ORIGINAL ARTICLE

A Systematic Literature Review and Meta-Analysis of Factors Associated with Methicillin-Resistant *Staphylococcus aureus* Colonization at Time of Hospital or Intensive Care Unit Admission

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OBJECTIVE. Screening for methicillin-resistant *Staphylococcus aureus* (MRSA) in high-risk patients is a legislative mandate in 9 US states and has been adopted by many hospitals. Definitions of high risk differ among hospitals and state laws. A systematic evaluation of factors associated with colonization is lacking. We performed a systematic review of the literature to assess factors associated with MRSA colonization at hospital admission.

DESIGN. We searched MEDLINE from 1966 to 2012 for articles comparing MRSA colonized and noncolonized patients on hospital or intensive care unit (ICU) admission. Data were extracted using a standardized instrument. Meta-analyses were performed to identify factors associated with MRSA colonization.

RESULTS. We reviewed 4,381 abstracts; 29 articles met inclusion criteria (n = 76,913 patients). MRSA colonization at hospital admission was associated with recent prior hospitalization (odds ratio [OR], 2.4 [95% confidence interval (CI), 1.3–4.7]; $P < .01$), nursing home exposure (OR, 3.8 [95% CI, 2.3–6.3]; $P < .01$), and history of exposure to healthcare-associated pathogens (MRSA carriage: OR, 8.0 [95% CI, 4.2–15.1]; *Clostridium difficile* infection: OR, 3.4 [95% CI, 2.2–5.3]; vancomycin-resistant *Enterococci* carriage: OR, 3.1 [95% CI, 2.5–4.0]; $P < .01$ for all). Select comorbidities were associated with MRSA colonization (congestive heart failure, diabetes, pulmonary disease, immunosuppression, and renal failure; $P < .01$ for all), while others were not (human immunodeficiency virus, cirrhosis, and malignancy). ICU admission was not associated with an increased risk of MRSA colonization (OR, 1.1 [95% CI, 0.6–1.8]; $P = .87$).

CONCLUSIONS. MRSA colonization on hospital admission was associated with healthcare contact, previous healthcare-associated pathogens, and select comorbid conditions. ICU admission was not associated with MRSA colonization, although this is commonly used in state mandates for MRSA screening. Infection prevention programs utilizing targeted MRSA screening may consider our results to define patients likely to have MRSA colonization.

Infect Control Hosp Epidemiol 2013;34(10):1077-1086

Methicillin-resistant *Staphylococcus aureus* (MRSA) is a common cause of healthcare-associated infections across the globe.[1-4] Many hospitals screen for MRSA colonization on admission as a key infection prevention strategy.[5-11] Active MRSA surveillance combined with implementation of barrier precautions with or without decolonization protocols has been associated with reduced MRSA transmission in investigations conducted in high prevalence settings.[11-15]

Universal screening of all admitted patients for MRSA has been suggested as a means to prevent MRSA transmission by identifying and isolating MRSA carriers.[6,16,17] However, such an approach can be resource intense and may pose practical challenges.[18,19] An alternative to universal screening is to test for MRSA among populations at the highest risk for colonization. In the United States, 9 states have passed legislation mandating MRSA screening for high-risk patients being admitted to the hospital, particularly those admitted to intensive care units (ICUs).[20] Unfortunately, current laws have disparate definitions of high-risk patients. For example, California has defined specific patient groups for active surveillance, while Illinois has mandated testing for all ICU admissions and other at-risk patients.[21,22]

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Received March 25, 2013; accepted June 18, 2013; electronically published August 19, 2013.

 0899-823X/2013/3410-0007$15.00. DOI: 10.1086/673157

Published medical literature can help determine which patients are most likely to be MRSA colonized. However, data from individual investigations are derived from specific populations that may not be generalizable to other geographic locales and populations. To provide more generalizable estimates, we performed a systematic review of the literature and meta-analysis of factors associated with MRSA colonization in patients admitted to hospitals and ICUs. The population of interest for the review included adults admitted to the hospital or ICU. The intervention studied was testing for MRSA within 48 hours of admission. The comparator pairs included patient-level and clinical characteristics. The outcome was MRSA colonization, and studies included retrospective and prospective reports of hospital- or unit-wide surveillance, excluding case-control studies.

METHODS

Search Strategy

To find published articles evaluating factors associated with MRSA colonization upon hospital and/or ICU admission, we performed a literature search of MEDLINE from 1966 to January 2012 and of EMBASE from January 1980 to January 2012, using the following terms: [(((((screening) OR swab) OR surveillance) AND (((methicillin) OR meticillin) OR oxacillin)) AND ((((((hospital) OR intensive care) OR ICU) OR inpatient) OR ward) OR unit)]. We limited results to English language and human subjects. In addition, we examined the bibliography of all identified articles to look for additional relevant references. Attempts were made to contact primary authors when primary data were not available.

Study Selection

Each abstract identified by the search criteria was examined (J.A.M., S.J.E., E.C.) using a quality tool designed to assess the validity of the individual studies, including selection and measurement bias.[23] To avoid potential selection bias, retrospective and prospective reports of hospital or unit-wide surveillance that contained data on factors associated with MRSA colonization in adults at hospital or ICU admission were included. Investigations were not excluded if they did not specifically state their MRSA screening methodologies or anatomic sites of screening but would have been excluded if they reported only nonstandardized methods of microbiologic testing. To avoid selection bias, investigations conducted during outbreaks were excluded. In addition, studies that collected data from pediatric patients or screened patients more than 48 hours after hospital admission (or more than 48 hours after ICU admission for ICU admission studies) were excluded. Reports describing clinical infections, nonhospitalized patients, laboratory-based surveys, or review articles were excluded. The full-text article was reviewed if 2 reviewers determined that the article potentially contained relevant data. Discrepant recommendations underwent arbitration by a third reviewer. Reviewers were not permitted to evaluate any article that they authored.

Data Extraction

Each article underwent independent, blinded, double data extraction by 2 reviewers (J.A.M., S.J.E., or E.C.) using a standardized instrument. Discrepancies in data extraction underwent arbitration by a third reviewer, and consensus was obtained by verbal discussion. Descriptive data collected for each study included time period of investigation, country of investigation, and hospital type (tertiary care, community, teaching, or other). Reviewers categorized the study population sampled (eg, ICU population, total hospital population, orthopedics). Compliance with MRSA screening protocols, MRSA diagnostic testing method, and method of body swabbing were also captured when available.

Data Analysis

Data on factors potentially associated with MRSA colonization were extracted from all articles. Mantel-Haenszel methods were used to calculate pooled odds ratios (ORs), 95% confidence intervals (CIs), and P values associated with each factor and MRSA colonization. Random effects (DerSimonian and Laird) were utilized to adjust standard errors.[24] To ensure that the pooled results of all studies were not biased by the process of combining results from multiple investigations (ie, Simpson's paradox), we performed graphical analysis and comparative analysis of data from each individual study.[25,26] The I^2 was calculated for each factor to determine the level of heterogeneity among the investigations analyzed.

RESULTS

Our search criteria yielded 4,381 abstracts, of which we found 735 of potential interest and selected their articles for full-text review. Abstracts were excluded from full-text review because of the following: limited to only clinical infections (n = 1,347), articles not pertinent to the subject matter (miscellaneous reasons; n = 718), laboratory-based surveys (n = 658), pediatrics (n = 353), review articles (n = 205), outpatient investigations (n = 192), or not about patients (n = 146; Figure 1).

Review of the full-text articles identified 24 investigations that had adequate data on factors associated with MRSA colonization. Articles were excluded because screening did not occur at admission (n = 344), the article did not contain primary data on MRSA or was a review/opinion piece (n = 328), the study was conducted in a long-term care facility (n = 13), screening occurred during an outbreak (n = 10), the study was conducted in pediatric patients (n = 9), or the study involved screening of healthcare workers only (n = 7; Figure 1). Bibliographic review of selected publications and expert opinion identified an additional 5 references for a total of 29 investigations included in the analysis.

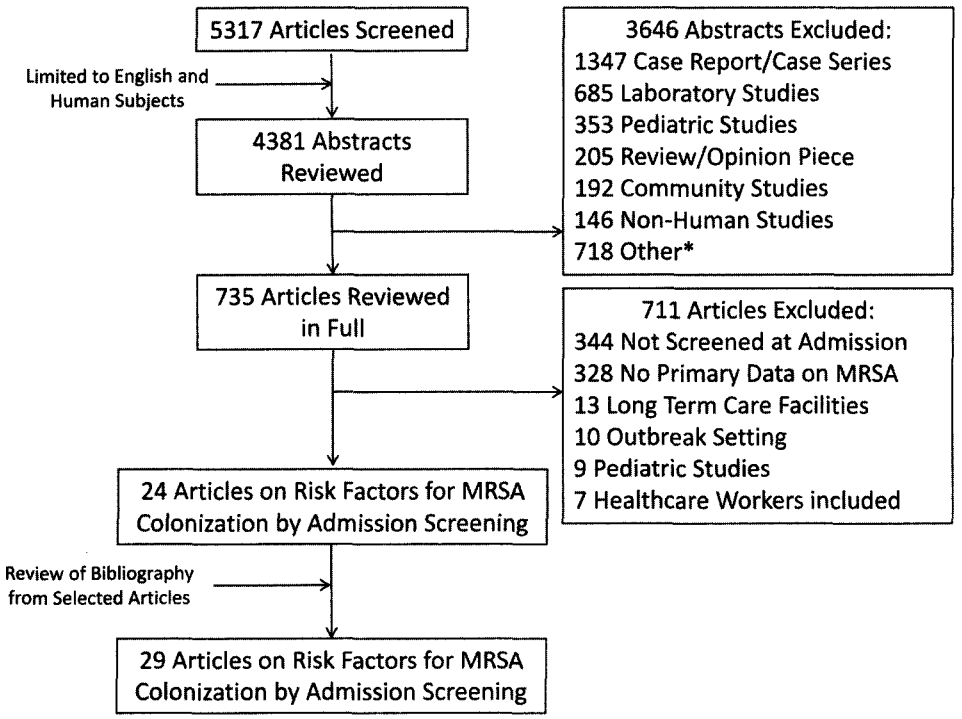

FIGURE 1. Results of the systematic review of the literature and selection of investigations to be included in the analysis.

Among the 29 investigations included in our analysis, 13 were conducted in Europe, and 11 were conducted in North America. Other studies were conducted in Asia ($n = 4$) and Australia ($n = 1$).[19,27-54] All studies were conducted between 1991 and 2009 and included a total of 76,913 patients. We identified 8 studies that focused solely on patients admitted to the ICU (Table 1).

Factors Associated with MRSA Carriage at Hospital Admission

Among the 21 studies evaluating MRSA colonization at hospital admission, we found that MRSA colonization was associated with prior healthcare exposure, such as history of hospitalization in the past 12 months (OR, 2.4 [95% CI, 1.3–4.7]; $P < .01$, $n = 15$ studies, 44,902 patients) and having been transferred from a nursing home (OR, 3.8 [95% CI, 2.3–6.3]; $P < .01$, $n = 18$ studies, 57,666 patients; Table 2). Being transferred from an outside hospital was not associated with MRSA colonization at screening (OR, 1.3 [95% CI, 0.7–2.3]; $P = .36$, $n = 10$ studies, 31,881 patients).

In addition to history of exposure to healthcare settings, MRSA colonization at hospital admission was associated with a history of infection or colonization with MRSA. Specifically, MRSA colonization was associated with both a history of an MRSA carriage in the past 6 months (OR, 14.4 [95% CI, 11.0–18.9]; $P < .01$, $n = 2$ studies, 5,936 patients) and a history of MRSA carriage at any time (OR, 8.0 [95% CI, 4.2–15.1]; $P < .01$, $n = 7$ studies, 29,145 patients).

Notably, MRSA colonization was associated with history of non-MRSA healthcare-associated infections. History of other exposure to healthcare-associated pathogens, including history of *Clostridium difficile* infection (OR, 3.4 [95% CI, 2.2–5.3]; $P < .01$, $n = 3$ studies, 29,250 patients) and vancomycin-resistant *Enterococci* (VRE) spp. carriage (OR, 3.1 [95% CI, 2.4–4.0]; $P < .01$, $n = 4$ studies, 29,671 patients), was also associated with MRSA colonization. Any infection, including community-onset infections, in the prior 3 months (OR, 3.6 [95% CI, 2.6–5.0]; $P < .01$, $n = 3$ studies, 12,299 patients) and recent antibiotic use (OR, 3.3 [95% CI, 2.4–4.5]; $P < .01$, $n = 14$ studies, 31,429 patients) were also associated with MRSA colonization on admission (Table 2).

Comorbidities associated with an increased likelihood of MRSA carriage at hospital admission included congestive heart failure, diabetes, chronic obstructive pulmonary disease (COPD), renal failure, and immunosuppression ($P < .01$ for all). MRSA colonization at admission screening was not associated with human immunodeficiency virus (HIV) infection, use of intravenous drugs, malignancy, or cirrhosis (Table 2).

Four articles examined the association between MRSA colonization at the time of hospital admission when admitted to an ICU as compared with a lower level of care. These investigations included data on 29,377 patients, including 2,469 admissions to the ICU. None of the individual articles found admission to an ICU to be associated with increased probability of MRSA colonization compared with routine

TABLE 1. Published Articles Evaluating Factors Associated with Methicillin-Resistant *Staphylococcus aureus* (MRSA) Colonization within 48 Hours of Hospital or Intensive Care Unit (ICU) Admission

Reference	Cohort	Location	Date of study	Sample size	No. of patients (%)	
					MRSA+	MRSA−
Mest et al,[27] 1994	Surgical ICU	Long Beach, CA	1991–1992	484	19 (4%)	465 (96%)
Troillet et al,[28] 1998	General medicine and select surgical services (vascular, podiatry, general surgery)	Boston, MA	1996	387	10 (3%)	377 (97%)
Campillo et al,[29] 2001	Patients with cirrhosis in chronic liver disease unit	Paris, France	1996–2000	748	125 (17%)	623 (83%)
Eveillard et al,[30] 2002	Geriatric ward	Amiens, France	2000	239	35 (15%)	204 (85%)
Samad et al,[31] 2002	General surgery or orthopedics	Wales, UK	2000–2001	430	23 (5%)	407 (95%)
Lucet et al,[34] 2003	ICU	Paris, France	1997–1997	746	53 (7%)	693 (93%)
Ho,[33] 2003	ICU	Hong Kong, China	1999	1,697	206 (12%)	1,491 (88%)
Marshall et al,[35] 2003	ICU	Victoria, Australia	2000–2001	1,185	80 (7%)	1,105 (83%)
Corea et al,[32] 2003	Routine surgery	Colombo, Sri Lanka	1998–1999	269	20 (7%)	249 (83%)
Merrer et al,[37] 2004	Patients with femoral neck fracture	Paris, France	2000	179	15 (8%)	164 (82%)
Fukuda et al,[36] 2004	All inpatients	Hirado, Japan	2000	136	12 (9%)	124 (91%)
Lucet et al,[39] 2005	Patients older than 75 years	Paris, France	2002	797	63 (8%)	734 (92%)
Hidron et al,[38] 2005	All admissions on Tuesday, Thursday, and Sunday	Atlanta, GA	2003	726	53 (7%)	673 (93%)
Sax et al,[40] 2005	All inpatients, excluding known MRSA carriers	Geneva, Switzerland	2001, 2003	672	31 (5%)	641 (95%)
Dupeyron et al,[41] 2006	Gastroenterology unit	Paris, France	2000–2004	2,242	206 (9%)	2,036 (91%)
Warren et al,[42] 2006	Surgical ICU	St. Louis, MO	2002–2004	775	82 (11%)	693 (89%)
Casas et al,[43] 2007	All inpatients, excluding known MRSA carriers and obstetrics or pediatrics	Barcelona, Spain	2001–2003	1,128	17 (2%)	1,109 (98%)
Russell et al,[46] 2008	Liver transplant unit	Los Angeles, CA	2000–2005	706	47 (7%)	659 (93%)
Riedel et al,[45] 2008	All inpatients	Iowa City, IA	2006	421	43 (10%)	378 (90%)
Chabernay et al,[44] 2008	All inpatients	Hanover, Germany	2005	509	27 (5%)	482 (95%)
Baykam et al,[47] 2009	All inpatients	Ankara, Turkey	2005	900	11 (1%)	889 (99%)
Nishikawa et al,[49] 2009	All inpatients older than 65 years	Aichi, Japan	2003	138	11 (8%)	127 (82%)
Kock et al,[48] 2009	All inpatients	Germany/Netherlands	2006	21,190	354 (2%)	20,836 (98%)
Niven et al,[50] 2009	ICU	Calgary, Canada	2005–2006	1,308	50 (4%)	1,258
Keene et al,[53] 2010	Patients with risk factor for MRSA colonization, excluding those with *S. aureus* clinical isolate within 3 months	New York, NY	2007–2008	200	29 (15%)	171 (85%)
Creamer et al,[51] 2010	All inpatients	Dublin, Ireland	2008–2009	489	115 (24%)	374 (76%)
Honda et al,[52] 2010	ICU	St. Louis, MO	2002–2007	9,523	674 (7%)	4,487 (93%)
Parvez et al,[19] 2010	All inpatients	Temple, TX	2008	5,375	581 (11%)	4,794 (89%)
Robicsek et al,[55] 2011	All inpatients, excluding those with prior MRSA cultures	Chicago, IL	2007–2008	23,314	520 (2%)	22,794

ward-level admissions. In the meta-analysis, ICU admission was not significantly associated with MRSA colonization (OR, 1.05 [95% CI, 0.6–1.82]; $P = .87$).

Analysis of Risk Factors for MRSA Carriage at ICU Admission

Data from articles limited to those assessing MRSA colonization upon ICU admission are summarized in Table 3. MRSA colonization at ICU admission was similarly associated with recent hospitalization (prior 12 months; OR, 2.4 [95% CI, 1.7–3.4]; $P < .01$, $n = 5$ studies, 7,587 patients) and exposure to MRSA in the past 6 months (OR, 14.4 [95% CI, 11.0–18.9]; $P < .01$, $n = 2$ studies, 5,936 patients). We again noted an association of MRSA colonization with non-MRSA healthcare-associated infections, including VRE carriage (OR, 3.3 [95% CI, 2.4–4.5]; $P < .01$, $n = 3$ studies, 6,357 patients) and *C. difficile* infection (OR, 4.0 [95% CI, 1.9–8.4]; $P < .01$, $n = 2$ studies, 5,936 patients). In addition, similar comorbid conditions present on ICU admission were associated with MRSA colonization, including congestive heart failure, COPD, diabetes, immunosuppression, and chronic renal failure ($P < .01$ for all associations; see Table 3).

We found no association between MRSA colonization at ICU admission and nursing home residency (OR, 2.6 [95% CI, 0.7–9.2]; $P = .14$, $n = 6$ studies, 8,333 patients) or transfer from another hospital (OR, 1.1 [95% CI, 0.7–1.6]; $P = .70$, $n = 4$ studies, 8,430 patients).

DISCUSSION

Our systematic review of the literature provides a robust analysis of the factors associated with MRSA colonization at the time of hospital and ICU admission. We reviewed more than 4,000 abstracts to identify 29 articles with data of sufficient

TABLE 2. Meta-Analysis of Risk Factors Associated with Methicillin-Resistant *Staphylococcus aureus* (MRSA) Colonization at Admission to Hospital

Variable	Articles	Sample size	OR	95% CI	*P*	I^2
Prior healthcare contact						
Nursing home resident	18	57,666	3.84	2.34–6.30	<.01	27.23
Hospitalization in past 12 months	15	44,902	2.43	1.26–4.70	<.01	0.00
Transfer from outside hospital	10	31,881	1.31	0.74–2.33	.36	55.17
Contact with nosocomial pathogens						
History of MRSA carriage	7	29,145	8.01	4.24–15.14	<.01	15.67
Carriage in past 6 months	2	5,936	14.42	10.98–18.93	<.01	0.00
History of *Clostridium difficile* infection	3	29,250	3.43	2.21–5.32	<.01	2.84
Any infection in prior 3 months	3	12,299	3.61	2.61–4.98	<.01	0.00
Vancomycin-resistant *Enterococci* carriage	4	29,671	3.12	2.46–3.95	<.01	0.00
Recent antibiotic use[a]	14	31,429	3.33	2.42–4.56	<.01	50.15
Type of admission						
Medical	5	27,022	2.29	1.09–4.79	.03	21.90
Surgical	9	36,863	1.22	0.77–1.93	.41	27.37
ICU	4	29,377	1.05	0.60–1.82	.87	34.85
Comorbid conditions						
Skin lesion present	5	25,707	2.63	1.02–6.77	.05	0.00
Wounds/bedsores present	10	31,875	3.02	1.57–5.78	<.01	0.00
Congestive heart failure	3	29,250	2.31	1.94–2.74	<.01	0.00
Diabetes	9	38,669	2.30	1.56–3.40	<.01	0.00
Chronic obstructive pulmonary disease	4	30,150	2.37	1.77–3.16	<.01	0.00
Chronic renal failure	2	10,992	1.77	1.42–2.20	<.01	0.00
Renal failure requiring dialysis	7	52,494	1.50	1.20–1.88	<.01	0.00
Immunosuppression	5	30,664	1.45	1.15–1.84	<.01	16.26
Human immunodeficiency virus	3	29,201	2.19	0.96–4.96	.06	0.00
Transplant candidate	3	6,642	0.95	0.66–1.36	.76	0.00
Malignancy	2	5,936	0.85	0.65–1.13	.27	0.00
Cirrhosis	4	6,274	0.99	0.73–1.33	.92	7.11
History of intravenous drug use	3	8,478	1.16	0.73–1.85	.53	8.64
Presence of a medical device						
Central venous catheter	6	51,586	1.72	0.70–4.23	.23	0.00
Urinary catheter	6	5,205	2.32	0.99–5.45	.05	0.00

NOTE. Results of our meta-analysis of risk factors associated with MRSA colonization at admission to the hospital demonstrates that exposure to nosocomial pathogens and history of healthcare exposure were strongly associated with MRSA carriage, whereas comorbid conditions had a lesser association. Type of admission—intensive care unit (ICU) versus routine ward admission or medical versus surgical—had no clear association with MRSA carriage. CI, confidence interval; OR, odds ratio.

[a] The I^2 value for this investigation was 55.7, suggesting heterogeneity among studies on the association between recent antibiotic use and MRSA colonization.

quality to warrant analysis. The investigations included in this review incorporate more than 75,000 patient admissions from diverse medical centers worldwide.

Our data are important to help improve and refine the growing practice of screening for MRSA colonization at hospital admission. Screening for MRSA is increasingly performed as a matter of routine clinical care.[7-9] Current data indicate that active surveillance combined with infection prevention and control measures may reduce MRSA transmission.[11-15] Unfortunately, despite the promise of screening programs, MRSA testing consumes a large amount of personnel time and hospital financial resources. Balancing the potential benefit of screening against the cost of program administration has hindered the widespread adoption of MRSA screening.[18,19]

Some programs have adopted targeted MRSA screening protocols to optimize potential benefit while limiting cost. Nine US states have legislated mandates that hospitals must screen for MRSA at hospital admission. Many states target high-risk hospital admissions, particularly patients admitted to ICUs.[20] Unfortunately, definitions of high risk are not consistent. The state of California requires screening for patients from a skilled nursing facility, dialysis patients, preoperative patients, ICU/burn unit admission, and those discharged from an acute care hospital in the past 30 days. In contrast, the state of Illinois requires surveillance of all ICU admissions

TABLE 3. Meta-Analysis of Risk Factors Associated with Methicillin-Resistant *Staphylococcus aureus* (MRSA) Colonization at Admission to Intensive Care Unit (ICU)

Variable	Articles	Sample size	OR	95% CI	*P*	I^2
Prior healthcare contact						
Hospitalization in past 12 months	5	7,587	2.38	1.69–3.36	<.01	15.76
Nursing home	6	8,333	2.62	0.74–9.25	.14	0.00
Transfer from outside hospital	4	8,430	1.08	0.73–1.59	.70	31.24
Contact with nosocomial pathogens						
History of MRSA carriage	3	6,357	12.83	8.51–19.33	<.01	10.75
Carriage in past 6 months	2	5,936	14.42	10.98–18.93	<.01	0.00
History of *Clostridium difficile* infection	2	5,936	3.98	1.89–8.37	<.01	0.00
Any infection in prior 3 months	3	12,299	3.61	2.61–4.98	<.01	0.00
Vancomycin-resistant *Enterococci* carriage	3	6,357	3.27	2.37–4.52	<.01	0.00
Recent antibiotic use	6	5,568	2.84	2.10–3.84	<.01	0.00
Type of admission						
Medical ICU	3	3,219	3.21	2.29–4.49	<.01	0.00
Surgical ICU	5	10,618	1.38	0.69–2.73	.36	0.00
Comorbid conditions						
Congestive heart failure	2	5,936	2.09	1.73–2.53	<.01	0.00
Chronic obstructive pulmonary disease	2	5,936	1.98	1.67–2.36	<.01	9.18
Diabetes	2	10,992	3.78	3.24–4.41	<.01	0.00
Immunosuppression	3	8,125	1.46	1.22–1.75	<.01	0.00
Chronic renal failure	2	10,992	1.77	1.42–2.2	<.01	0.00
Renal failure requiring dialysis	2	5,936	1.34	0.98–1.82	.07	0.00
Wounds/bedsores	3	8,125	1.65	0.96–2.85	.07	0.00
Human immunodeficiency virus	1	5,161	1.41	0.65–3.03	.38	...
Skin lesion	3	3,653	2.02	0.70–1.30	.20	0.94
Cirrhosis	2	5,936	0.99	0.74–1.34	.97	0.00
Transplant candidate	3	6,642	0.95	0.66–1.36	.76	
History of intravenous drug use	1	5,161	0.95	0.78–1.16	.60	...
Malignancy	2	5,936	0.85	0.65–1.13	.27	0.00
Presence of a medical device						
Central venous catheter	1	2,189	2.01	1.31–3.10	<.01	...
Urinary catheter	2	2,428	2.38	0.93–6.07	.07	0.00

NOTE. Results of our meta-analysis of risk factors associated with MRSA colonization at admission to the ICU demonstrates again that exposure to nosocomial pathogens and history of healthcare exposure were associated with MRSA carriage. Interestingly, type of ICU admission—medical versus surgical—did have an association with MRSA carriage, whereas type of non-ICU admission did not. As with hospital admissions, comorbid conditions had a lesser association with MRSA carriage. CI, confidence interval; OR, odds ratio.

and other at-risk patients.[21,22] Our systematic review and meta-analysis provide data on specific populations and specific factors that are associated with MRSA colonization. Our data can provide guidance as to which populations could be selected for targeted MRSA screening and may suggest an opportunity to optimize patient selection through hospital-based, clinical databases.[55]

Despite the rising community carriage of MRSA, our analysis found that factors indicative of prior healthcare contact were strongly and consistently associated with MRSA colonization. Patients with recent hospitalization and nursing home residence were more likely to be MRSA carriers, perhaps suggestive of exposure to high-risk settings for MRSA acquisition. As hospital systems become increasingly electronic and able to readily signal readmission and prior discharge disposition to a healthcare facility, these data can and have been purposed for targeted MRSA screening protocols.[56]

Further supporting evidence that exposure to high risk-healthcare settings is a strong predictor of MRSA colonization is its association with other healthcare pathogens, such as a history of *C. difficile* infection or VRE carriage. Beyond high-risk healthcare exposure, such pathogens may also be a proxy measure for underlying factors that increase acquisition risk, that is, antibiotic exposure, which is thought to increase the risk of MRSA colonization through selective pressure.[57,58] Data from our analysis support the observation that recent antibiotic exposure was associated with MRSA colonization. While a history of VRE may obviate the need for screening since contact precautions are usually already applied, a history of VRE or *C. difficile* infection may be suggestive of the need for decolonization or other strategies that target a range of multidrug-resistant pathogens. With an increasing number of hospitals tracking a history of multidrug-resistant pathogens, an opportunity may exist to focus efforts on a high-risk population at hospital admission.

The strong association of MRSA colonization with history

of MRSA is well documented and supported by this analysis.[59-61] In contrast to the above risk factors, which may hone a target population for screening, this information may be used to prevent rescreening of patients who are unlikely to have lost carriage. This may also provide cost savings.

Our review identified select comorbid conditions—such as diabetes, COPD, and congestive heart failure—that were associated with MRSA colonization at hospital and ICU admission. Reasons for these associations may be repeated hospital exposure or other host-related factors that increase the chance of acquiring MRSA. We report a trend toward an association between HIV infection and MRSA colonization, but this does not reach statistical significance. Other investigations have associated HIV infection with MRSA colonization.[62-64] Prior publications have also suggested that patients with intravenous drug use or cirrhosis were at higher risk for MRSA carriage, but we did not find such an association in our review.[65,66] These data may provide further opportunities to develop targeted screening protocols by linking screening to clinical pathways for the management of congestive heart failure or insulin dosing protocols for diabetic patients.

Interestingly, we did not find an increased likelihood of MRSA colonization among hospitalized patients being admitted to ICUs (compared with non-ICUs). Moreover, the 4 studies included in our meta-analysis comparing ICU admissions to routine ward admissions contained robust data from a range of geographic and clinical practice, including more than 2,000 ICU admissions and more than 25,000 hospital admissions. The investigations were conducted in both the United States ($n = 3$) and Europe ($n = 1$) and include both tertiary and community hospitals (tertiary, 4; community, 2; 1 investigation was a multisite study). We note that only 1 of the 4 investigations[55] attempted to adjust for comorbid conditions or other factors associated with MRSA colonization, but this may have been expected to have increased rather than diminished an association with ICU admission.

As evidence indicates a rising prevalence of MRSA colonization in the general US community, it is plausible that MRSA prevalence in the non-ICU setting may be becoming similar to ICU populations.[67,68] Regardless, while ICU patients may not be more likely to have MRSA colonization, the potential consequences of colonization or MRSA infection may be more grave in ICU patients. Thus, screening may be reasonable in this population for clinical rather than epidemiologic reasons.

There are limitations to our investigation. First, despite the number of investigations included in our analysis and the robust sample size of many of the comparisons, our findings may not be generalizable to all practice settings. Many studies included in our analysis were done in academic medical centers, which may not reflect patient populations at other types of medical centers, and studies often did not control for the same factors. However, the heterogeneity among the studies was generally low for each factor. The only significant factor with a moderate I^2 was recent antibiotic use at admission to the hospital. This may be due to the variable ways in which recent antibiotic use were determined. Additionally, our data are focused on identifying MRSA colonization and do not consider the impact of MRSA infections on the patient populations who may be screened. The grave consequence of MRSA infection for critically ill or immunocompromised populations may justify screening, regardless of a low colonization probability, especially if a history of MRSA would broaden empiric antibiotic regimens to include MRSA. In addition, screening may be justified in patients with extensive or infected wounds because they may present a high risk for transmission to others. Finally, data from our review focused on nasal MRSA colonization. We found no systematic data on risk of extranasal MRSA colonization (eg, pharyngeal, inguinal) on admission. Extranasal colonization may be an important reservoir of MRSA and does not always correlate with nasal colonization.[69,70]

In summary, our systematic literature review and meta-analysis identifies patient characteristics that may enhance detection of MRSA colonization upon admission to the hospital. These results continue to support healthcare-associated exposures as the major source of MRSA, despite the fact that MRSA carriage is now common in the community. These data may help inform hospital policies on MRSA screening and enable electronic targeting of screening using electronic medical records. While a few academic centers have developed screening algorithms tailored to their specific patient populations,[71] these results may assist hospitals select screening criteria when resources for tailored algorithms are not available.

ACKNOWLEDGMENTS

Financial support. The current project was supported by the Agency for Healthcare Research and Quality grant RC4AI092327. J.A.M.'s effort was also supported by National Institutes of Health/National Center for Research Resources/National Center for Advancing Translational Sciences grant KL2TR000122 to the University of California–Los Angeles Clinical and Translational Science Institute.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

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