

## Methicillin-Resistant *Staphylococcus aureus* Infection or Colonization at Hospital Admission: Multivariable Risk Factor Screening to Increase Efficiency of Surveillance Culturing

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1 **Abstract**

2 Identifying methicillin-resistant *Staphylococcus aureus* (MRSA) colonization or  
3 infection present at admission has become important in reducing subsequent nosocomial  
4 transmission, but the most efficient surveillance methods remain to be defined. We performed  
5 anterior nares surveillance cultures of all patients at admission to and discharge from the general  
6 internal medicine floor in our community hospital over a 7 week period, and patients completed  
7 a questionnaire on MRSA risk factors. Of the 401 patients, 41 (10.2%) had admission MRSA.  
8 Of the 48 risk measures analyzed, 10 were associated significantly with admission MRSA, and 7  
9 of these were independently associated in stepwise logistic regression analysis. Factor analysis  
10 identified 8 latent variables that contained most of the predictive information in the 48 risk  
11 measures. Repeat logistic regression analysis including the latent variables revealed 3  
12 independent risk measures for admission MRSA: nursing home stay (RR=6.18; 95% CI: 3.56–  
13 10.72; p<0.0001), prior MRSA infection (RR=3.97, 95% CI: 1.94–8.12; p=0.0002), and the third  
14 latent variable (Factor 3; RR=3.14; 95% CI: 1.56–6.31; p=0.0013) representing the combined  
15 effects of homelessness, jail stay, promiscuity, and intravenous or other drug use. Multivariable  
16 models had greater sensitivity for detecting admission MRSA than any single risk measure and  
17 allowed detection of 78% to 90% of admission MRSA from admission surveillance cultures on  
18 46% to 58% of admissions. If confirmed in additional studies, multivariable questionnaire  
19 screening at admission might identify a subset of admissions for surveillance cultures that would  
20 more efficiently identify most admission MRSA.

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1 Methicillin-resistant *Staphylococcus aureus* (MRSA) continues to be a cause of  
2 significant morbidity and mortality. Infection with MRSA, compared to methicillin-sensitive  
3 *Staphylococcus aureus* strains, has been associated with higher mortality rates (4,9,10,13), longer  
4 lengths of stay in the hospital and higher hospital charges (1,9,26,29). In recent years the  
5 prevalence of community-acquired MRSA has increased in certain segments of the community  
6 resulting in admission to hospitals of increasing numbers of patients MRSA-positive at  
7 admission who can then spread the organism in the hospital. These findings have increased the  
8 need to devise systems that efficiently screen admitted patients to identify those at high-risk for  
9 having MRSA and isolating them to prevent subsequent nosocomial spread.

10 Presently a highly contested question is whether to culture all patients for MRSA at  
11 hospital admission, a proposition that has been criticized as too expensive (31,38). To identify a  
12 more cost-effective middle ground, we undertook a quality improvement study in our hospital to  
13 identify high-risk groups that could be cultured selectively on admission to detect all admission  
14 MRSA patients more efficiently. Commonly, investigators have made a distinction between  
15 MRSA colonization and MRSA infection when assessing associated risk factors. Given that our  
16 objective was to identify all patients MRSA-positive on admission who potentially could spread  
17 MRSA to other patients in the hospital, we counted all patients with a positive screening or  
18 clinical culture within 48 hours of hospital admission as having “admission MRSA” regardless  
19 of where the organism might have been acquired.

20 In the past clinical investigators have used univariate and multivariable analyses to  
21 identify risk factors that are independently associated with MRSA. These statistical tools, while  
22 valuable, do little to explore the collinearities between potential risk factors. Simply stated,  
23 several risk factors that might not be independently associated with MRSA individually might be

1 more importantly associated with MRSA as part of a group of related risk factors. To look more  
2 deeply into the collinearities among the risk factors associated with admission MRSA, we used  
3 factor analysis, a technique relatively new to the field of infectious diseases but which has been  
4 used effectively in other scientific fields, such as psychiatry and genomics (23,27,32).

## 6 MATERIALS AND METHODS

7 **Subjects and data collection.** The study population included patients admitted directly, or  
8 transferred from other floors, to the general internal medicine floor between the dates of April 22  
9 and June 10, 2005. We collected surveillance swabs on admission to and discharge from the unit  
10 from both anterior nares of all 401 patients. We cultured only the anterior nares to detect MRSA  
11 colonization, since in adults, it has been demonstrated repeatedly that they are the most sensitive  
12 and cost-efficient screening site and the addition of other sites has been shown not to add  
13 significantly to the sensitivity (22,34,37). Although different types of MRSA are associated with  
14 nosocomial spread, the issue facing hospitals is identifying any MRSA on admission, regardless  
15 of where it originated; therefore, we also included those patients admitted with clinical cultures  
16 positive for MRSA within the first 48 hours of hospital admission. On the study's internal  
17 medicine floor it is common practice to obtain a culture on potentially infected sites; therefore,  
18 no selection bias was introduced by including admission MRSA-positive clinical cultures. At the  
19 time of nasal swab collection, patients filled out a survey questionnaire with a nurse available to  
20 clarify questions as needed. The questionnaire included questions regarding history of MRSA  
21 infection, prior hospitalization in the past year, prior antibiotic use in the past 6 months and  
22 compliance, nursing home stay in the past year, number of comorbidities (sum of the number  
23 checked from a list including diabetes mellitus, heart disease, cancer/malignancy, hypertension,

1 respiratory disease, intestinal disease, and renal failure), dialysis in the past year, central venous  
2 catheter in the past year, surgery in the past year, tracheostomy in the past year, percutaneous  
3 feeding tube in the past year, skin breakdown in the past year, use of a fitness center, community  
4 pool, or tanning salon, contact sports, type and frequency of illicit drug use in the past year and  
5 ever, number of sex partners in the past year, males having sex with males, household size,  
6 family member with history of MRSA infection in the past year, bathing frequency, jail stay in  
7 the past year, and recent history of homelessness. The study was undertaken as a quality  
8 improvement and infection control measure within our hospital.

9 **Case definition of admission MRSA.** A case of admission MRSA was defined as a patient  
10 who had a nasal surveillance culture and/or a clinical culture positive for MRSA collected within  
11 48 hours of admission to the hospital.

12 **Characterization of isolates.** Samples were submitted to the laboratory in BD double-swab  
13 cassettes with Stuarts transport medium. The samples were plated directly onto BD Chromagar  
14 selective for MRSA, which has a sensitivity of 95.4% after 24 hours of incubation, increasing to  
15 100% after 48 hours incubation, and a specificity of 100% after 24 hours incubation without  
16 enrichment (12). Chromagar plates were incubated up to 48 hours at 35° C in ambient air (non-  
17 CO<sub>2</sub> enriched) environment. Plates were evaluated for significant growth at 24 and 48 hours.  
18 Isolates were identified as MRSA on the basis of colony morphology on Chromagar and were  
19 submitted for susceptibility testing. Susceptibility studies were performed on the Dade  
20 Microscan instrument using commercially prepared minimum inhibitory concentration (MIC)  
21 panels inoculated according to manufacturer's protocols and read after overnight incubation.  
22 Antibiotic susceptibility results were interpreted according to Clinical and Laboratory Standards  
23 Institute (CLSI) standards (35). Forty (97.6%) of the 41 MRSA isolates that were obtained

1 within 48 hours of admission were typed by pulsed-field gel electrophoresis (PFGE) at the Texas  
2 Department of State Health Services Laboratory. Overnight cultures grown at 35-37° C on Brain  
3 Heart Infusion plates were used to make cell suspensions. Two hundred microliters of the cell  
4 suspensions were treated with 5 microliters of lysostaphin 1 mg/mL. Plugs were cast with 1.2%  
5 SeaKem gold agarose from Cambrex and treated with a lysis solution (Tris, NaCl, NaOH,  
6 EDTA, Brij 58, sodium deoxycholate, N-laryl Sarcosine). After washing with TE buffer, the  
7 plugs were digested at room temperature with 20 Units of Sma I restriction endonuclease from  
8 New England Biolabs. A 1.2% agarose gel was cast. The Pulse-Field Gel parameters were:  
9 Initial switch time: 2.0 seconds; Volts/cm: 6; Final switch time: 50.0 seconds; Included angle:  
10 120; Run time: 20 hours. The gels were stained with ethidium bromide from Sigma. The gel  
11 images were analyzed using Molecular Analyst software from BioRad. Comparisons were made  
12 using the local MRSA database.

13 **Statistical methods.** We examined the univariate associations of the risk measures with  
14 admission MRSA using the Frequency procedure of SAS (SAS Institute, Cary, NC, version 9.1),  
15 using Fisher's exact test and the Cochran-Armitage trend test to test significance. We used the  
16 Logistic procedure of SAS to perform stepwise logistic regression analysis of admission MRSA  
17 cases with all risk measures in the pool of predictors. Review of the  $X^2$ -to-enter statistics at each  
18 step of the analysis identified many collinear measures competing to enter the model. To attempt  
19 to understand the information in multicollinearities, we performed a factor analysis of the 58 risk  
20 measures, using the principal axes method of factor analysis (with the squared multiple  
21 correlations of each variable with all other variables as the prior communality estimates) and  
22 varimax (orthogonal) rotation in the Factor procedure of SAS. To determine the number of  
23 factors to extract, we inspected the scree plot for a break point and examined the clinical

1 plausibility of the combinations of risk measures loading on the factors in alternative models  
2 with different numbers of factors. The model with eight factors appeared the most clinically  
3 plausible. We then extracted the eight orthogonal factor scales, created additional dichotomized  
4 indicator variables for the eight scales by arbitrarily dividing each at the 50<sup>th</sup> percentile, and  
5 added the continuous and dichotomized factor measures to the pool of the original risk measures  
6 for analysis in further stepwise logistic regression modeling. Multicollinearity was assessed by  
7 examining the changes in significance to enter of all variables remaining in the pool of predictors  
8 at each step, and the validity of the logistic regression models was assessed by calculating the  
9 Hosmer-Lemeshow goodness-of-fit statistic and the area under the receiver-operator  
10 characteristic (ROC) curve (17). Finally, we used the Generalized Linear Modeling (Genmod)  
11 procedure of SAS to derive unbiased estimates of the prevalence relative risk (RR) and 95%  
12 confidence interval of each variable in the final logistic regression model, according to the  
13 method of Spiegelman and Hertzmark (39).

## 14 15 RESULTS

16 **Description of case-patients and antibiotic susceptibility patterns.** A total of 420  
17 consecutive admissions were screened, and 401 (95%) agreed to participate. Of the participants,  
18 264 (66%) were admitted directly to the internal medicine floor; 137 (34%) were transferred to  
19 the internal medicine floor from other hospital services.

20 Of the 401 studied, 41 (10%) had an admission MRSA-positive culture. Of the 41 case-  
21 patients, 26 (63%) were positive by nasal surveillance culture and 15 (37%) were identified only  
22 by clinical culture (Table 1); 22 of the 26 positive surveillance cultures and all 15 positive  
23 clinical cultures were obtained within 24 hours of admission. Of those identified by surveillance

1 cultures, 9 later were identified by clinical culture as well. Thirty-eight of the 41 MRSA isolates  
2 underwent antibiotic susceptibility testing; 2 (5%) were susceptible to erythromycin, 33 (87%) to  
3 clindamycin, 36 (95%) to gentamicin, 37 (97%) to trimethoprim/sulfamethoxazole, 36 (95%) to  
4 tetracycline, and 38 (100%) to vancomycin. A single susceptibility pattern (resistant to  
5 ampicillin, penicillin, oxacillin, cefazolin, ceftriaxone, and erythromycin, and susceptible to  
6 clindamycin, gentamicin, trimethoprim/sulfamethoxazole, tetracycline, and vancomycin) was  
7 identified in 26 (67%) of the 39 isolates. Of the 40 isolates tested by PFGE, 20 distinct patterns  
8 were identified. SM-Star-703 was identified in 15 (38%) of the 40 specimens tested and the  
9 second most common pattern, SM-Star-538, was identified in only 4 specimens. SM-Star-703 is  
10 the pattern most commonly found among MRSA isolates tested at the Texas Department of  
11 Health Public Health Lab and is closely related to the USA 300 pattern (Ana Maria Valle-Rivera,  
12 e-mail communication with author, 18 Aug 2006) which is one of the primary types causing  
13 community-acquired infections nationwide (28). No PFGE pattern was significantly associated  
14 with any individual risk measures.

15 **Univariate analysis.** Of the 48 risk measures analyzed, 10 were associated significantly with  
16 admission MRSA colonization or infection, with risk ratios ranging from 0.40 to 6.24 (Table 2).  
17 Of the multinomial risk measures, we found significant dose-response relationships for days of  
18 prior hospitalization in the past year ( $p = .016$ ), days previously on antibiotics in the past 6  
19 months ( $p = .005$ ), and years using intravenous drugs ( $p = .023$ ), with only a marginally significant  
20 dose-response for days in jail ( $p = .100$ ), but no dose-response for age ( $p = .79$ ) (Table 3).

21 **Stepwise logistic regression analysis.** In the stepwise logistic regression analysis, only six of  
22 the 10 dichotomous risk measures and only the age category 31 to 45 years from the continuous  
23 risk measures remained independently associated with admission MRSA (Table 4). The seven

1 risk measures had adjusted risk ratios ranging from 1.82 to 10.81. This model fit the data well  
2 (area under the ROC curve = 0.80, Hosmer-Lemeshow goodness-of-fit statistic = 0.90). If the 15  
3 patients with MRSA clinical infection at admission were excluded, the adjusted relative risks  
4 remained similar but non-IV drug abuse and age group 31-45 years were no longer statistically  
5 significant due to reduced statistical power (data not shown).

6 **Factor analysis with revised logistic regression analysis.** The factor analysis identified the  
7 best model as an 8-factor model (Appendix). Adding the resulting 8 factor scales to the pool of  
8 predictors in the stepwise logistic regression analysis yielded a more parsimonious 3-variable  
9 model that fit the data approximately as well as the seven-variable logistic model (area under the  
10 ROC curve=0.73, Hosmer-Lemeshow goodness of fit statistic = 0.68, Table 5). The first two  
11 variables, prior nursing home stay in the past year (RR=6.18) and history of MRSA (RR= 3.97),  
12 were the two strongest variables in the previous seven-variable model (Table 4). The third  
13 variable, however, Factor 3 (dichotomized) (RR=3.14), represented the combined effects of  
14 homelessness, jail stay in the past year, promiscuity (2 or more sex partners in the past year), and  
15 illicit drug use in the past year (intravenous and other).

16 **Accuracy and screening burden of risk measures.** In assessing the usefulness of the various  
17 risk measures for increasing the efficiency of admission surveillance culturing for MRSA, we  
18 found that the individual risk measures significantly associated with admission MRSA, used  
19 alone, lacked sufficient sensitivity (i.e., detected too small a percentage of admission MRSA  
20 cases) to be useful in screening (Table 6). Hospitalization in the past year had the highest  
21 sensitivity (61%) of the individual risk measures (the sensitivity was 69% if patients with clinical  
22 MRSA infections were excluded). All of the multivariable risk measures had substantially  
23 higher sensitivities (Table 6). If all patients answering “yes” to any of the variables in a

1 multivariable model were selected for admission surveillance cultures, 46% to 58% of  
2 admissions would have to be cultured (screening burden) and 78% to 90% of admission MRSA  
3 would be detected (sensitivity, Table 6). Screening patient admissions with any of the 7 risk  
4 measures in the initial logistic regression model shown in Table 4 would provide the most  
5 sensitive detection (90% of admission MRSA) while requiring cultures in 58% of admissions.  
6 Screening for the variables in the model in Table 5, derived from factor analysis, would detect a  
7 slightly lower percentage of admission MRSA cases but would require culturing a smaller  
8 percentage of admissions (Table 6).

## 10 DISCUSSION

11 Our findings provide possible new insight into the profile of patients who bring MRSA  
12 into a hospital, which might be exploited to improve the efficiency of surveillance for admission  
13 MRSA. Logistic regression analysis of a large battery of admission risk measures identified a  
14 model of only 7 risk measures that strongly predicts admission MRSA. Besides the expected  
15 high risk of admission MRSA in patients with a past history of MRSA infection and those who  
16 recently were in a nursing home, our factor analysis identified a latent factor, Factor 3, defined  
17 by combinations of homelessness, promiscuity, intravenous drug use, other illicit drug use, and  
18 recent stay in jail that predicted admission MRSA approximately as well. When this latent  
19 variable was introduced into the multivariable logistic regression analysis, all five of its  
20 component risk measures became non-significant, indicating that this one latent variable captures  
21 all the predictive information for admission MRSA risk of all five component risk measures.  
22 Further research of this phenomenon might produce an efficient method for defining the subset  
23 of patients to screen for admission MRSA.

1 Factor analysis, sometimes called principal components analysis, is a data reduction  
2 method increasingly used in biomedical science to interpret datasets with large numbers of  
3 independent variables showing complex patterns of multicollinearity (23,27,32). Epidemiologic  
4 studies most often deal with multicollinearity by performing multivariable analyses to identify  
5 the best set of risk measures that independently predict the outcome and reject the collinear  
6 measures that did not make it into the final model as “not independently associated.” Such  
7 models give an overly simplistic picture by implying that the final model variables are singly  
8 important and the rejected collinear ones are not. A latent variable identified by factor analysis  
9 may give a truer picture by demonstrating that a component of risk is conferred by a combination  
10 of the collinear variables best measured by the latent factor scale rather than by the single most  
11 strongly associated variable alone. In our study factor analysis identified a new complex risk  
12 factor that may be useful, along with the two other simpler characteristics identified, for focusing  
13 admission cultures to detect admission MRSA more efficiently.

14 Our multivariable model of admission MRSA and the risk measures that contribute to the  
15 latent variable Factor 3 appear plausible in light of prior research. History of nursing home stay  
16 in the past year and history of MRSA infection are well known and expected sources of  
17 admission MRSA (11,16,20,21). Intravenous drug use, high-risk sex, and homelessness have  
18 each been found to be independent risk factors of MRSA infection or colonization in some  
19 settings (3,6-8,14,24,40); however, while many studies have described MRSA infection and  
20 colonization within jail populations (2,6,7,33), this study is the first one to show that a history of  
21 jail stay, a component of Factor 3, may be associated with admission MRSA.

22 Two of the other risk measures that did not appear in the final model—men who have sex  
23 with men (MSM) and age>75—were the only ones of the displaced measures to maintain

1 residual explanatory power, but when they entered, they were not quite significant and thus did  
2 not appear in the final model. We examined the strength of association of MSM with each of the  
3 eight latent factors from the factor analysis and found it not to be highly associated with any of  
4 them. While some of its association with admission MRSA could be attributed to the latent  
5 variable Factor 3, MSM appeared to explain a small component of admission MRSA risk  
6 independent of any of the other factors, suggesting some other risk attribute of MSM that this  
7 study, due to its relatively small size and perhaps unmeasured characteristics, was unable to  
8 explain. Future studies should test whether infection with human immunosuppressive virus  
9 (HIV), not measured in our study, might explain this residual association.

10 Our study found the prevalence of MRSA colonization in our patient population to be  
11 8.7%, which is higher than findings of similar studies (19-22,25). Including those patients with  
12 clinical MRSA infections and negative surveillance cultures, the prevalence of admission MRSA  
13 actually was 10.2% in this study population. Without active surveillance methods, 17 (41%) of  
14 the 41 patients with admission MRSA would not have been identified. Although these 17  
15 patients were found only to be colonized with MRSA, it has been shown that patients with only  
16 MRSA colonization can be significant sources for spread of MRSA in the hospital  
17 (5,11,16,18,30,36). If rapid MRSA identification methods, such as Chromagar or polymerase  
18 chain reaction (PCR), are used for admission surveillance cultures but not for clinical cultures,  
19 active admission surveillance would provide advance identification of MRSA in 26 (63%) of the  
20 41 patients with admission MRSA.

21 One advantage of our study was the availability of a relatively large hospital population  
22 with higher prevalence of admission MRSA than found in many similar studies; this gave it more  
23 statistical power for analysis of risk factors. Also, use of the recently described generalized linear

1 modeling approach for multivariable estimation of relative risks when outcomes are not rare (36)  
2 provided unbiased prevalence relative risk estimates for the risk measures appearing in our  
3 logistic regression models.

4 While our study population was larger than those in many similar studies, a larger study  
5 population will be needed to characterize some of the more subtle associations uncovered, such  
6 as some potentially independent risk associated with MSM. In addition, allowing nurses to help  
7 patients with the questionnaire could have interjected misclassification, but since neither the  
8 nurses nor the patients knew at the time who was MRSA-positive, the misclassification is most  
9 likely nondifferential, and therefore not an information bias. The restriction of the study patients  
10 to mostly adult internal medicine and post-surgical patients with no pediatric or obstetrical  
11 patients limits somewhat the insight into other potential MRSA risk determinants unique to other  
12 patient groups in the hospital.

13 The recent debate over whether hospitals should identify MRSA colonization at the time  
14 of admission has tended to focus on the two extreme options, culturing all admissions for MRSA  
15 or doing no admission surveillance culturing (31,38). Patients admitted with either MRSA  
16 infection or colonization can transmit MRSA to other hospitalized patients. We found that  
17 admission surveillance culturing could identify between 41% and 63% of admission MRSA that  
18 would either not be detected or be detected days later by clinical cultures. Comprehensive  
19 admission culturing, however, is expensive. This study provides new insight into the risk factors  
20 associated with admission MRSA and suggests an efficient middle ground in the debate: a  
21 recommendation to screen admitted patients initially with a short questionnaire or interview of  
22 questions that would identify most admission MRSA and perform admission surveillance  
23 cultures only on patients with a positive response to any of the questions.

1 In a similar study, measuring MRSA colonization at admission with slightly different  
2 data collection methods, Furuno et al. (15) determined that screening patients based on a single  
3 risk measure, hospitalization in the past year, detected 76% of admission MRSA while requiring  
4 surveillance cultures (surveillance culturing burden) in 65% of admissions; in our study, this  
5 measure included 61% of admission MRSA with surveillance culturing burden of 52%.  
6 Screening for the presence of any of the 5 risk measures in our Factor 3 detected 78% of  
7 admission MRSA with surveillance culturing burden of 51% of admission. Adding recent  
8 nursing home stay and history of MRSA infection to these 5 further increased the sensitivity to  
9 83% and the surveillance culturing burden to 53%. Screening instead for any of the 7 variables  
10 in our first logistic regression analysis reached the top sensitivity of 90% but increased the  
11 culturing burden to 58% of admissions. The limited size of our study and its focus on a general  
12 internal medicine floor in a single hospital prevent us from concluding which model will prove  
13 the most useful and efficient in reducing the cost of surveillance culturing for admission MRSA  
14 in other hospitals. The main importance of our study is in illustrating the potential usefulness of  
15 multivariable models in admission screening and potential approaches to developing such  
16 models. Further research should determine whether multivariable screening improves sensitivity  
17 and efficiency in other hospital settings and what risk measures contribute most powerfully to  
18 admission screening.

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TABLE 1. Comparison of admission methicillin-resistant *Staphylococcus aureu*-positive<sup>a</sup> and -negative groups on demographic and clinical characteristics

	MRSA+	MRSA-	<i>P</i>
Total patients	41	360	
Mean age (years, standard deviation)	47.7 (15.0)	47.6 (16.3)	0.97
Male sex (%)	26 (63)	185 (51)	0.19
Mean length of stay (days, standard deviation)	6.1 (6.3)	4.7 (6.6)	0.28
Admission MRSA <sup>b</sup> definition components (%)			
Admission surveillance culture positive, no admission clinical culture performed	17 (41.4%)		
Admission surveillance culture positive, admission clinical culture positive	9 (22.0%)		
Admission surveillance culture not performed, clinical admission culture positive <sup>c</sup>	3 (7.3%)		
Admission surveillance culture negative, clinical admission culture positive	15 (36.6%)		

<sup>a</sup>Infection or colonization.

<sup>b</sup>Culture performed within 2 days of hospital admission

<sup>c</sup>Transferred from other wards where admission cultures were not performed. All 3 were surveillance culture positive upon arrival to our ward, but >48 hours after hospital admission.

TABLE 2. Association of binomial risk measures with admission methicillin-resistant *Staphylococcus aureus* infection or colonization

Risk measure	Not exposed			Exposed			RR	95% CI	P
	n / N	Rate (%)	n / N	Rate (%)	n / N	Rate (%)			
History of nursing home stay <sup>a</sup>	33 / 386	8.5	8 / 15	53.30	6.24	3.51 – 11.09	<0.0001		
Lives in a nursing home	33 / 386	8.5	8 / 15	53.30	6.24	3.51 – 11.09	<0.0001		
History of wound or skin infection <sup>a</sup>	22 / 295	7.5	19 / 106	17.90	2.40	1.36 – 4.26	0.0044		
Lives in a home or apartment	12 / 57	21.1	29 / 344	8.40	0.40	0.22 – 0.74	0.0077		
History of MRSA infection ever	35 / 382	9.2	6 / 19	31.60	3.45	1.66 – 7.18	0.0078		
Took antibiotics as an outpatient <sup>b</sup>	25 / 314	8	16 / 87	18.40	2.31	1.29 – 4.13	0.0083		
Took antibiotics while in the hospital <sup>b</sup>	28 / 329	8.5	13 / 72	18.10	2.12	1.16 – 3.89	0.0290		
History of IV drug use ever	35 / 375	9.3	6 / 26	23.10	2.47	1.15 – 5.34	0.0382		
Uses IV drugs <sup>a</sup>	27 / 317	8.5	14 / 84	16.70	1.96	1.07 – 3.56	0.0409		
Uses other illicit drugs <sup>a</sup>	18 / 237	7.6	23 / 164	14.00	1.85	1.03 – 3.31	0.0441		
Man who has sex with men	37 / 386	9.6	4 / 15	26.70	2.78	1.14 – 6.80	0.0559		
Lives alone	28 / 320	8.8	13 / 81	16.00	1.83	1.00 – 3.38	0.0642		
Sexually promiscuous <sup>a</sup>	30 / 334	9	11 / 67	16.40	1.83	0.96 – 3.46	0.0773		
History of jail stay <sup>a</sup>	32 / 349	9.2	9 / 52	17.30	1.89	0.96 – 3.72	0.0845		
Antibiotics prescribed by physician <sup>b</sup>	25 / 291	8.6	16 / 110	14.50	1.69	0.94 – 3.05	0.0958		
History of surgery <sup>a</sup>	28 / 313	8.9	13 / 88	14.80	1.65	0.89 – 3.05	0.1147		
Homeless	35 / 369	9.5	6 / 32	18.80	1.98	0.90 – 4.34	0.1210		
Ever in hospital isolation	30 / 332	9	11 / 69	15.90	1.76	0.93 – 3.35	0.1228		
Admitted directly to study ward	10 / 140	7.1	31 / 261	11.90	1.66	0.84 – 3.29	0.1670		
Male	15 / 190	7.9	26 / 211	12.30	1.56	0.85 – 2.86	0.1863		
History of dialysis <sup>a</sup>	38 / 386	9.8	3 / 15	20.00	2.03	0.71 – 5.84	0.1899		
Uses only clean needles for IV drugs	38 / 385	9.9	3 / 16	18.80	1.90	0.66 – 5.50	0.2178		
Admitted from another hospital	31 / 266	11.7	10 / 135	7.40	0.64	0.32 – 1.26	0.2234		
Sexually monogamous <sup>a</sup>	27 / 227	11.9	14 / 174	8.00	0.68	0.37 – 1.25	0.2456		
History of hospitalization <sup>a</sup>	16 / 194	8.2	25 / 207	12.10	1.46	0.81 – 2.66	0.2489		
Currently has a PEG tube	40 / 397	10.1	1 / 4	25.00	2.48	0.44 – 13.89	0.3515		
Rarely takes a bath	41 / 387	10.6	0 / 14	0.00	ND		0.3782		
Shares needles for IV drugs	40 / 395	10.1	1 / 6	16.70	1.65	0.27 – 10.09	0.4787		
Took all antibiotics prescribed <sup>b</sup>	25 / 267	9.4	16 / 134	11.90	1.28	0.71 – 2.31	0.4849		
Overnight stay for surgery <sup>a</sup>	33 / 336	9.8	8 / 65	12.30	1.25	0.61 – 2.59	0.5079		
Transferred from IMC unit	38 / 357	10.6	3 / 44	6.80	0.64	0.21 – 1.99	0.5998		
Percutaneous catheter/medical device <sup>a</sup>	31 / 312	9.9	10 / 89	11.20	1.13	0.58 – 2.22	0.6948		
Transferred from observation unit	39 / 369	10.6	2 / 32	6.30	0.59	0.15 – 2.34	0.7589		
Sexually abstinent <sup>a</sup>	27 / 270	10	14 / 131	10.70	1.07	0.58 – 1.97	0.8612		
History of PEG tube <sup>a</sup>	40 / 391	10.2	1 / 10	10.00	0.98	0.15 – 6.42	1.0000		
Lives in jail	41 / 399	10.3	0 / 2	0.00	NE		1.0000		

History of tracheostomy <sup>a</sup>	41 /	396	10.4	0 /	5	0.00	NE		1.0000
Currently has a tracheostomy	41 /	397	10.3	0 /	4	0.00	NE		1.0000
Took antibiotics at home <sup>b</sup>	39 /	381	10.2	2 /	20	10.00	0.98	0.25 – 3.76	1.0000
Goes to the gym	37 /	363	10.2	4 /	38	10.50	1.03	0.39 – 2.74	1.0000
Goes to the tanning salon	41 /	400	10.3	0 /	1	0.00	NE		1.0000
Plays contact sports	39 /	381	10.2	2 /	20	10.00	0.98	0.25 – 3.76	1.0000
Family contact with MRSA <sup>a</sup>	41 /	397	10.3	0 /	4	0.00	NE		1.0000
Family contact with skin infection <sup>a</sup>	39 /	376	10.4	2 /	25	8.00	0.77	0.20 – 3.01	1.0000
Shared towels with MRSA contact <sup>a</sup>	40 /	390	10.3	1 /	11	9.10	0.89	0.13 – 5.88	1.0000
Provided wound care to contact <sup>a</sup>	40 /	390	10.3	1 /	11	9.10	0.89	0.13 – 5.88	1.0000
Transferred from intensive care unit	40 /	383	10.4	1 /	18	5.60	0.53	0.08 – 3.65	1.0000
Transferred from telemetry unit	37 /	361	10.2	4 /	40	10.00	0.98	0.37 – 2.60	1.0000

<sup>a</sup> n, number of patients with MRSA infection or colonization on admission.

<sup>b</sup> N, total number of patients exposed to the risk measure.

<sup>c</sup> In the past year.

<sup>d</sup> In the past 6 months.

<sup>e</sup> IV, intravenous.

<sup>f</sup> PEG, percutaneous endoscopic gastrostomy.

<sup>g</sup> IMC, intermediate care unit.

<sup>h</sup> NE, not estimable.

TABLE 3. Tests for dose-response effects of continuous risk measures for MRSA infection or colonization on admission

Risk measure	n <sup>a</sup> / N <sup>b</sup>	Rate (%)	RR	95% CI	P <sub>trend</sub> <sup>c</sup>
Days of prior hospitalization					
in past year					
0 days	16 / 194	8.2	1.00		
1-7 days	14 / 144	9.7	1.18	0.59 – 2.34	
>7 days	11 / 50	22.0	2.67	1.32 – 5.38	0.016
Days previously on antibiotics					
in past 6 months					
0 days	18 / 238	7.6	1.00		
1-7 days	6 / 64	9.4	1.24	0.51 – 2.99	
>7 days	17 / 99	17.2	2.27	1.22 – 4.22	0.010
Years of IV <sup>d</sup> drug abuse, lifetime					
0 years	36 / 377	9.5	1.00		
1-4 years	2 / 8	25.0	2.62	0.76 – 9.05	
>4 years	3 / 11	27.3	2.86	1.04 – 7.87	0.023
Days in jail in past year					
0 days	32 / 349	9.2	1.00		
1 day	2 / 15	13.3	1.45	0.38 – 5.51	
>1 day	6 / 34	17.6	1.92	0.87 – 4.27	0.10
Age groups					
18-30 years	4 / 62	6.5	1.00		
31-45 years	18 / 121	14.9	2.31	0.82 – 6.52	
45-60 years	11 / 138	8.0	1.24	0.41 – 3.73	
61-75 years	6 / 52	11.5	1.79	0.53 – 6.00	
>75 years	2 / 27	7.4	1.15	0.22 – 5.90	0.79

<sup>a</sup>n, number of patients with MRSA infection or colonization on admission.

<sup>b</sup>N, total number of patients.

<sup>c</sup>P<sub>trend</sub>, *p* value from Cochran-Armitage test for trend.

<sup>d</sup>IV, intravenous.

TABLE 4. Adjusted prevalence relative risk (RR) of seven risk measures from a multivariable linear model of MRSA infection or colonization on admission

Risk measure	RR	95% CI	<i>P</i>
Nursing home stay in past year	10.81	5.90 – 19.80	<0.0001
History of MRSA infection ever	3.72	1.64 – 8.42	0.0017
Male who has sex with men	3.24	1.34 – 7.88	0.0093
IV <sup>a</sup> drug abuse in past year	2.61	1.10 – 6.15	0.029
Non-IV drug abuse in past year	1.88	0.93 – 3.83	0.080
Outpatient antibiotics in past year	1.84	1.07 – 3.13	0.026
Ages 31-45 <sup>b</sup>	1.82	1.03 – 3.23	0.040

Generated by the SAS Genmod procedure with the log link function (37). The

corresponding multivariable logistic regression model had area under the receiver-operator characteristic (ROC) curve = 0.80 and Hosmer-Lemeshow goodness-of-fit

$p = 0.90$ .

<sup>a</sup>IV, intravenous.

<sup>b</sup>This age group was compared with all other age groups.

TABLE 5. Adjusted prevalence relative risk (RR) of two risk measures and a factor analysis scale from a multivariable linear model of MRSA infection or colonization on admission

Risk measure	RR	95% CI	<i>P</i>
History of nursing home stay in past year	6.18	3.56 – 10.72	<0.0001
History of MRSA infection ever	3.97	1.94 – 8.12	0.0002
Factor 3 scale of homeless, jailed, promiscuous and drug user <sup>a</sup>	3.14	1.56 – 6.31	0.0013

Generated by the SAS Genmod procedure with the log link function (37).

The corresponding multivariate logistic regression analysis had receiver-operator characteristic (ROC) area = 0.73 and

Hosmer-Lemeshow goodness-of-fit  $p = 0.68$ .

<sup>a</sup>Dichotomized at the 50th percentile.

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TABLE 6. Accuracy and screening burden of selected screening criteria for determining which patients have an admission screening culture for MRSA

Risk criteria for admission screening	Sensitivity (%) <sup>*</sup>	Specificity (%) <sup>†</sup>	Screening burden (%) <sup>‡</sup>
Univariate screening criteria			
Male who has sex with men	10	97	4
History of MRSA infection ever	15	96	5
IV drug use in past year	15	94	6
Nursing home stay in past year	20	98	4
Non-IV drug use in past year	34	81	21
Outpatient antibiotics in past year	39	80	22
Age 31-45	44	71	30
Hospitalization in past year	61	49	52
Multivariate screening criteria			
Homeless, jail, promiscuous or drug abuser (Factor 3)	78	52	51
Any of the 6 measures in Table 4 except age 31-45	80	58	46
Any of the 3 measures in Table 5	83	50	53
Any of the 7 measures in Table 4	90	46	58

<sup>\*</sup>Percentage of MRSA-positive admissions that would be assigned to having an admission surveillance culture

<sup>†</sup>Percentage of MRSA-negative admissions that would be assigned to having no admission surveillance culture

<sup>‡</sup>Percentage of all admissions that would be assigned to having an admission surveillance culture

APPENDIX. Factor loadings of 50 risk measures on eight orthogonal factors explaining MRSA infection or colonization on admission

Risk measure	Factors							
	F1	F2	F3	F4	F5	F6	F7	F8
History of taking antibiotics	87 <sup>a</sup>	-4	-3	3	7	6	5	0
Took all antibiotics prescribed	83 <sup>a</sup>	-4	-10	-1	10	1	7	-4
Took antibiotics as an outpatient	73 <sup>a</sup>	-7	0	5	-2	-5	5	12
Antibiotics prescribed by physician	72 <sup>a</sup>	4	-5	-7	6	5	2	-4
Took antibiotics while in hospital	66 <sup>a</sup>	-4	4	15	-2	-6	5	14
Doctors used gown in room	33 <sup>a</sup>	1	9	-1	-5	-3	7	16
History of MRSA infection	30 <sup>a</sup>	7	4	-1	-1	-3	4	4
Took old, leftover antibiotics	27 <sup>a</sup>	8	-1	-3	-2	9	11	-13
History of wound or skin infection	24 <sup>a</sup>	-6	13	17	-7	4	21	3
Transferred from another hospital	1	96 <sup>a</sup>	-3	6	15	-14	2	1
Transferred from telemetry unit	2	48 <sup>a</sup>	-18	-7	11	11	-20	22 <sup>a</sup>
Transferred from IMC <sup>b</sup> unit	0	41 <sup>a</sup>	14	2	29 <sup>a</sup>	-19	0	-4
Transferred from observation unit	-4	38 <sup>a</sup>	-5	9	-8	-22 <sup>a</sup>	28 <sup>a</sup>	-11
Transferred from intensive care unit	3	36 <sup>a</sup>	3	9	-15	10	-2	-10
First hospital admission	-1	-94 <sup>a</sup>	2	-4	-14	14	-2	-1
Homeless	2	-13	66 <sup>a</sup>	9	-2	1	-15	10
Lives alone	-2	-1	55 <sup>a</sup>	32 <sup>a</sup>	9	-16	-16	12
History of jail stay	4	-1	43 <sup>a</sup>	-13	-1	9	3	8
Uses illicit drugs (non-intravenous)	1	1	42 <sup>a</sup>	-20	3	21 <sup>a</sup>	16	-3
Sexually promiscuous	1	-3	34 <sup>a</sup>	-8	15	50 <sup>a</sup>	14	-16
Uses intravenous drugs	6	4	30 <sup>a</sup>	-5	29 <sup>a</sup>	29 <sup>a</sup>	41 <sup>a</sup>	-14
Uses only clean needles	1	-2	16	-4	33 <sup>a</sup>	22 <sup>a</sup>	39 <sup>a</sup>	-15
Lives in jail	0	5	20	-5	7	3	5	1
Male gender	1	2	19	8	5	-5	-12	-7
Man who has sex with men	0	-2	13	-2	0	-2	4	-7
Lives in home or apartment	3	7	-66 <sup>a</sup>	-37 <sup>a</sup>	7	-1	17	-5

History of NH <sup>c</sup> or LTC <sup>d</sup> facility stay	8	-3	4	62 <sup>a</sup>	-8	8	-9	7
Lives in nursing home	7	1	5	60 <sup>a</sup>	-9	5	-8	3
Sexually abstinent	4	-3	-2	51 <sup>a</sup>	21	-40 <sup>a</sup>	2	-2
Ages 76-90	-7	9	-6	48 <sup>a</sup>	-12	-7	-3	-7
Currently with PEG <sup>e</sup> tube	0	9	-15	40 <sup>a</sup>	9	9	1	4
Ages 61-75	11	4	-22 <sup>a</sup>	28 <sup>a</sup>	-7	-17	-1	8
Lives with 1 other person	7	-5	-12	-25 <sup>a</sup>	-5	-25 <sup>a</sup>	-8	-17
Ages 31-45	6	11	26 <sup>a</sup>	-30 <sup>a</sup>	-25 <sup>a</sup>	30 <sup>a</sup>	1	15
Has only one sex partner	2	2	-29 <sup>a</sup>	-51 <sup>a</sup>	-28 <sup>a</sup>	-1	-10	11
History of tracheostomy	3	1	1	-2	78 <sup>a</sup>	-5	-16	13
Currently with tracheostomy	-2	5	4	-4	76 <sup>a</sup>	-3	-15	15
History of PEG <sup>e</sup> tube	8	6	-17	30 <sup>a</sup>	35 <sup>a</sup>	9	4	7
Shares needles	-2	8	15	-4	32 <sup>a</sup>	7	7	5
Ages 16-30	-9	-13	-21 <sup>a</sup>	5	9	66 <sup>a</sup>	1	-10
Goes to community gym or pool	-2	-1	2	-2	4	30 <sup>a</sup>	-2	-8
Plays contact sports	0	-13	9	2	-1	24 <sup>a</sup>	-8	0
Ages 46-60	-4	-9	7	-20	29 <sup>a</sup>	-64 <sup>a</sup>	0	-10
Contact with skin infection history	14	-3	-4	-3	-6	-4	68 <sup>a</sup>	6
Helped with wound care	7	-5	-3	-2	-3	-2	62 <sup>a</sup>	8
Shared towels with contact	6	-4	-1	-1	-7	-4	53 <sup>a</sup>	-1
Contact with history of MRSA	11	9	-1	-2	0	-3	31 <sup>a</sup>	5
History of surgery	8	0	6	-2	-6	-7	11	76 <sup>a</sup>
Overnight stay for surgery	0	-4	4	-4	0	-8	6	74 <sup>a</sup>
History of hospital stay	40 <sup>a</sup>	-9	-2	9	10	2	2	43 <sup>a</sup>
Indwelling catheter	15	-3	-8	4	19	-4	8	40 <sup>a</sup>
History of hemodialysis	11	6	-3	0	18	-4	-4	30 <sup>a</sup>

<sup>a</sup> Values above the root mean square of all values in the table (>20).

<sup>b</sup> IMC, intermediate care unit.

<sup>c</sup> NH, nursing home.

<sup>d</sup> LTC, long-term care.

<sup>e</sup> PEG, percutaneous endoscopic gastrostomy.

Factor loadings from principal factor analysis were multiplied by 100 and rounded to the nearest integer. The variables, goes to a tanning salon and rarely takes a bath, did not load strongly on any of the eight factors.