene at all with patient encounters than healthcare workers who prefer just hand washing. We have aggressively pitched a preference for using alcohol hand rub for hand hygiene whenever appropriate in order to cultivate higher hand hygiene rates.

The official CDC recommendation is for hand hygiene after patient contact. Our observational studies suggested that leaving hand hygiene to the discretion of the healthcare worker as to whether they had patient contact, or 'much' patient contact did not cultivate a habit of hand hygiene. We thus adopted a more stringent expectation of hand hygiene on entry and exit to a patient room and between procedures on the same patient. Since alcohol hand rub has been made readily available at the doors of every patient room and takes seconds, we believe this tighter standard is a practical way to cultivate good hand hygiene habits.

When hands are soiled or a patient demonstrates *Clostridium difficile* associated diarrhea, we require hand washing with anti-microbial soap and water. We have been aggressive at removing barriers that reduce the likelihood of appropriate hand washing. We have installed sinks to improve convenience at our long-term care facility. We replaced shallow sinks and troublesome faucets with better functioning equipment in our ICU's. Finally, we have carefully inspected and adjusted the water pressure in inpatient rooms to eliminate splashing that can inhibit hand washing.

The bottom line is that we believe hand hygiene is the single most effective way to reduce contact transmission. We believe expectations for 100% appropriate hand hygiene must be clear from leadership and reinforced by peer-to-peer immediate staff feedback. All barriers to performing hand hygiene and all excuses for not doing hand hygiene need to be removed.

D. Precaution practices

Our discussions with staff revealed that 'Precautions' are generally thought of as applying to patients known to be carriers of resistant organisms. We review the fact that all patients are under at least *Standard* Precautions, requiring hand hygiene for all encounters, and gloving and gowning for fluid exposure risks. We also review the components of Contact Precautions for identified MRSA carriers.

E. Surveillance culture importance

The fact that 60-80% of the MRSA reservoir is typically not identified without surveillance culturing motivates our program to swab all patients on admission and on discharge. We emphasize that not knowing how big the 'rest of the iceberg' is in the unidentified MRSA reservoir contributes to a false sense of safety and fails to protect all patients from transmission.

F. Use of contact precaution list

We also introduce the class to the Contact Precautions List that prints on every unit so they can reliably know who should be in contact precautions. This list is generated from positive laboratory MRSA culture results (both nares and clinical). Any inpatient with a positive culture within the prior two years appears on this list. Patients can be removed from the list if they have two negative nares cultures, spaced at least two weeks apart, while not receiving antibiotic therapy. The underlying principle here is that every one must have a readily available checklist on their unit to confirm the contact precaution need of every patient.

G. Case for cultural change

Finally, we discuss the need for healthcare workers to become advocates for giving immediate feedback to their peers when they see a violation. We suggest that the current culture, where healthcare workers frequently observe other healthcare workers violating precautions and say nothing, actually reinforces the wrong behavior. When silence is the norm, advocating patient safety is perceived as abnormal and confrontational. We want to turn this culture upside down, it should seem unacceptable to see a precaution violation and not give immediate feedback. Healthcare workers should get used to constant feedback and compliance needs to be perceived as very abnormal.

The practical issue is how to efficiently train staff to lead this cultural change. We start by talking about the problem openly. We also suggest memorizing a couple of diplomatic sentences to give feedback to the offender. In this way, there is no fumbling for words in a difficult situation. These rote comments should also be accompanied by a universal gesture we are promoted to remind others to do hand hygiene. This gesture consists of holding the hands up at shoulder level with the palms in. Finally, we discuss the do's and don'ts of what to say to other nurses and doctors who are seen failing to comply with precautions.

VII. Feedback Measuring implementation performance and Connecting behavior with patient outcomes

A. Implementation metrics

Compliance with placement of patients in contact precautions is supposed to be checked against the unit MRSA carrier list every morning on each unit by the charge nurse or a designated nurse. This check is to be recorded daily in acute care and twice weekly in long-term care, then submitted monthly to a data coordinator who compiles the information to track compliance. The inspection consists of checking if all carriers are placed in appropriate rooms, have correct signage posted, and have isolation supplies available. Typical isolation compliance rates run about 98%.

B. Admission swabbing

The nares swabbing of every patient is indicated as one task on the task list for unit admission. The charge nurse reviews the unit admissions checklist by the end of the shift to ensure that all admissions tasks have been completed for each admission. A tally is kept as to how many admitted patients are swabbed within 24 hours of admission and charted. Typical admission swabbing rates run over 95%.

C. Discharge swabbing

All patients are swabbed on discharge to determine if a nosocomial transmission has occurred. This swabbing is incorporated as part of the discharge procedure and compliance is also charted. Typical discharge swabbing rates run over 90%.

D. Soap & sanitizer monitoring

We also weigh soap dispenser bags and alcohol hand rub canisters every 7-14 days to determine consumption on the inpatient surgery and surgical intensive care units. We then divide this total consumption by the unit dosage per hand hygiene event and the total bed days of care. This estimates the maximum possible hand hygiene events per bed day of care that could have occurred in the time period. While not precise, this metric gives a good upper bound on the hand hygiene rate: early change out of canisters or material spoilage would only decrease the hand hygiene rate. We plot the soap and alcohol handrub events per bed day of care over time by unit.

VIII. Countermeasure effectiveness

The ultimate test of all of these countermeasures is whether patients are becoming colonized or infected. We combine the nosocomial colonization and infection rates to get an overall nosocomial transmission rate. Intuition would suggest that the higher the MRSA reservoir, that is the higher the percentage of incoming patients are MRSA carriers, the higher the expected transmission rate. However, our hypothesis is that if contact precautions are complied with, the size of the MRSA reservoir will not impact the transmission rate.

A. Nosocomial colonization rate per 1000 BDOC (Bed Days of Care)

We track the colonization rate per 1000 BDOC by dividing the number of patients with positive discharge and negative admissions swabs by the bed days of care.

B. Nosocomial infection rate per 1000 BDOC

We track the nosocomial infection rate per 1000 BDOC by dividing the number of patients positive for MRSA infection and negative on admission by the bed days of care.

C. Nosocomial transmissions per 1000 MRSA BDOC

The total MRSA transmission rate is simply the sum of the nosocomial colonizations and infections divided by the total bed days of care for the period.

D. Nosocomial transmission index

We also calculate a nosocomial transmission index that divides the nosocomial transmission rate by the MRSA pressure (MRSA BDOC divided by the Total BDOC). This gives us a scales transmission rate of nosocomial transmissions per MRSA BDOC. This gives us a strong measure of the effectiveness of our contact precautions at stopping MRSA transmission.

IX. Real Time Problem Solving

A key driver of success in implementing these countermeasures is to follow up immediately on implementation problems as they are identified.

A. Follow up on all transmissions

When any transmission, whether colonization or infection occurs, a quick review of the case is performed to look for contributing factors. This has produced many practice changes. While no cause and effect can ever be directly attributed to the transmission, each case often points to some likely weakness in our barriers to transmission. These case learnings are strongest when they engage the staff in asking "5-Why's" as to what could have happened and are followed by prompt communication of learnings to the wider staff. This prompt communication impacts the staff in a number of ways: first, awareness is raised that more transmissions are occurring that originally thought; secondly, that their actions matter in reducing transmissions; and third, that they may have insight into identifying further weaknesses in our defenses against transmission.

B. Setting up a hypothesis for testing

A further learning from real-time problem solving is that every countermeasure we come up with must be regarded as a hypothesis to be tested. When countermeasures are implemented as being 'tentative', we are more likely to question their effectiveness and practicality. Through this real-time testing, we have often found that initial 'solutions' had weaknesses that required revision.

X. Managing patient transfers

For receiving units, a patient's MRSA status is readily available on the formal electronic *Transfer Note* completed by the transferring unit and the cover sheet of the computerized patient record. As mentioned, the daily list of MRSA carriers is also printed out on each unit every morning. Finally, a Communications Center that coordinates transfers tracks the MRSA status and makes note in its transfer instructions. This wide availability of information on who is a carrier ensures that no unit is unaware of the MRSA status of the internal patients it receives.

XI. Visual environment

Part of making the cultural change to aggressively shut down all pathways for MRSA transmission requires embedding into the visual environment the best way to work. This helps to remove ambiguity in task execution and improves collaboration and efficiency.

A. Gown lines on floor

Gown lines on the floors of dedicated isolation rooms help to make clear the appropriate garb for different interactions with patients. One of the problems we encountered when trying to enforce universal gowning in contact precautions was resistance from doctors and nurses. These healthcare workers pointed out that many of their encounters with patients require them to enter the room, talk with the patient, and perhaps review the input/outputs sheets, but otherwise not contact the patient or the environment. We settled on a compromise to accommodate these low risk encounters. We marked off a perimeter an arms-length from the patient bed, furniture and other equipment, outside of which healthcare workers could safely interact with the patient without needing to gown. This perimeter was marked with a red, floor-marking tape and signs posted at each end stating the need to gown. The input/output clipboards were also removed from the end of the bed to a wall-mounted box. In this way, it is unambiguous as to where a healthcare worker needs to be gowned or can remain ungowned.

B. "Right to Clean Hands" sign in every room

Across from every inpatient bed on the inpatient surgery unit, we have placed an attractive framed poster stating, "Patients, You have a Right to Clean Hands. Please remind everyone to sanitize or wash their hands when entering or exiting the room." This poster is prominent in the field of view of the patients and has prompted some patients to speak up about hand hygiene lapses. More importantly this poster reminds healthcare workers of the expected standard of hand hygiene and the commitment to patient safety.

C. Visual management boards for directing patient placement.

We deploy a system of visual management boards to better coordinate the flow of updated information on patients, appointments, attending RN's and MD's and room stata. One large board is in public view at the nurses' station listing patient names in color, room numbers and the assigned RN. Beds that are available occupied or in some state of cleaning are also listed. As admissions, discharges and cleanings occur, different healthcare workers continuously update the boards to facilitate communication. The entire board is highly adaptable as the information is posted with white board markers or magnetic sign strips.

Compliance with patient privacy was achieved by keeping a written record of oral requests by admitting RN's of the patients' permissions to post their names. A second, smaller private board is hung inside the nurses' station where it is not visible to the public. Here doctors' names, order of contact, pagers, etc is posted to expedite contact. The patient names and services for the doctors are color-coded to facilitate quick reference.