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Simulation Shows Hospitals That Cooperate On Infection Control Obtain Better Results Than Hospitals Acting Alone

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Abstract

Efforts to control life-threatening infections, such as with methicillin-resistant *Staphylococcus aureus* (MRSA), can be complicated when patients are transferred from one hospital to another. Using a detailed computer simulation model of all hospitals in Orange County, California, we explored the effects when combinations of hospitals tested all patients at admission for MRSA and adopted procedures to limit transmission among patients who tested positive. Called "contact isolation," these procedures specify precautions for health care workers interacting with an infected patient, such as wearing gloves and gowns. Our simulation demonstrated that each hospital's decision to test for MRSA and implement contact isolation procedures could affect the MRSA prevalence in all other hospitals. Thus, our study makes the case that further cooperation among hospitals—which is already reflected in a few limited collaborative infection control efforts under way—could help individual hospitals achieve better infection control than they could achieve on their own.

A hospital often has its own infection control personnel, programs, and initiatives that are not coordinated with other hospitals unless they are associated legally or financially. Hospitals frequently invest heavily to control their health care–associated infection rates and often undertake measures that are unrelated to control measures at other hospitals.

One example of the infectious agents that hospitals seek to control is methicillin-resistant *Staphylococcus aureus*, or MRSA. MRSA is widespread in US hospitals, with an estimated 278,203 hospitalizations (95% confidence interval: 252,788, 303,619) and 6,639 MRSA-related deaths in 2005[1] and a reported prevalence of 66.4 colonizations or infections per 1,000 inpatients in 2010.[2]

Indeed, it may be highly cost-effective for an individual hospital to implement MRSA control measures, such as actively screening patients for the bacteria and requiring health care workers to practice contact isolation procedures when interacting with patients who test positive.[3] Contact isolation procedures require hospital staff to wear gloves and gowns upon entering a room occupied by an infected patient and whenever interacting with an infected patient or the patient's environment.

Previously, we showed that hospitals in Orange County, California, which has a population of three million people, were interconnected through direct patient transfers and indirect sharing by the readmission of a patient to a different hospital after an intervening stay at home or elsewhere.[4,5] Depending on hospital infection control practices or lapses, such patient sharing was shown to either quell or facilitate the spread of infectious diseases such as MRSA, which patients can carry for months or years, to other regional hospitals, even those miles away from the originating hospital.[6]

The question then arises whether cooperation among hospitals can lead to gains in infection control, which an individual hospital could not otherwise achieve.

Using a computational model developed by our National Institutes of Health Models of Infectious Disease Agent Study MRSA Working Group, we sought to determine the impact of a two-part intervention: testing all patients at admission for MRSA colonization and employing contact isolation procedures for all staff interacting with positive patients. We assessed the impact of this intervention in Orange County hospitals, individually and in combination, and compared it to the impact when the intervention was implemented in all Orange County hospitals or in a subset of those hospitals.

Study Data And Methods

ORANGE COUNTY PATIENT FLOW AND MRSA TRANSMISSION MODEL

Building on previous work, we further developed our Regional Health-care Ecosystem Analyst model of all twenty-nine acute care hospitals serving adult patients in Orange County. Five hospitals were long-term acute care facilities that served patients with prolonged, high-level medical needs. The model simulated an average of 3,740 virtual patients daily, each represented by a computational agent, moving among these hospitals and the community. The model also simulated the transmission of MRSA within these hospitals.[6]

In the model, virtual patients testing positive or negative for MRSA were admitted to Orange County hospitals at rates obtained from actual hospital records. These virtual patients were then assigned to a hospital intensive care unit or general ward for lengths-of-stay that corresponded to actual lengths-of-stay for patients admitted to that hospital.

Upon discharge, the model returned some virtual patients to the community and others to a different hospital. Some patients were readmitted to the same or a different hospital at a later date, all according to probabilities derived from empirical data, as previously described.[5]

Our model contained detailed representations of each adult hospital in the county, including representations of each facility's intensive care units, where applicable, and general wards and hospital beds in each unit and ward.[6] Hospital-specific data were obtained from several sources. The hospital-specific data included annual admissions and hospital lengths-of-stay for adult patients from the California Office of Statewide Health Planning and Development.[7]

Comprehensive matrices on how Orange County hospitals share patients, through direct interfacility transfers as well as discharges and readmissions, came from detailed analyses of this data set.[5] Information about the number of hospital intensive care units, bed capacity, and average length-of-stay within those units came from surveys of each hospital.[8] Online Appendix Exhibit 1 provides key model input parameters.[9]

ACTIVE SURVEILLANCE CULTURES AND CONTACT ISOLATION

The two-part intervention of interest was the testing for MRSA of all patients who were admitted and the subsequent adopting of contact isolation procedures for all patients who tested positive. Appendix Exhibit 2 shows how this intervention was implemented.[9]

Our experiments assumed that the MRSA screen had a sensitivity (the ability or probability of the test to correctly identify patients who have MRSA) of 75 percent[10–13] and specificity (the ability or probability of the test to correctly identify patients who do not have MRSA) of 97 percent. We also assumed a turnaround time, from test start to obtaining results, of two days.[14]

Contact isolation of a patient began only after a test result returned positive, including both true and false positives—regardless of whether the patient was truly colonized, meaning that the bacteria were present on the body. Contact isolation was modeled as a percentage reduction in MRSA transmission, based upon the degree of compliance that was applied.

Each day the resulting number of new MRSA cases (colonization) in a hospital ward or intensive care unit depended on, first, the number of susceptible and infectious patients on contact isolation; second, the number of those not on contact isolation; and third, the

compliance of health care workers with the contact isolation procedures. A more detailed description can be found in the online Appendix Methodology.[9]

Our baseline scenario assumed that patients who were MRSA-positive lost MRSA carriage over time, with MRSA-carriage duration drawn from a distribution based on published estimates.[15–18] One-third of patients who were MRSA-positive remained positive,[19] and the remaining two-thirds of MRSA-positive patients gradually became MRSA-negative during the subsequent year. Additional sensitivity analysis explored the effects of indefinite MRSA carriage.

EXPERIMENTS

Experiments explored the effects of implementing active surveillance cultures and contact isolation for MRSA in the following groupings of hospitals. First was single hospitals: implementing surveillance and isolation in only one hospital in the county to assess direct and indirect benefits. Experiments varied according to the hospital implementing the intervention. Second was high-volume hospitals: those with 10,000 or more annual admissions ($n = 11$). Third was high-capacity hospitals: the largest hospitals in Orange County by bed capacity—three largest (average: 307 beds), five largest (average: 281 beds), and ten largest (average: 232 beds). Fourth was all hospitals in Orange County ($N = 29$).

Sensitivity analyses varied contact isolation compliance—that is, how well health care workers and other staff members adhered to contact isolation procedures (25 percent, 50 percent, and 75 percent). Outcomes included assessment of the attributable changes in MRSA prevalence in each hospital over time after screening was implemented. In other words, we assessed the relative decrease in MRSA prevalence from pre-intervention levels and the number of averted cases per year after surveillance and isolation took full effect, which was approximately six months after implementation.

LIMITATIONS

Models, by definition, are simplifications of real life and, therefore, do not incorporate all possible factors and outcomes.[20,21] For example, our model did not include factors such as comorbidities that could affect MRSA transmission.

Although our model is heavily based on real-world data, all data sources and collection methods have their limitations. For instance, the baseline MRSA prevalence may change from year to year. Our model did not account for hospitals outside Orange County that might exchange patients with Orange County hospitals, although we noted that 86 percent of patients stayed within the county for care.

Orange County is a large metropolitan area with a rather diverse population, including a wide range of racial, ethnic, and socioeconomic groups. However, its hospitals might not be representative of other counties because the number, size, and types of hospitals may differ. In addition, our study focused only on adult patients and did not include pediatric hospitals or long-term care facilities.

Study Results

IMPACT OF INTERVENTION AT ONE HOSPITAL ON OTHER HOSPITALS

Our simulation found that the implementation of surveillance and isolation at one hospital decreased MRSA prevalence not only in that hospital, but also in many other hospitals in the county that had not implemented the intervention. The magnitude of the effect depended on which hospital implemented the intervention.

A hospital employing surveillance and isolation with 75 percent compliance realized a median relative MRSA prevalence decrease of 11.27 percent (range: 6.73–19.08 percent) and averted a median thirty-seven MRSA cases (range: 2–261) during the course of a year.

Indirectly, many of the remaining hospitals—that is, those not employing the intervention—also experienced a reduction in MRSA prevalence (median: 0.27 percent; range: 0.00–12.61 percent) and number of MRSA cases averted per year (median: 1; range: 0–15). For example, when hospital F implemented surveillance and isolation, it experienced a 6.73 percent relative MRSA decrease (averting seven cases a year) and caused a 0.14 percent median (range: 0.0–9.2 percent) relative MRSA decrease in all other hospitals, averting thirty cases per year. Hospital H showed a 19.08 percent median relative MRSA decrease after the intervention was initiated, averting thirty-four cases per year and achieving a 0.28 percent MRSA reduction (range: 0.00–10.22 percent; forty-four cases a year) in all other hospitals.

Surveillance and isolation implemented in hospital I had the largest effect on the network, a median 0.69 percent relative MRSA decrease in all other hospitals (range: 0.06–10.59 percent), averting eighty-six cases per year, and a 16.95 percent median relative decrease in its own MRSA prevalence, averting 261 cases per year.

EFFECTS FOR ALL HOSPITALS ADOPTING SURVEILLANCE AND CONTACT ISOLATION

Exhibit 1 depicts the benefits to acute care hospitals when other hospitals also implement surveillance and isolation. Appendix Exhibit 3 shows the benefits to each facility, both the relative reduction in MRSA prevalence and number of cases averted.[9]

When all Orange County hospitals implemented the intervention simultaneously at a 75 percent contact isolation compliance, acute care hospitals experienced a further proportional decrease in MRSA prevalence beyond what they could achieve alone (median: 3.85 percent additional decrease; range: 0.81–8.97 percent). Long-term acute care facilities experienced an even higher proportional decrease in MRSA prevalence (median: 12.13 percent additional decrease; range: 1.29–15.35 percent).

Notably, only twelve hospitals, including two long-term acute care facilities, had more gains —that is, a reduction in MRSA prevalence—when the ten highest-capacity hospitals implemented the intervention compared to when they implemented surveillance and isolation individually (relative change differences of 2.85 percent or less). Fourteen facilities had larger reductions when those with 10,000 admissions or more implemented the intervention, versus when individual hospitals did so (Appendix Exhibit 3).[9]

Exhibit 2 illustrates the increasing benefits—relative decreases in MRSA prevalence and number of averted cases per year—to all Orange County hospitals when more hospitals adopted the intervention (see Appendix Exhibit 4 for full version).[9] The more hospitals that implemented surveillance and isolation, the greater was the reduction in MRSA prevalence and the more MRSA cases were averted in each hospital.

However, note that this relationship was not linear. Doubling the number of hospitals that employed surveillance and isolation from the five to the ten highest-capacity hospitals—that is, increasing the average number of people screened per year from 93,280 to 160,678— more than doubled the benefits.

BENEFITS OF IMPROVING COMPLIANCE WITH CONTACT PRECAUTIONS

Exhibit 2 also delineates how MRSA prevalence decreased, and the number of cases averted increased, when compliance with contact precautions was improved. The effects were somewhat linear.

Increasing isolation compliance from 25 percent to 50 percent tended to double the effects, while improving compliance from 50 percent to 75 percent further doubled the effects. These results emphasize the importance of not only increasing the number of hospitals implementing surveillance and isolation, but also of increasing isolation compliance in all participating hospitals.

These trends raise the question of whether greater reductions in MRSA prevalence are attained by improving compliance in hospitals already implementing the intervention or by focusing on convincing more hospitals to adopt the intervention. The answer depends on the size and connectedness of the hospitals.

Exhibit 3 shows the number of MRSA cases averted per year countywide when surveillance and isolation procedures were implemented in increasing numbers of county hospitals, progressively adding the next-largest hospital by bed capacity. The results highlight the benefits of improving compliance, which increases as more hospitals participate, and they enable comparison of the incremental gains from increasing the number of hospitals performing surveillance and isolation procedures with the gains from increasing isolation compliance in the currently participating hospitals.

EFFECTS OF MRSA CARRIAGE

Additional scenarios exploring the effects of making all MRSA colonization indefinite underscored the benefits of active surveillance cultures and isolation. When all hospitals implemented surveillance and isolation with 75 percent compliance, the median relative decrease in MRSA prevalence for Orange County was 15.8 percent with MRSA carriage loss and 19.8 percent with indefinite carriage.

Discussion

Our study showed that concerted infection control campaigns among a regional group of hospitals can yield substantial indirect benefits for hospitals involved and for hospitals not involved in the campaign. What's more, the synergistic effects of persuading other hospitals in the same county to implement control mechanisms can help individual hospitals achieve better MRSA control than they can on their own. The more hospitals that work together, the more benefits accrue; doubling the number of hospitals that adopt the intervention can more than double the improvement in infection control.

These synergistic effects arise from the fact that hospitals often share patients throughout a county. Even when one hospital enforces strict infection control policies, its patients can be infected by MRSA-colonized patients from other hospitals that have less stringent infection control policies.

In fact, for some hospitals, having other hospitals implement some degree of MRSA control may be as effective or even more effective than improving procedures in a single hospital. Although our study explored the possibility of all hospitals' using surveillance and contact isolation, our general finding would hold even if hospitals used different infection control procedures, as long as the procedures reduced the prevalence of MRSA colonization.

There has been some effort to stimulate cooperation among hospitals in controlling MRSA and other hospital-acquired infections. Statewide approaches and interventions to reduce hospital-acquired infections have been successful in Iowa; Pennsylvania; Michigan; New York; Wisconsin; and the Siouxland region of Iowa, Nebraska, and South Dakota.[22–27]

In the Siouxland region, the implementation of surveillance cultures and isolation led to a reduction in infections from another bacterium, vancomycin-resistant *Enterococcus*.[23] Other collaborative efforts, such as the Iowa Healthcare Collaborative, have had success from several initiatives. A majority (93 percent) of Iowa's hospitals implemented the MRSA control measures recommended by the 5 Million Lives Campaign of the Institute for Healthcare Improvement to some degree.[27]

Although it encountered implementation problems, the Pittsburgh Regional Health Initiative has created a culture of change to improve overall patient safety by providing opportunities to learn, increasing general awareness, and identifying common problems and solutions.[28]

These initiatives show the willingness of multiple hospitals to work together toward a common goal and to achieve an overall reduction in disease burden. However, to our knowledge, there has not been an evaluation of potential synergistic effects of facility interventions in a region.

In recent years, a number of collaborative initiatives have evolved.[29] For example, in California the Safety Net Initiative, with a grant from the Blue Shield of California Foundation, is building a learning collaborative among public hospitals to reduce hospital-acquired infections—specifically, central-line infections and sepsis.

The Health Services Advisory Group of California, in collaboration with the Hospital Association of Southern California, has launched a Centers for Medicare and Medicaid Services Learning and Action Network to improve the quality of care. A major component is the Reducing Healthcare-Associated Infections Project. Its emphasis is preventing catheter-associated urinary tract infections, *Clostridium difficile* infections, and surgical site infections.

The California Healthcare-Associated Infection Prevention Initiative is another similar collaborative. The primary motivation for these collaboratives has been to share knowledge and best practices rather than to closely coordinate infection control measures.

To date, few studies have demonstrated and quantified the synergistic effects of hospitals within a large region coordinating infection control measures to achieve greater gains than they could achieve individually. Understanding these added benefits could provide extra motivation to hospitals to work more closely together. Computational modeling and simulation can be a useful tool for understanding infection control, especially at a regional level. Forecasting the effects of policies before enacting them can save valuable time and resources.

To that end, our study aimed to demonstrate the benefits of cooperation for each hospital, which may motivate hospitals to overcome barriers to cooperation. These obstacles are real. Hospitals have different budgets, resources, leadership, and competing priorities.[30] Enforcing the same infection control procedures may be easier in some hospitals and more challenging in others.[31] Information systems, reporting measures, and organizational structures may also be quite disparate.

It is also possible that as Medicare and other insurers continue to reduce reimbursements to hospitals with health care–associated infections, a hospital could use the achievement of

infection rates that are lower than its competitors as a selling point to patients, insurers, and potential partners. A hospital could then make successful infection control policies and interventions into potential competitive advantages that it would be loath to share with other hospitals.[32,33]

As in this study, modeling and simulation can help extend the data collected from retrospective and prospective studies and make the case for cooperation. Modeling and simulation can serve as virtual "policy laboratories" for public health officials, policy makers, hospital administrators, and other health care decision makers. Here, modeling enables us to quantify the indirect and added benefits attained from regional efforts of admission screening for MRSA and greater compliance with contact precautions.

Conclusion

Our study shows that coordination of MRSA prevention practices in infection control, even among small groups of hospitals, can benefit all hospitals in a county, even those that do not implement the intervention. The effects of persuading other hospitals in the same county to implement control mechanisms can help hospitals achieve better infection control than they could on their own. The more hospitals that work together, the greater the benefits accrued.

This relationship is also nonlinear; doubling the number of hospitals can more than double the improvement in infection control. Concerted infection-control campaigns reflect the fact that hospitals are rarely isolated islands but instead share patients extensively with other hospitals in a county. All hospitals may also benefit greatly from improved compliance with infection control measures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

NOTES

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Biographies

Bruce Y. Lee is an associate professor of medicine, epidemiology, and biomedical informatics at the University of Pittsburgh.

In this month's *Health Affairs*, Bruce Lee and coauthors report on their simulation of efforts to control life-threatening hospital-acquired infections when patients are transferred from one hospital to another. The simulation demonstrated that each hospital's decision to test for methicillin-resistant *Staphylococcus aureus*, or MRSA, and contain the bacterium's spread could affect prevalence in all other hospitals—and thus makes the case that collaborative infection control efforts can help individual hospitals achieve better infection control than they can achieve on their own.

Lee is an associate professor of medicine, epidemiology, and biomedical informatics at the University of Pittsburgh. He founded and directs the Public Health and Infectious Disease Computational and Operations Research (PHICOR) group, which specializes in designing economic and operational computer models, simulations, and tools that help decision makers tackle infectious diseases of global importance.

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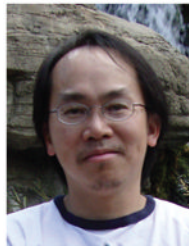
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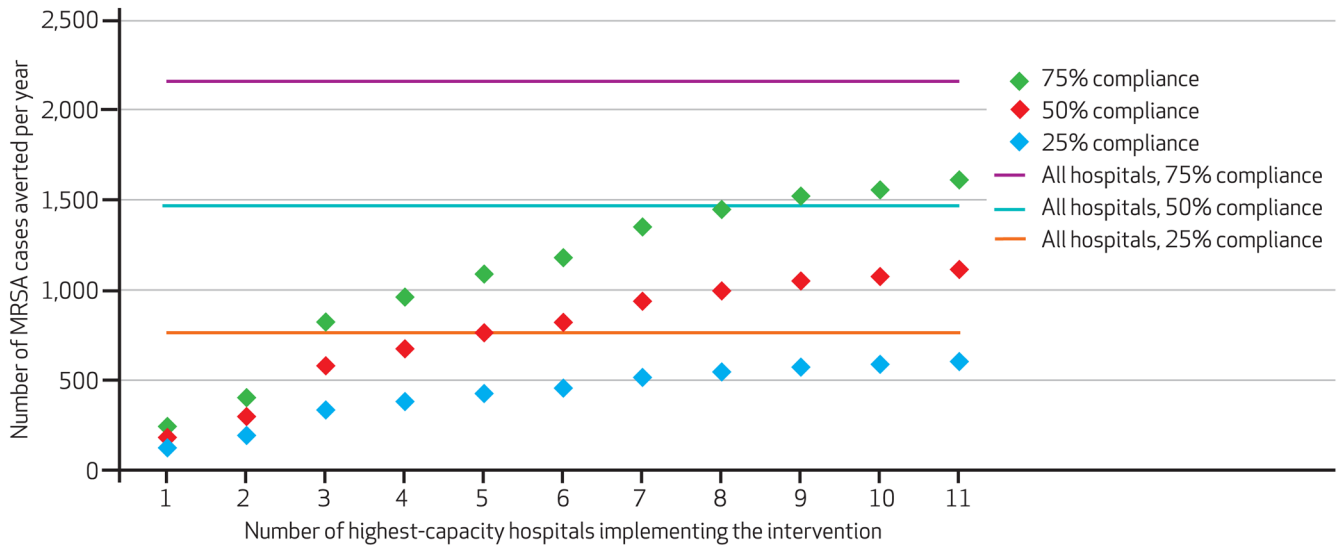
EXHIBIT 3. Number Of MRSA Cases Averted Per Year Countywide By Implementing Surveillance And Contact Isolation In The Highest-Capacity Hospitals At Varying Contact Isolation Compliance Rates Over 10 Simulated Years
SOURCE Author-generated data. **NOTES** For number of highest-capacity hospitals, starting with the largest and progressively adding the next-largest by capacity. MRSA is methicillin-resistant *Staphylococcus aureus*.

EXHIBIT 1

Relative Reduction In MRSA Prevalence For Various Active Surveillance And Contact Isolation Campaigns
Implemented At 75 Percent Contact Isolation Compliance Over 10 Simulated Years

	This hospital only (%)	5 highest- capacity hospitals (%)	10 highest- capacity hospitals (%)	All hospitals (%)
ACUTE CARE HOSPITAL AFFECTED				
A	14.9	2.2	2.8	20.2
B	13.6	14.4	14.8	15.6
C	13.5	2.3	3.5	19.6
D	10.3	11.4	12.0	13.6
E	8.3	1.0	2.7	11.9
F	6.7	2.3	4.7	12.2
G	9.9	1.6	2.9	14.9
H	19.1	1.9	2.6	22.8
I	17.0	17.2	17.7	18.5
J	12.5	1.2	14.2	16.8
K	10.6	1.2	12.6	14.6
L	16.9	17.6	19.3	20.2
M	12.5	2.3	3.6	17.2
N	9.4	1.7	3.1	15.5
O	11.2	1.6	13.2	15.6
P	13.1	1.3	2.1	15.9
Q	8.7	0.7	9.7	10.6
R	15.6	0.36	0.7	16.4
S	9.8	1.2	2.4	13.5
T	11.3	1.7	2.8	20.2
U	8.6	0.9	9.2	9.4
V	12.2	12.7	13.1	13.9
W	10.5	2.9	4.7	17.8
X	9.3	1.5	3.0	16.5
COUNTYWIDE ACUTE CARE REDUCTION				
Mean	—	4.3	7.4	16.0
Median	—	1.7	4.2	15.7

SOURCE Author-generated data. **NOTE** MRSA is methicillin-resistant *Staphylococcus aureus*.

EXHIBIT 2

Benefits Of Implementing Active Surveillance And Contact Isolation Campaigns In Selected Subsets Of Hospitals Over 10 Simulated Years

Percent contact isolation compliance	Highest-capacity hospital	3 highest-capacity hospitals	5 highest-capacity hospitals	10 highest-capacity hospitals	11 highest-volume hospitals[a]	All hospitals
MEDIAN REDUCTION IN EACH HOSPITAL'S MRSA PREVALENCE (%)						
25	0.2	0.5	0.7	1.5	1.6	5.7
50	0.3	0.9	1.3	3.1	3.1	10.9
75	0.4	1.3	1.7	4.7	4.8	15.9
MEDIAN NUMBER OF MRSA CASES AVERTED IN EACH HOSPITAL[b]						
25	1.0	2.1	2.2	4.1	4.2	18.8
50	1.1	2.9	4.1	7.3	7.8	36.2
75	1.4	4.0	5.7	10.1	10.2	52.6

SOURCE Author-generated data. **NOTE** MRSA is methicillin-resistant *Staphylococcus aureus*.

[a]Those with 10,000 or more admissions (11 in Orange County).

[b]Per year, after the implementation of surveillance and isolation has taken full effect (approximately six months).