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State of the Science Review

How often are health care personnel hands colonized with multidrug- resistant organisms? A systematic review and meta-analysis

Ana Montoya MD, MPH [a,*], Richard Schildhouse MD [b,c], Anupama Goyal MBChB [b], Jason D. Mann MSA [b], Ashley Snyder MPH [b], Vineet Chopra MD [b,c], Lona Mody MD [a,d]

[a] Division of Geriatric and Palliative Medicine, Department of Internal Medicine, University of Michigan School of Medicine, Ann Arbor, MI
[b] Division of Hospital Medicine, Department of Internal Medicine, University of Michigan School of Medicine, Ann Arbor, MI
[c] Division of General Medicine,Department of Internal Medicine, Veterans Affairs Ann Arbor Healthcare System, Ann Arbor, MI
[d] Geriatrics Research Education and Clinical Center, Veterans Affairs Ann Arbor Healthcare System, Ann Arbor, MI

Key Words:
Hand hygiene
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Acute care
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Background: Hands of health care personnel (HCP) can transmit multidrug-resistant organisms (MDROs), resulting in infections. Our aim was to determine MDRO prevalence on HCP hands in adult acute care and nursing facility settings.

Methods: A systematic search of PubMed/MEDLINE, Web of Science, CINAHL, Embase, and Cochrane CENTRAL was performed. Studies were included if they reported microbiologic culture results following HCP hands sampling; included prevalent MDROs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus*, *Clostridium difficile*, *Acinetobacter baumannii*, or *Pseudomonas aeruginosa*, and were conducted in acute care or nursing facility settings.

Results: Fifty-nine articles comprising 6,840 hand cultures were included. Pooled prevalence for MRSA, *P aeruginosa*, *A baumannii*, and vancomycin-resistant *Enterococcus* were 4.26%, 4.59%, 6.18%, and 9.03%, respectively. Substantial heterogeneity in rates of pathogen isolation were observed across studies (I^2 = 81%-95%). Only 4 of 59 studies sampled for *C difficile*, with 2 of 4 finding no growth. Subgroup analysis of MRSA revealed the highest HCP hand contamination rates in North America (8.28%). Sample collection methods used were comparable for MRSA isolation (4%-7%) except for agar direct contact (1.55%).

Conclusions: Prevalence of common MDROs on HCP hands vary by pathogen, care setting, culture acquisition method, study design, and geography. When obtained at an institutional level, these prevalence data can be utilized to enhance knowledge, practice, and research to prevent health care–associated infections.

Health care–associated infections (HAIs) are frequent but often preventable events.[1-6] HAIs caused by multidrug-resistant organisms (MDROs) necessitate treatment with broad-spectrum antibiotics, further contributing to the potential for antibiotic resistance.[1,7]

A number of interventions can reduce HAIs and MDROs in health care settings.[3,8-10] These interventions include early identification of patients at risk for HAI, provider education and training, auditing of cleaning and hygiene practices, surveillance of institutional HAIs, and antibiotic stewardship.[4-6,10,11] However, 1 of the most important and foundational evidence-based practices to reduce HAI is hand hygiene. For hospitalized patients, health care personnel (HCP) are a vector for MDROs as their hands frequently contact contaminated medical devices and environmental surfaces.[12-21] Thus, HCP hand hygiene is an important step in breaking the transmission chain for development of HAIs, an area extensively researched.[10,15,22-25] Recent systematic reviews have identified a number of interventions, including staff education, performance feedback, and environmental restructuring,[26,27] yet low compliance by HCP continues to be a concern.[15,23,28] Despite extensive focus on hand hygiene, there is a paucity of literature regarding MDRO contamination rates on HCP hands and potential influencing

* Address correspondence to Ana Montoya, MD, MPH, University of Michigan Health System, Geriatrics Center, 4260 Plymouth Rd, Rm B1 337, Ann Arbor, MI 48109.
E-mail address: amontoya@med.umich.edu (A. Montoya).

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factors. Two questions remain: (1) What is the burden of MDRO prevalence on HCP hands? and (2) What are the factors influencing this prevalence?

We performed a systematic review of the literature to determine the prevalence of MDROs on the hands of HCP in acute as well as post-acute nursing facility settings. We were particularly interested in factors that could be associated with higher prevalence of MDROs on HCP hands such as geographic location, acuity of health care setting, or sample collection method. We anticipate this information will (1) simplify our current understanding of the complex transmission dynamics; (2) define factors that influence HCP hand contamination; and (3) aid the design of thoughtful, effective interventions to prevent HAIs.

METHODS

Data sources and searches

With the assistance of a reference librarian (J.M.) we performed serial searches of multiple databases, including Pubmed/MEDLINE (via Ovid), Web of Science, CINAHL, Embase, and Cochrane CENTRAL on December 20, 2016. Using controlled vocabularies and Medical Subject Headings terms, various combinations of key words, including "nursing home," "acute care," "multidrug-resistant organism," "hand hygiene," and "health care worker" were used to identify relevant studies. Several content experts reviewed the final list of included articles for completeness and identification of other relevant studies. No restrictions on the search were placed (eg, date of publication, type of publication, study design, or language). The search was last updated on June 30, 2017.

Study selection

We included studies that (1) reported microbiologic culture results following sampling of hands of HCPs; (2) included specific MDRO organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), *Clostridium difficile*, *Acinetobacter baumannii*, and *Pseudomonas aeruginosa*; and (3) were conducted in an acute care (eg, medical or surgical ward or intensive care unit [ICU]) or nursing facility setting. Studies that were not published in English, conducted in an outpatient setting (eg, clinics and emergency departments) during known or suspected infectious outbreaks or did not test for antibiotic resistance were excluded. Pediatric and neonatal studies were excluded, given the unique differences in the HCP-patient interaction in this population. Two authors (A.M. and R.S.) independently determined study eligibility. Any differences in opinion regarding inclusion were adjudicated by a third author (V.C.). Where relevant, study authors were contacted for additional data to ascertain eligibility.

Data extraction and quality assessment

Two authors (A.G. and R.S.) used a standardized template to extract data independently and in duplicate. Data fields included author name, year of publication, study design (eg, cross-sectional, randomized control trial), geographic location (eg, Asia, North America, Europe), care setting (eg, ICU, general ward, nursing facility), HCP activity when sampled, method of sample collection (eg, swab, juice glove, and agar direct contact), number of HCPs assessed, and outcomes such as pathogen isolation, type of MDRO, and prevalence. A care setting designation of "mixed inpatient group" was given to studies that reported only pooled data from multiple hospital units (eg, general ward, ICU, or operating rooms in combination). Post acute care settings such as rehabilitation units, long-term care wards, and skilled nursing facilities were collectively designated as the "nursing facility" setting. For studies that analyzed a specific infection control intervention (eg, a new environmental cleaning method, novel antiseptic, or new hand hygiene initiative) only hand culture data from the control group were extracted to avoid potential influence from nonroutine practices. The specific activity performed by HCPs immediately prior to sampling was noted for each study if mentioned, including whether hands were cleaned prior to sampling. If HCPs were sampled on the ward during their clinical tour with no further description, a designation of "direct patient care" was used. Regarding the swab method of sample collection, studies were classified as using a moist swab only if a liquid agent was mentioned.

As recommended by the Cochrane Collaboration, 2 authors (A.M. and A.G.) independently assessed risk of bias in the included studies. For randomized controlled trials, the Cochrane Collaboration tool[29] was used to determine risk of bias, with studies achieving low-risk scores in all 6 domains considered high quality. For observational studies, the Newcastle-Ottawa scale[30] that utilizes a star system to assess the quality of study in 3 domains (selection of study groups, comparability of groups, and ascertainment of outcome) was used. Because no studies included comparability measures, this was removed from the assessment of risk of bias for all studies.

Data synthesis and analysis

We analyzed studies by their detection rates of MDROs from HCP hand cultures. We calculated the prevalence of each MDRO by dividing the number of positive HCP hand cultures by the total number sampled. To minimize the effect of zero prevalence studies on the overall estimate, we stabilized the variances using the Freeman-Tukey double arcsine transformation for data with a binomial distribution.[31] Random-effects meta-analysis with exact confidence intervals (CIs) was then performed to pool the prevalence of each study population with an isolated MDRO.[31] All meta-analyses were conducted using the metaprop command in Stata.[32,33] Meta-analysis was only performed for an MDRO if 2 or more of the resulting subgroups contained 5 or more studies. Between-study heterogeneity was assessed using Cochrane's Q statistic and the I^2 statistic, and sources were explored through restriction of analyses to pre-specified subgroups.[34] Heterogeneity was classified as low (25%), moderate (50%), or high (75%) according to methods published by Higgins et al.[35]

Subgroup analyses were conducted to establish whether sampling method, care setting, geographic location by continent, or study design affected the results of the aggregate analysis. All data analysis was conducted using Stata MP v14.2 (StataCorp LLC, College Station, TX). This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[36]

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all of the data in the study and had final responsibility for the decision to submit for publication.

RESULTS

Search results and study details

A total of 6,335 articles were retrieved by our electronic search, of which 57 met inclusion criteria. Two additional studies provided by content experts were identified, leading to a total of 59 articles in the systematic review (Fig 1). Forty-seven (79.7%) of the included studies used a cross-sectional design,[37-83] 7 (11.9%) used pre-post designs,[84-90] 3 (5.1%) were randomized controlled trials,[91-93] and 2 (3.4%) used mixed designs (eg, nonrandomized single arm, nonrandomized control).[94,95] Twenty-three (39%) of the studies were conducted in Asia,[37,38,43,48,50,52,55,57,60,61,66,67,71,73-76,78,80,81,84,92,94] 18 (30.5%) in North America,[39,40,42,44,45,51,53,54,63,64,70,86-88,90,91,93,95] 13 (22%) in

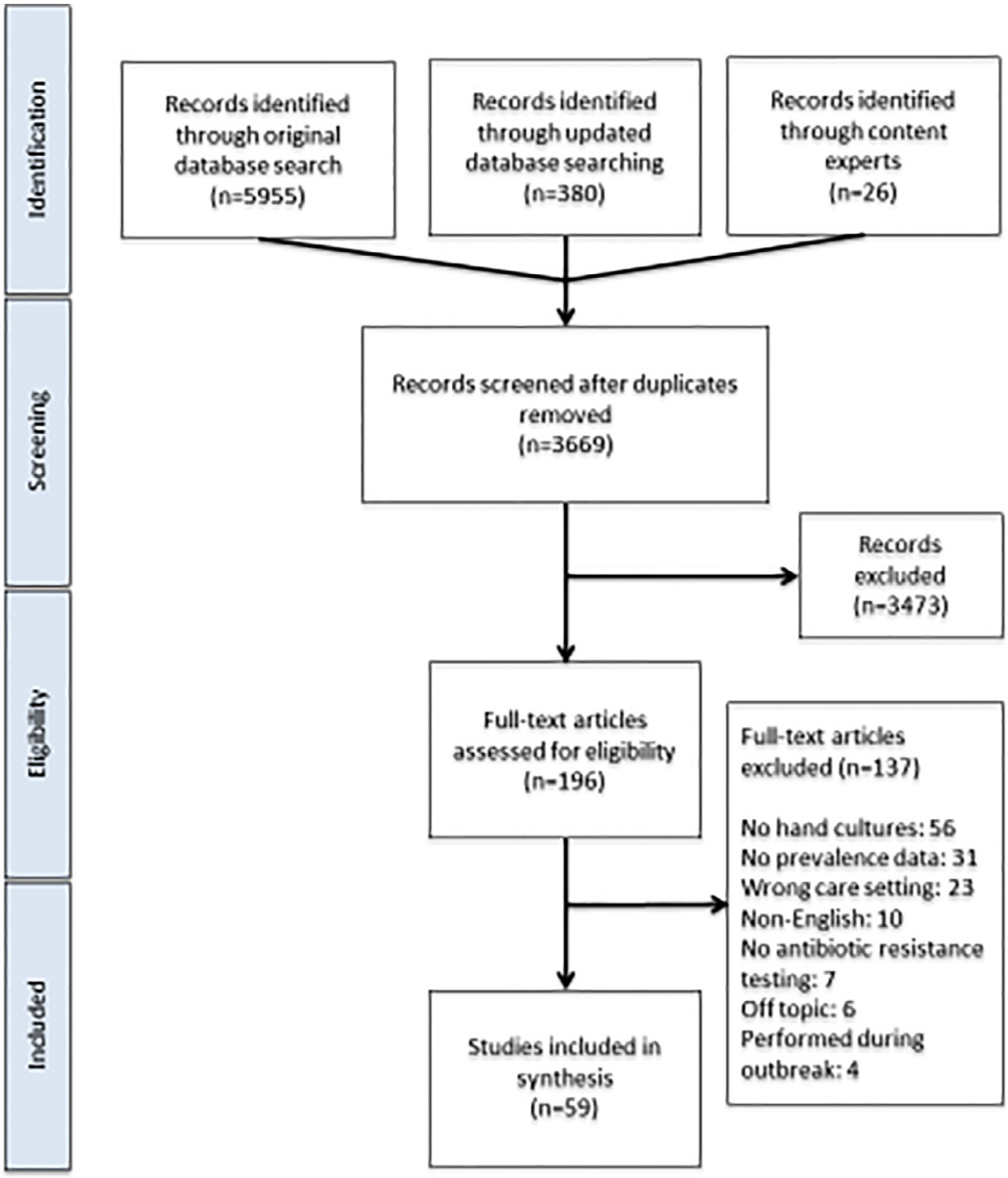

Fig 1. Flow diagram of study selection.

Europe,[41,46,47,56,59,65,69,72,77,79,82,85,89] 2 (3.4%) in South America,[62,68] 2 (3.4%) in Africa,[49,58] and 1 (1.7%) in Australia.[83] Inter-rater agreement for study eligibility was 0.95.

Twenty (33.9%) of the studies were performed after sampling HCP hands on general wards,[38,42-44,47,48,51,55,56,61,67,71,73,74,77,78,85,86,89,92] 20 (33.9%) in an ICU setting,[39,45,46,48,52,55,58-60,69-71,75-77,82,83,87,91,95] 19 (32.2%) in mixed inpatient settings,[37,40,41,49,50,57,62,64-66,68,72,79-81,84,90,93,94] and 5 (8.5%) in nursing facilities.[39,53,54,63,88] Regarding HCP activities performed at time of sampling, 28 (47.5%) studies were collected samples during direct patient care,[37,39,40,44,52-54,57,58,60,62-64,69,70,75,77-79,81-83,85,87,89,90,92,94] 26 (44.1%) were unspecified,[38,41,42,45-51,55,56,59,61,66,68,71-74,76,80,84,86,88,93] and 5 (8.5%) were captured after specific activities (ie, entering the ward or exiting a patient's room).[43,65,67,91,95] A number of collection methods were used to isolate organisms. Specifically, juice glove (dipping hands into a glove containing nutrient broth) was used in 20 (33.9%) studies,[39,40,45,48,51,53,54,58,68-70,78,79,81,87-89,91,92,95] moist swab (using sterile saline solution or nutrient broth) was used in 17 (28.9%),[37,41,43,50,52,55,57,59,66,67,74,76,80,83,84,90,94] agar direct contact (plates or applicators with solid media) was used in 13 (22%),[42,44,46,56,60,62-64,71,72,77,82,85] swab was used in 7 (11.9%),[38,47,49,65,73,75,86] and subungual scraping was used in 1 (1.7%).[61] One study did not specify a collection method.[93] Study characteristics can be found in Table 1.

Microbiologic data from culture of HCP hands

Of the 59 included studies, 42 (71.2%) tested for MRSA, 17 (28.8%) for *P aeruginosa*, 14 (23.7%) for *A baumannii*, 8 (13.6%) for VRE, and 4 (6.8%) for *C difficile*. Within these studies, the number of HCP hand samples reported ranged from 13-762,[63,75] with results from 6,840 samples reported in total. The pooled prevalence of MDROs on HCP hands grouped by organism can be found in Figure 2.

Table 1
Characteristics of included studies

Study, year	Country	Study design	Care setting	HCP activity when sampled	Sample collection method	Total samples (n)	MDRO prevalence					Risk of bias
							MRSA	VRE	*Clostridium difficile*	*Pseudomonas aeruginosa*	*Acinetobacter baumannii*	
Malamouladas et al,[56] 1983	United Kingdom,	Cross-sectional	Ward	NS	Agar direct contact	34	—	—	0%	—	—	Low
Horn et al,[51] 1988	United States,	Cross-sectional	Ward	NS	Juice glove	28	17.9%	—	—	3.6%	10.7%	Low
Wise and Tosolini,[83] 1990	Australia	Cross-sectional	ICU	DPC, HW prior	Moist swab	94	—	—	—	—	7.4%	Low
Opal et al,[64] 1990	United States	Cross-sectional	Inpatient	DPC	Agar direct contact	242	9.5%	—	—	—	—	Low
Darouiche et al,[86] 1991	United States	Pre-post	Ward	NS	Swab	45	6.7%	—	—	—	—	Low
Larson et al,[53] 1992	United States	Cross-sectional	NF	DPC, HW prior	Juice glove	79	3.8%	—	0%	—	—	Low
Lee et al,[54] 1994	United States	Cross-sectional	NF	DPC	Juice glove	41	2.4%	—	—	—	–	Low
Namura et al,[61] 1995	Japan	Cross-sectional	Ward	NS	Subungal scraping	56	5.4%	—	—	—	–	Low
Bonilla et al,[40] 1997	United States	Cross-sectional	Inpatient	DPC	Juice glove	123	—	29.3%	—	—	—	Low
Suh et al,[73] 1998	Korea	Cross-sectional	Ward	NS	Swab	60	8.3%	—	—	—	—	Low
Aravind et al,[38] 2000	India	Cross-sectional	Ward	NS	Swab	36	27.8%	—	—	—	—	Low
Corona-Nakamura et al,[45] 2001	Mexico	Cross-sectional	ICU	NS	Juice glove	47	—	—	—	6.4%	—	Low
Nogueras et al,[62] 2001	Argentina	Cross-sectional	Inpatient	DPC	Agar direct contact	100	4.0%	—	—	3.0%	2.0%	Low
Bayuga et al,[39] 2002	United States	Cross-sectional	ICU/NH	DPC, HW prior	Juice glove	184	—	—	—	—	2.9%/4.3%	Low
Goyal et al,[50] 2002	India	Cross-sectional	Inpatient	NS	Moist swab	150	4.7%	—	—	—	—	Low
Cespedes et al,[42] 2002	United States	Cross-sectional	Ward	NS	Agar direct contact	193	0.5%	—	—	—	—	Low
Mody et al,[88] 2003	United States	Pre-post	NF	NS	Juice glove	44	—	9.1%	—	—	—	Low
Tammelin et al,[77] 2003	Sweden	Cross-sectional	ICU/Ward	DPC	Agar direct contact	133	0%/0%	—	—	—	—	Low
Dancer et al,[46] 2006	Scotland	Cross-sectional	ICU	NS	Agar direct contact	18	0%	—	—	—	—	Low
Hayden et al,[87] 2006	United States	Pre-post	ICU	DPC	Juice glove	94	—	55.3%	—	—	—	Low
Vernon et al,[95] 2006	United States	Nonrandomized single arm	ICU	Exit from patient room	Juice glove	86	—	16.3%	—	—	—	Low
Wilson et al,[82] 2007	United Kingdom	Cross-sectional	ICU	DPC	Agar direct contact	175	3.4%	—	—	—	—	Low
Rogues et al,[69] 2007	France	Cross-sectional	ICU	DPC	Juice glove	127	—	—	—	5.5%	—	Low
Markogiannakis et al,[59] 2008	Greece	Cross-sectional	ICU	NS	Moist swab	42	—	—	—	—	28.6%	Low
Akpinar et al,[37] 2009	Turkey	Cross-sectional	Inpatient	DPC	Moist swab	66	6.1%	—	—	1.5%	—	Low
Mayank et al,[60] 2009	India	Cross-sectional	ICU	DPC	Agar direct contact	120	—	—	—	28.3%	—	Low
Rocha et al,[68] 2009	Brazil	Cross-sectional	Inpatient	NS	Juice glove	30	3.3%	—	—	—	—	Low
Ulger et al,[80] 2009	Turkey	Cross-sectional	Inpatient	NS	Moist swab	200	10.0%	—	—	—	—	Low
O'Fallon et al,[63] 2009	United States	Cross-sectional	NF	DPC	Agar direct contact	13	0%	0%	—	—	—	Low
Creamer et al,[85] 2010	Ireland	Pre-post	Ward	DPC	Agar direct contact	264	4.5%	—	—	—	—	Low
Eksi et al,[48] 2010	Turkey	Cross-sectional	ICU/Ward	NS	Juice glove	124	0%/4.9%	0%/0%	—	2.4%/1.2%	14.3%/2.4%	Low
Talaie et al,[76] 2011	Iran	Cross-sectional	ICU	NS	Moist swab	70	1.4%	—	—	—	—	Low
Khodavaisy et al,[52] 2011	Iran	Cross-sectional	ICU	DPC	Moist swab	40	—	—	—	2.5%	5.0%	Low
Babu et al,[84] 2011	India	Pre-post	Inpatient	NS	Moist swab	20	—	—	—	10.0%	—	Low
Paul et al,[67] 2011	India	Cross-sectional	Ward	At ward entrance	Moist swab	88	—	—	—	2.3%	—	Low
Bearman et al,[91] 2012	United States	Randomized control	ICU	At start and end of shift	Juice glove	31	35.5%	6.5%	—	—	—	High
Kundrapu et al,[93] 2012	United States	Randomized control	Inpatient	NS	NS	38	39.5%		10.7%	—	—	High
Squeri et al,[72] 2012	Italy	Cross-sectional	Inpatient	NS	Agar direct contact	235	0.4%	—	—	—	—	Low
Malini et al,[57] 2012	Bangalore	Cross-sectional	Inpatient	DPC	Moist swab	150	2.0%	—	—	—	—	Low
Mansour et al,[58] 2013	Egypt	Cross-sectional	ICU	DPC	Juice glove	60	—	—	—	8.3%	—	Low
Monistrol et al,[89] 2013	Spain	Pre-post	Ward	DPC, before new patient	Juice glove	89	2.2%	—	—	21.3%	—	Low
Tan et al,[78] 2013	Singapore	Cross-sectional	Ward	DPC	Juice glove	75	5.3%	1.3%	—	—	1.3%	Low
Gaikwad et al,[94] 2013	India	Nonrandomized control	Inpatient	DPC	Moist swab	98	16.3%	—	—	2.0%	—	Low
Gebreyesus,[49] 2013	Ethiopia	Cross-sectional	Inpatient	NS	Swab	177	6.2%	—	—	—	—	Low
Rosenthal et al,[70] 2014	United States	Cross-sectional	ICU	DPC	Juice glove	102	3.9%	—	—	—	—	Low
Mahalingam et al,[55] 2014	Sri Lanka	Cross-sectional	ICU/Ward	NS	Moist swab	88	0%/15.5%	—	—	—	—	Low
Paduszyńska et al,[65] 2014	Poland	Cross-sectional	Inpatient	During MD rounds	Swab	25	8.0%	—	—	—	8.0%	Low
Pal et al,[66] 2015	India	Cross-sectional	Inpatient	NS	Moist swab	286	0.3%	—	—	0.0%	11.2%	Low
Shi et al,[71] 2015	China	Cross-sectional	ICU/Ward	NS	Agar direct contact	112	0%/0%	—	—	—	—	Low
Tomas et al,[90] 2015	United States	Pre-post	Inpatient	DPC	Moist swab	84	—	—	2.4%	—	—	Low
Ho et al,[92] 2015	Singapore	Randomized control	Ward	DPC	Juice glove	120	6.7%	—	—	—	—	Low

(*continued on next page*)

Table 1 (*Continued*)

Study, year	Country	Study design	Care setting	HCP activity when sampled	Sample collection method	Total samples (n)	MDRO prevalence					Risk of bias
							MRSA	VRE	*Clostridium difficile*	*Pseudomonas aeruginosa*	*Acinetobacter baumannii*	
Drago et al,[47] 2015	Italy	Cross-sectional	Ward	NS	Swab	52	1.9%	—	—	—	—	Low
Tajeddin et al,[75] 2016	Iran	Cross-sectional	ICU	DPC	Swab	762	3.7%	—	—	0%	1.4%	Low
Visalachy et al,[81] 2016	India	Cross-sectional	Inpatient	DPC	Juice glove	157	1.3%	—	—	2.5%	0.6%	Low
Castro et al,[41] 2016	Portugal	Cross-sectional	Inpatient	NS	Moist swab	169	4.7%	—	—	—	—	Low
Colburn et al,[44] 2016	United States	Cross-sectional	Ward	DPC	Agar direct contact	202	6.4%	—	—	—	—	Low
Sun et al,[74] 2016	China	Cross-sectional	Ward	NS	Moist swab	265	—	—	—	12.8%	—	Low
Tselebonis et al,[79] 2016	Greece	Cross-sectional	Inpatient	DPC	Juice glove	125	1.6%	—	—	—	23.2%	Low
Chang et al,[43] 2017	Taiwan	Cross-sectional	Ward	Between surgeries	Moist swab	72	4.2%	—	—	—	4.2%	Low

DPC, direct patient care; *HW prior*, handwashing immediately prior to sample collection; *ICU*, intensive care unit; *MDRO*, multidrug-resistant organisms; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *NF*, nursing facility; *NS*, not specified; *VRE*, vancomycin-resistant *Enterococcus*.

Gram-positive organisms

(A) MRSA

Forty-two (71.2%) studies tested for MRSA, yielding a pooled prevalence of 4.26% (95% CI, 2.92-5.80)[37,38,41-44,46-51,53-55,57,61-66,68,70-73,75-82,85,86,89,91-94] among 5,288 samples collected across all care settings. Of these, 6 studies reported a 0% prevalence in at least 1 care setting.[46,48,55,63,71,77] Across studies, a high level of heterogeneity was observed in rates of MRSA isolation ($I^2 = 80.7\%$; $P < .001$), with 31 cross-sectional studies showing a pooled prevalence of 3.25% (95% CI, 2.12-4.57) vs 7 non–cross-sectional studies (eg, pre-post, randomized control trial), with a prevalence of 12.49% (95% CI, 5.27-21.98). When grouping by continent, North America showed the highest pooled prevalence of 8.28% (95% CI, 3.54-14.52), followed by Asia (3.96%; 95% CI, 2.08-6.31), and Europe (2.54%; 95% CI, 1.04-4.53) (Fig 3). With respect to sampling method, studies utilizing swabs revealed a prevalence of 6.90% (95% CI, 3.25-11.61), moist swab 4.89% (95% CI, 2.08-8.64), and juice glove 4.48% (95% CI, 2.09-7.55), whereas agar direct contact cultures were positive in 1.55% (95% CI, 0.28-3.51) (Fig 4). One study using subungual scraping and another with an unknown collection method were excluded as no suitable comparators existed.[61,93] When comparing the ICU to the general ward plus mixed inpatient group, MRSA prevalence differed but was not significant (2.20% [95% CI, 0.34-5.12] vs 5.14% [95% CI, 3.40-7.17]).

(B) VRE

Eight (13.6%) studies screened for VRE, with a total of 590 samples collected. This yielded a pooled prevalence of 9.03% (95% CI, 0.74-23.37)[40,48,63,78,87,88,91,95] and a high level of heterogeneity ($I^2 = 95.3\%$, $P < .001$). Two studies reported a 0% prevalence.[48,63] Six studies were conducted in North America[40,63,87,88,91,95] and 2 from Asia.[48,78] Four studies reported findings from the ICU,[48,87,91,95] 2 from general wards,[48,78] 2 from nursing facilities,[63,88] and 1 from the mixed inpatient group.[40] Given the limited number of studies, subgroup analysis was not performed.

(C) C difficile

Four (6.8%) studies reported culturing for the presence of the bacterium *C difficile* (not spores), with a total of 235 samples collected[53,56,90,93] in multiple care settings. Two of 4 studies reported a 0% prevalence[53,56], whereas 2 others reported a prevalence of 10.7%[93] and 2.4%.[90] Three studies were conducted in North America[53,90,93] and 1 in Europe.[56] Two studies were from the mixed inpatient group,[90,93] along with 1 from the general ward[56] and 1 from a nursing facility.[53] Given the limited number of studies, subgroup analysis was not performed.

Gram-negative organisms

(A) P aeruginosa and A baumannii

Seventeen (28.8%) studies tested for *P aeruginosa* on HCP hands, with a total of 2,477 samples collected. A pooled prevalence of 4.59% (95% CI, 1.54-8.89) was observed for this pathogen across these studies,[37,45,48,51,52,58,60,62,66,67,69,74,75,81,84,89,94] with a high level of heterogeneity observed ($I^2 = 93.4\%$; $P < .001$). Two of these studies reported a 0% prevalence.[66,75] Regarding geography, 12 studies were conducted in Asia,[37,48,52,58,60,66,67,74,75,81,84,94] 2 in North America,[45,51] 2 in Europe,[69,89] and 1 in South America.[62] Seven studies reported data from the ICU,[45,48,52,58,60,69,75] 6 from the mixed inpatient group,[37,62,66,81,84,94] 5 from general wards,[48,51,67,74,89] and none from nursing facilities. Subgroup analysis was limited to care setting comparing the ICU vs the general ward plus mixed inpatient group, which showed statistically similar rates of *P aeruginosa* carriage at 5.67% (CI, 0.11-16.75) and 3.93% (CI, 0.92-8.47) on HCP hands, respectively.

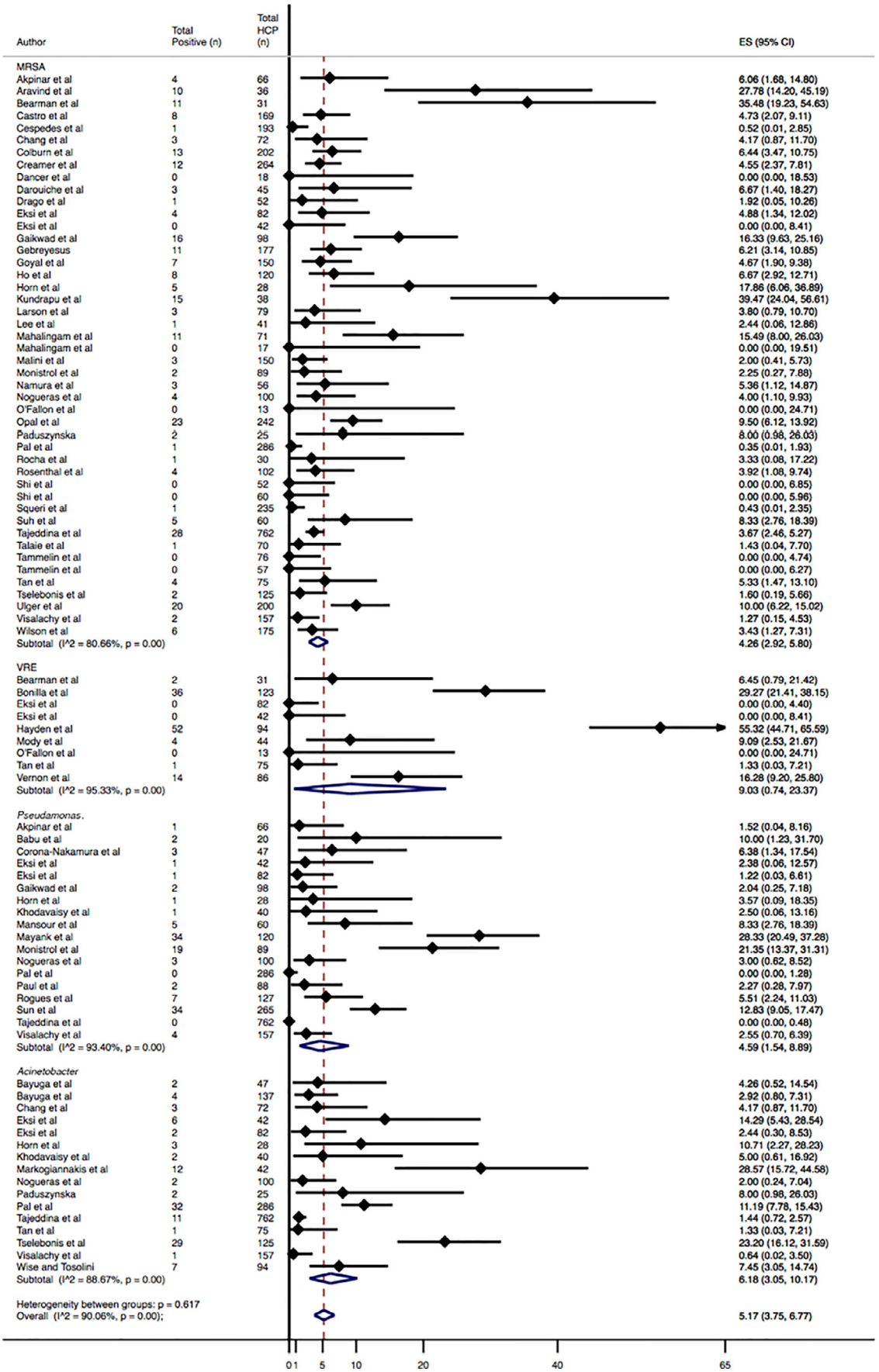

Fig 2. Pooled prevalence of multidrug-resistant organisms on HCP hands by organism. *CI*, confidence interval; *ES*, effect size; *HCP*, health care personnel; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *VRE*, vancomycin-resistant *Enterococcus*.

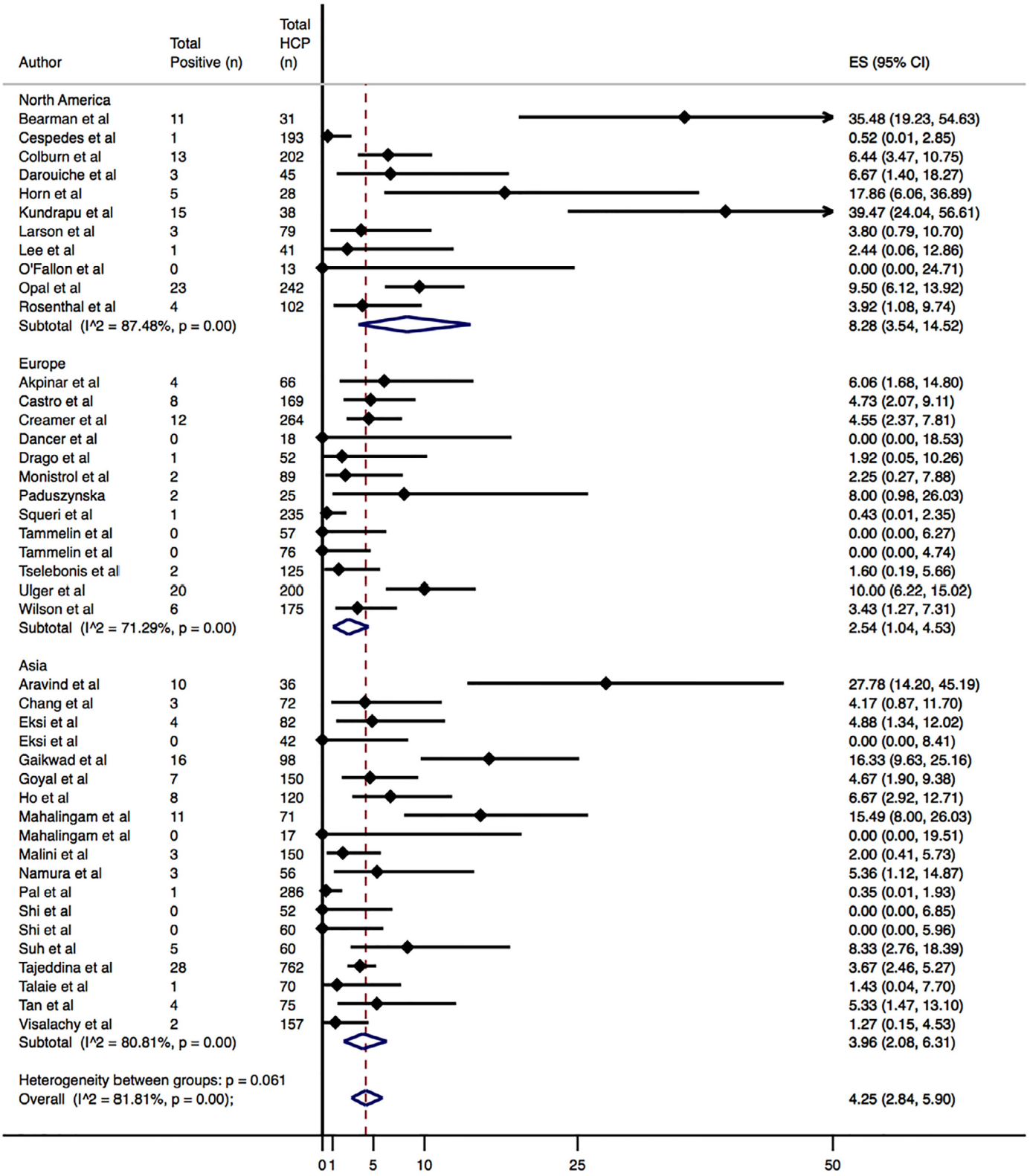

Fig 3. Pooled prevalence of methicillin-resistant *Staphylococcus aureus* on HCP hands by continent. *CI*, confidence interval; *ES*, XXX; *HCP*, health care personnel.

Fourteen (23.7%) studies reported culturing for *A baumannii*, with a total of 2,154 samples collected. Across 14 studies, the pooled prevalence of *A baumannii* was 6.18% (95% CI, 3.05-10.17),[39,43,48,51,52,59,62,65,66,75,78,79,81,83] with a high level of heterogeneity observed ($I^2 = 88.7\%$, $P < .001$). Regarding geography, 7 studies were conducted in Asia,[43,48,52,66,75,78,81] 3 in Europe,[59,65,79] 2 in North America,[39,51] and 1 each in South America[62] and Australia.[83] Six studies reported data from the ICU,[39,48,52,59,75,83] 5 from the mixed inpatient group,[62,65,66,79,81] 4 from the general ward,[43,48,51,78] and 1 from a nursing

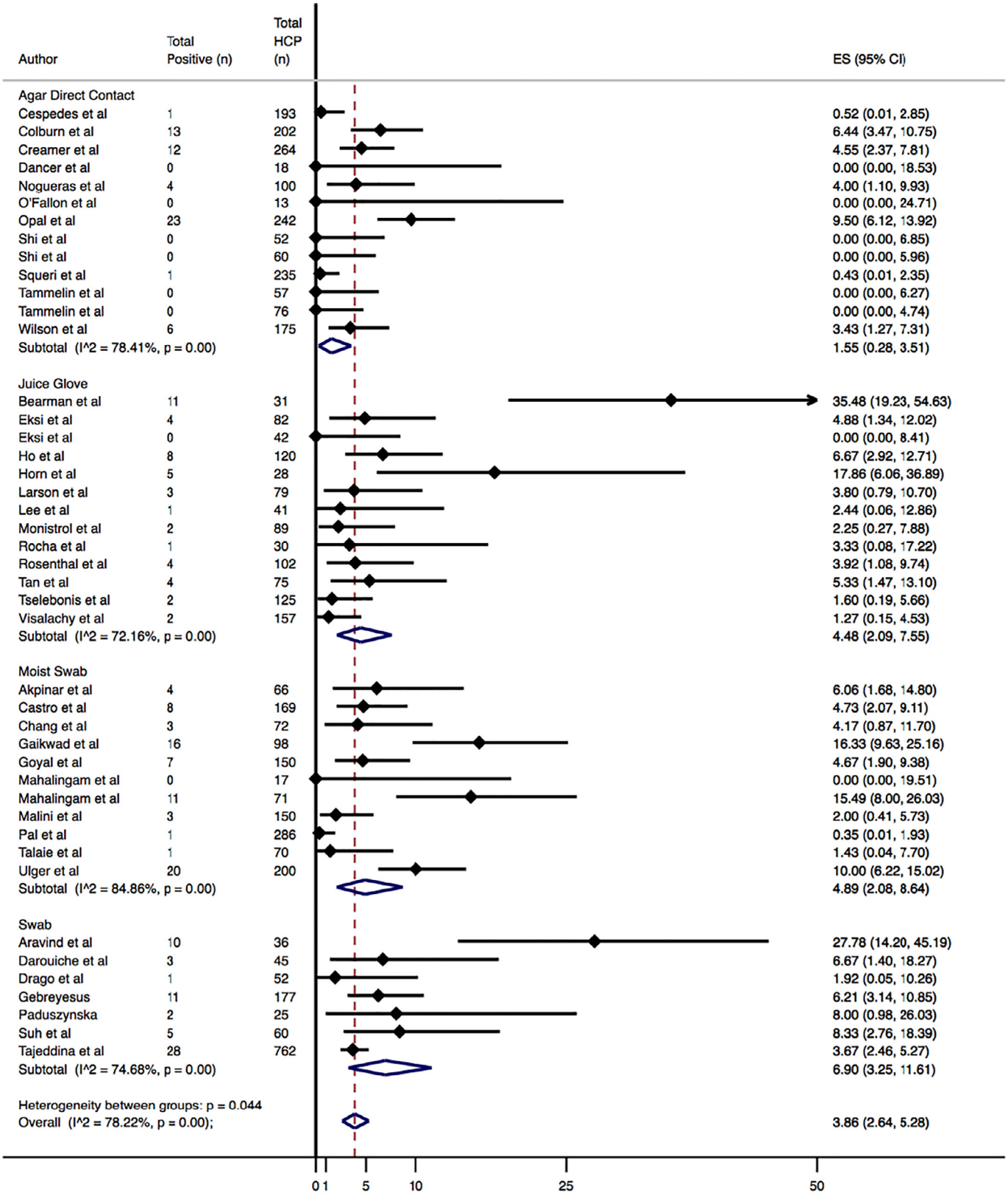

Fig 4. Pooled prevalence of methicillin-resistant *Staphylococcus aureus* on HCP hands grouped by sample collection method. *CI*, confidence interval; *ES*, XXX; *HCP*, health care personnel.

facility.[39] Subgroup analysis was limited to care setting comparing the ICU vs the general ward plus mixed inpatient group, which revealed statistically similar rates of *A baumannii* carriage at 7.52% (95% CI, 2.16-15.37) and 5.60% (95% CI, 1.70-11.22), respectively.

Risk of study bias

Fifty-seven (96.7%) studies were determined to be a low risk for bias using the Newcastle-Ottawa or Cochrane tool, whereas 2 (3.4%) were considered high risk (Table 1). The Cohen κ coefficient for adjudication of study bias, used to measure inter-rater agreement, was 0.90.

CONCLUSIONS

With the increase in prevalence of MDROs within health care facilities, both the complexity and cost of treating HAIs continues to rise.[96] Because HCP hands are often a vector for MDRO transmission, an understanding of the prevalence of various MDROs on HCP hands is critical to understand the risk of transfer, rate of patient MDRO acquisition, and potential for subsequent infection. In this systematic review, we pooled rates of MDRO contamination on HCP hands and found that the pooled prevalence of each organism ranged from 4%-9%.

The global epidemiology of MRSA has been extensively studied and varies considerably by continent.[46,97-100] In the 42 studies included in this review, the highest rates of MRSA were found among those conducted in North America (8.28%), followed by Asia (4.23%), and Europe (2.47%). This observation is not unexpected, given an overall higher prevalence of MRSA among patients in the United States compared to most other countries.[97] However, the finding that this also holds true for HCP hands is novel and important. With further investigation, it may be possible to develop appropriate HCP MDRO contamination thresholds at the facility or unit level, above which targeted infection control efforts could be implemented. This "triggered therapy" approach could potentially balance the cost-effectiveness of targeted interventions and the development of antibiotic resistance with the clinical impact to most efficiently lower the risk of HAI acquisition.

Several methods are used to culture HCP hands, including swabs, agar direct contact, and juice glove, with the latter generally considered the most sensitive sampling method for MRSA.[101] Interestingly, when grouping studies by sample collection method, we found that HCP MRSA rates also varied widely (Fig 4). Agar direct contact had the lowest observed prevalence rate (1.55%), with 4 studies demonstrating 0% prevalence.[46,63,71,77] Conversely, juice glove and swab (including moist swab) collection methods had consistently higher observed rates, ranging from 4.48%-6.90%. This finding is critical to consider when developing future studies or surveillance programs, as the use of direct contact agar, although easier, cheaper, and faster, may not be accurate.

We expected ICU HCP to demonstrate a higher prevalence of *P aeruginosa, A baumannii*, and MRSA, as these organisms are a frequent cause of HAIs in this setting.[98,102] We did, however, observe a slightly higher rate of *P aeruginosa* in the ICU as compared to the inpatient floor group (5.67% vs 3.93%), with a similar trend for *A baumannii* as well (7.52% vs 5.60%). However, rates for MRSA in the ICU were lower than the inpatient group (2.20% vs 5.14%). The reason for this is unclear but may relate to the small number of ICU studies in general (10 ICUs vs 33 inpatient studies). Furthermore, 5 of the 10 ICU studies reported recovery rates of 0%, of which 3[46,71,77] used the agar direct method. Nurse-to-patient ratios have been associated with higher rates of health care–associated infection.[103-105] The number of patients that a HCP interacts with during their tour, as opposed to the intensity of patient care, may be more important to MDRO hand acquisition and subsequent HAI occurrence.

Upon subgroup analysis of studies that sampled for MRSA, significant differences in prevalence rates by study design were observed. For example, cross-sectional studies showed a pooled prevalence of 3.25% compared to 12.49% for all other designs, such as randomized controlled studies, pre-post studies, and nonrandomized arm studies. This finding highlights the influence of study design and measurement (eg, smaller sample size, limitation to a single unit or patient type, repeat culturing of subjects, and culturing over prolonged periods) on outcome rates. Specifically, as cross-sectional studies measure at a specified time, they may underestimate or overestimate true rates of pathogen prevalence.

Our results should be considered in the context of several limitations. First, 19 studies reported only pooled data from the acute care setting, combining samples from general care wards, the ICU, and other inpatient care areas. Although we did identify these separately as "inpatient" in Table 1, and the majority of these results were from general care wards, our ability to elucidate MDRO prevalence rates within different hospital units is limited. Second, grouping by continent may be overly broad, as many included studies were single-center with variability in infection control and hygiene practices, consistent with findings from other studies.[4,8-10,100] Third, we acknowledge that although many studies inferred samples were collected during direct patient care activities, often the circumstances at the time of collection were not explicitly reported, nor was the timing of the last hand hygiene or antiseptic solution used, or the difference in local endemic levels of MDRO, leading to potential variability between studies in the transient bacterial load on HCP hands at the time of sampling. Fourth, as many of the included studies were of the cross-sectional design with sampling at a single point in time, we are unable to determine whether MDROs isolated from a hand culture represent persistent colonization or transient contamination. Whereas our systematic review was robust, only 5 studies were identified pertaining to MDROs in nursing facilities, thus limiting our understanding of prevalence rates in this group. Finally, our review identified results spanning the last 30 years, and it is likely that MDRO prevalence rates have changed over this time period.

We note several strengths. By summarizing results by type of pathogen, care setting, geographic location, and sampling methodology, we are able to identify prevalence trends in specific groups helping to inform future work in the field. Additionally, inclusion of diverse important MDROs in multiple care settings provides new and important findings. Our study included a thorough search of the literature by a reference librarian using robust methodology, and although the literature on prevalence of MDROs in nares, wounds, and environmental sites is well published, to our knowledge, this is the first comprehensive systematic review and meta-analyses of MDRO prevalence on HCP hands.

We conclude that HCP hands are frequently contaminated with various MDROs across all care settings. The rates of HCP contamination appear to vary not only by continent, but are also influenced by patient contamination, culture methods, and study design. In the future, thoughtful standardization of population selection, study design, and collection methods is critical, as it would allow a more detailed, broadly applicable analysis of MDRO trends over time.

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