2015

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Antimicrobial Susceptibility Profiles of *Staphylococcus aureus* Isolates Recovered from Humans, Environmental Surfaces, and Companion Animals in Households of Children with Community-Onset Methicillin-Resistant *S. aureus* Infections

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Our objective was to determine the antibiotic susceptibility profiles of *Staphylococcus aureus* isolates recovered from 110 households of children with community-onset methicillin-resistant *S. aureus* (MRSA) infections. Cultures were obtained from household members, household objects, and dogs and cats, yielding 1,633 *S. aureus* isolates. The *S. aureus* isolates were heterogeneous, although more than half were methicillin resistant. The highest proportion of MRSA was found in bathrooms. The majority of isolates were susceptible to antibiotics prescribed in outpatient settings.

Antimicrobial-resistant bacterial infections are a global problem (1–3). Few studies have described the antimicrobial resistance profiles of *Staphylococcus aureus* strains in the community, specifically in household environments (4, 5). Household vectors, including humans, environmental fomites, and companion animals, may serve as reservoirs for methicillin-resistant *S. aureus* (MRSA) transmission (5–7). We describe here the antibiotic susceptibility patterns of *S. aureus* isolates recovered from these household vectors. Understanding the antibacterial resistance profiles of *S. aureus* strains in the environment may inform empirical antibiotic selection in clinical settings.

Following approval from the Washington University human and animal institutional review boards, pediatric patients (n = 110) with community-onset MRSA infections and their household contacts (n = 388) were enrolled through St. Louis Children's Hospital (SLCH) and community pediatric practices from January 2013 to May 2014, as previously described (4). Study visits were conducted in the participants' homes, occurring up to 10 times over 24 months at 3-month intervals. During each visit, cultures were obtained from the axillae, anterior nares, and inguinal folds (ESwabs; Becton Dickinson, Franklin Lakes, NJ) from all consenting household members, up to 21 frequently touched standardized household objects (Table 1; ESwabs and Baird-Parker agar contact plates; Hardy, Santa Maria, CA) (4, 8), and the anterior nares and dorsal fur of indoor dogs and cats (BBL CultureSwab liquid Amies, regular aluminum wire; Becton Dickinson).

In accordance with Clinical and Laboratory Standards Institute (CLSI) guidelines for creating a cumulative antibiogram report (9), the first *S. aureus* isolate recovered from each pet, household object, or body site of each household member was included in the analysis. Antibiotic susceptibility testing (Table 1) of *S. aureus* isolates was performed by Kirby-Bauer disk diffusion (10, 11). High-level mupirocin resistance was confirmed by the detection of *mupA* (12). Isolates with intermediate susceptibility were categorized as resistant (11). MRSA isolates resistant to β-lactams plus three additional systemic antimicrobial classes (i.e., excluding mupirocin) were classified as multidrug resistant (MDR4) (13, 14).

Statistical analysis was conducted with SPSS 22 for Windows (IBM SPSS, Chicago, IL). Isolate susceptibilities were compared between human, pet, and environmental isolates using the Fisher's exact or chi-square test. P values of <0.05 were considered significant.

As summarized in Table 1, 1,633 unique *S. aureus* isolates were characterized, including 770 human isolates (47%) (110 from sites of infection and 660 from sites of colonization), 815 environmental isolates (50%), and 48 companion animal isolates (3%) (39 from dogs and 9 from cats). Overall, 52% of the *S. aureus* isolates recovered from household environmental surfaces were methicillin resistant, as were 52% of the human colonization isolates (index patients and household contacts), and 63% of the pet colonization isolates. All isolates were susceptible to trimethoprim-sulfamethoxazole, linezolid, ceftaroline, and rifampin, while the majority of isolates were susceptible to clindamycin, tetracycline, and mupirocin (Table 1). Overall, multidrug resistance (MDR4) was low, comprising 4% of all recovered *S. aureus* isolates.

S. aureus isolates recovered from index patient infection cultures had a higher prevalence of erythromycin (83%) and ciprofloxacin (58%) resistance than that of isolates recovered from index patient colonization sites (54%, $P < 0.001$, and 33%, $P < 0.001$, respectively). Index patient-infecting isolates trended to possess a higher prevalence of MDR4 than that of their colonizing isolates (9% versus 3%, $P = 0.07$). There were no significant dif-

Received 25 June 2015 Returned for modification 15 July 2015
Accepted 20 July 2015
Accepted manuscript posted online 27 July 2015
Citation Morelli JJ, Hogan PG, Sullivan ML, Muenks CE, Wang JW, Thompson RM, Burnham C-AD, Fritz SA. 2015. Antimicrobial susceptibility profiles of *Staphylococcus aureus* isolates recovered from humans, environmental surfaces, and companion animals in households of children with community-onset methicillin-resistant *S. aureus* infections. Antimicrob Agents Chemother 59:6634–6637. doi:10.1128/AAC.01492-15.
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doi:10.1128/AAC.01492-15

TABLE 1 Antimicrobial susceptibility profiles of *S. aureus* isolates recovered from households of children with community-onset MRSA infection

Location from which isolate was recovered	No. of *S. aureus* isolates tested	% susceptible[a]										% MDR4[d]
		MET[b]	CLI[c]	ERY	SXT	RIF	TET	CIP	LZD	CPT	MUP	
Overall	1,633	45	90	47	100	100	98	68	100	100	96	4
People	770	42	90	44	100	100	98	65	100	100	96	4
Index patient	263	26	91	34	100	100	99	58	100	100	95	5
Infection	110[e]	0[f]	94	17	100	100	99	42	100	100	98	9
Colonization	153	44	89	46	100	100	99	67	100	100	94	3
Anterior nares	61	48	89	53	100	100	100	67	100	100	97	3
Axillae	31	42	90	48	100	100	100	61	100	100	87	0
Inguinal folds	61	41	89	39	100	100	98	69	100	100	95	3
Household contact colonization[g]	507	50	89	49	100	100	98	68	100	100	96	4
Anterior nares	228	55	90	52	100	100	99	69	100	100	97	4
Axillae	110	44	90	46	100	100	99	69	100	100	95	5
Inguinal folds	169	47	88	47	100	100	96	67	100	100	95	4
Adult household contact colonization	278	49	88	45	100	100	97	67	100	100	95	4
Anterior nares	120	56	88	48	100	100	98	69	100	100	96	3
Axillae	62	42	90	40	100	100	98	69	100	100	95	3
Inguinal folds	96	46	85	44	100	100	95	63	100	100	93	5
Child household contact colonization	229	51	91	55	100	100	99	69	100	100	97	4
Anterior nares	108	55	91	57	100	100	99	69	100	100	99	5
Axillae	48	46	90	52	100	100	100	67	100	100	94	6
Inguinal folds	73	48	92	52	100	100	99	73	100	100	97	3
Pets	48	38	85	48	100	100	100	69	100	100	96	8
Dog	39	41	87	56	100	100	100	74	100	100	100	8
Anterior nares	16	38	88	69	100	100	100	81	100	100	100	6
Dorsal fur	23	44	87	48	100	100	100	70	100	100	100	9
Cat	9	22	78	11	100	100	100	44	100	100	78	11
Anterior nares	4	25	75	25	100	100	100	25	100	100	75	25
Dorsal fur	5	20	80	0	100	100	100	60	100	100	80	0
Environment	815	48	90	50	100	100	98	71	100	100	97	3
Living room	166	44	88	52	100	100	99	69	100	100	97	4
TV remote control	52	42	90	44	100	100	98	67	100	100	96	4
Telephone	36	36	92	53	100	100	100	71	100	100	97	0
Computer keyboard and mouse	37	51	87	62	100	100	100	73	100	100	97	5
Video game controller	41	46	83	54	100	100	98	66	100	100	98	5
Bathroom	404	50	90	49	100	100	98	72	100	100	98	2
Sink faucet handle	43	49	86	49	100	100	98	67	100	100	98	5
Hand towel	22	32	86	41	100	100	100	62	100	100	96	5
Index bath towel	27	63	93	59	100	100	100	78	100	100	100	0
Toilet handle	33	58	88	55	100	100	94	79	100	100	100	0
Door handle	32	47	91	41	100	100	100	63	100	100	97	0
Light switch	39	49	92	49	100	100	100	64	100	100	100	5
Sink	52	48	94	54	100	100	100	75	100	100	98	0
Bathtub or shower	44	50	89	46	100	100	96	82	100	100	98	2
Soap bar or dish in bathtub or shower	17	29	82	29	100	100	88	65	100	100	100	6
Toilet seat	47	60	89	55	100	100	98	81	100	100	100	0
Countertop	48	48	92	46	100	100	96	70	100	100	96	2
Kitchen	190	49	91	52	100	100	99	71	100	100	95	3
Hand towel	22	55	91	50	100	100	100	68	100	100	96	0
Sink faucet handle	35	46	97	60	100	100	100	66	100	100	94	3
Sponge/cloth	32	47	94	59	100	100	100	75	100	100	94	3
Refrigerator door handle	55	47	86	49	100	100	100	71	100	100	95	6
Kitchen table	46	52	91	44	100	100	98	74	100	100	96	0
Bedroom	55	40	89	46	100	100	98	64	100	100	95	4
Bed sheets and pillowcase	55	40	89	46	100	100	98	64	100	100	95	4

[a] MET, methicillin; CLI, clindamycin; ERY, erythromycin; SXT, trimethoprim-sulfamethoxazole; RIF, rifampin; TET, tetracycline; CIP, ciprofloxacin; LZD, linezolid; CPT, ceftaroline; MUP, mupirocin.

[b] As predicted by cefoxitin testing.

[c] Clindamycin-susceptible isolates exhibiting inducible clindamycin resistance ($n = 144$) were considered clindamycin resistant.

[d] Multidrug resistance (MDR4) here was defined as β-lactam resistance plus resistance to three additional systemic antimicrobial drug classes (i.e., excluding mupirocin).

[e] Some infection isolates were unable to be obtained by the study team and are thus missing various susceptibility data; therefore, % susceptibility is out of <110 for RIF ($n = 84$), CIP ($n = 85$), LZD ($n = 76$), CPT ($n = 64$), and MUP ($n = 64$).

[f] Study entry criteria specified a MRSA infection.

[g] Does not include the isolates recovered from index patients.

ferences in antibiotic susceptibility between colonizing isolates recovered from index patients and those from household contacts.

The household environmental surfaces with the highest prevalence of MRSA isolates were the soap bar/dish in the bathtub/shower (71%), bathroom hand towel (68%), and telephone (64%). MDR4 isolates were most commonly recovered from the soap bar/dish in the bathtub/shower (6%), refrigerator door handle (6%), computer keyboard/mouse (5%), and bathroom light switch (5%). There were no significant differences in antibiotic susceptibilities in a comparison of isolates recovered from different areas of the home, e.g., the living room, bathroom, kitchen, and bedroom.

The overall number of *S. aureus* isolates recovered from pets was relatively small ($n = 48$), although these isolates were most frequently methicillin resistant (63%) compared to isolates recovered from human (58%) or environmental sources (52%; $P = 0.03$). Companion animal isolates also had the highest prevalence of MDR4 (8%) compared to that of human (4%) or environmental isolates (3%; $P = 0.04$). Resistance to erythromycin and mupirocin was higher in isolates recovered from cats than that in dogs (89% versus 44%, $P = 0.02$, and 22% versus 0%, $P = 0.03$, respectively).

In this study of antimicrobial susceptibility patterns of *S. aureus* isolated from household vectors, more than half of the recovered isolates were MRSA; of note, the majority of isolates were susceptible to systemic antibiotics commonly prescribed for *S. aureus* infections in outpatient settings (15) and were universally susceptible to the newer antimicrobials linezolid and ceftaroline (16, 17). Interestingly, 5% of the isolates recovered from index patients were mupirocin resistant, which is higher than findings of a prior study by our group conducted from 2007 to 2009, in which 2% (50 of 2,425) of the *S. aureus* isolates collected from a similar patient population were mupirocin resistant (12).

Environmental surfaces may serve as reservoirs for MRSA transmission within households. In this study, the soap bar/dish, bathroom hand towel, and telephone possessed the highest prevalence of MRSA. Additionally, MDR4 strains were commonly recovered from the refrigerator door handle, computer keyboard/mouse, and bathroom light switch. Similar to other studies, these findings may reflect the high frequency of contact with these surfaces by a variety of household members, compared to surfaces likely to be unique to the index patient (e.g., bed linens or bath towels) (5, 18). In our population, a high proportion of strains recovered from pet dogs and cats were MRSA, consistent with a notable increase in the prevalence of antibiotic-resistant staphylococcal strains in companion animals over the past decade (19, 20).

The present study analyzed a broad range of antimicrobial susceptibility profiles of *S. aureus* isolates from households of children with MRSA infections. The strengths of this study include the large number of isolates collected and the breadth, standardization, and longitudinal sampling of humans, household environments, and companion animals. Although the isolates are from a single metropolitan area, the households represent a diverse geographic (121-mi diameter) and sociodemographic catchment. A limitation is that several sampled sites (cats and various environmental surfaces) did not provide the minimum number ($n = 30$) of isolates necessary to audit an antibiogram profile (11), which may provide a limited picture of antimicrobial trends.

In conclusion, we observed a heterogeneous population of *S. aureus* isolates in households of children with MRSA infections. As personal *S. aureus* colonization and the colonization of household contacts and environmental surfaces are putative reservoirs for subsequent infection, we are encouraged by the fact that the majority of isolates were susceptible to commonly prescribed antibiotics used for community-onset *S. aureus* infection.

ACKNOWLEDGMENTS

We thank Meghan Wallace for contributing her technical expertise. We thank Rachel Orscheln, Lisa Robertson, Mary Boyle, Madeline Martin, Jennifer Seigel, and the SLCH pediatric ambulatory wound service for their assistance in patient recruitment and Jane Garbutt and the physicians and staff of the participating Washington University Pediatric and Adolescent Ambulatory Research Consortium practices, including Mercy Pediatrics-Union and Washington, Johnson Pediatric Center, Heartland Pediatrics, Forest Park Pediatrics, Tots Through Teens, Pediatric Healthcare Unlimited, Northwest Pediatrics-St. Charles, Fenton Pediatrics, LLC, and Southwest Pediatrics. We thank the SLCH clinical microbiology laboratory technologists for procuring clinical isolates from the participants. We also thank Michael Talcott and Mary Ellenberger for providing training in animal culturing and Victoria Fraser and Sarah Gehlert for assistance with study design. These individuals and entities did not receive compensation (financial or otherwise) for their contributions.

Funding for this project was provided by the Children's Discovery Institute of Washington University and St. Louis Children's Hospital, National Institutes of Health grants K23-AI091690, KL2-RR024994, and UL1-TR000448, and grant R01-HS021736 from the Agency for Healthcare Research and Quality.

The content of this article is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Agency for Healthcare Research and Quality.

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