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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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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

John J. Morelli,*a* Patrick G. Hogan,*a* Melanie L. Sullivan,*a* Carol E. Muenks,*a* Jeffrey W. Wang,*a* Ryley M. Thompson,*a* Carey-Ann D. Burnham,*a,b* Stephanie A. Fritz*a*

Departments of Pediatrics* and Pathology & Immunology;* Washington University School of Medicine, St. Louis, Missouri, USA

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 tended to possess a higher prevalence of MDR4 than that of their colonizing isolates (9% versus 3%, *P* = 0.07). There were no significant dif-
### TABLE 1 Antimicrobial susceptibility profiles of S. aureus isolates recovered from households of children with community-onset MRSA infection

<table>
<thead>
<tr>
<th>Location from which isolate was recovered</th>
<th>No. of S. aureus isolates tested</th>
<th>% susceptible&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MET&lt;sup&gt;b&lt;/sup&gt;</th>
<th>CLI&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ERY</th>
<th>SXT</th>
<th>RIF</th>
<th>TET</th>
<th>CIP</th>
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<th>MDR4&lt;sup&gt;d&lt;/sup&gt;</th>
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<sup>a</sup> MET, methicillin; CLI, clindamycin; ERY, erythromycin; SXT, trimethoprim-sulfamethoxazole; RIF, rifampin; TET, tetracycline; CIP, ciprofloxacin; LZD, linezolid; CPT, ceftaroline; MUP, mupirocin.

<sup>b</sup> As predicted by cefoxitin testing.

<sup>c</sup> Clindamycin-susceptible isolates exhibiting inducible clindamycin resistance (<i>n</i> = 144) were considered clindamycin resistant.

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

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

<sup>f</sup> Study entry criteria specified a MRSA infection.

<sup>g</sup> Does not include the isolates recovered from index patients.

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ferences in antibiotic susceptibility between colonizing isolates re-
covered from index patients and those from household contacts.

The household environmental surfaces with the highest prev-
ance 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 han-
dle (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 differ-
ent 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 recov-
ered 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 environmen-
tal isolates (3%; P = 0.04). Resistance to erythromycin and mupi-
rocin was higher in isolates recovered from cats than that in dogs
(89% versus 44%, P = 0.02, and 22% versus 0%, P = 0.03, respec-
tively).

In this study of antimicrobial susceptibility patterns of S. au-
reus isolated from household vectors, more than half of the recov-
ered isolates were MRSA; of note, the majority of isolates were
susceptible to systemic antibiotics commonly prescribed for S. au-
reus 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 trans-
mission within households. In this study, the soap bar/dish, bath-
room hand towel, and telephone possessed the highest prev-
ance of MRSA. Additionally, MDR4 strains were commonly re-
covered 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 sur-
faces likely to be unique to the index patient (e.g., bed linens or
bathtowels) (5, 18). In our population, a high proportion of
strains recovered from pet dogs and cats were MRSA, consist-
tent 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 sus-
ceptibility profiles of S. aureus isolates from households of chil-
dren with MRSA infections. The strengths of this study include
the large number of isolates collected and the breadth, standardiza-
tion, and longitudinal sampling of humans, household environ-
ments, and companion animals. Although the isolates are from a
single metropolitan area, the households represent a diverse geo-
graphic (121-mi diameter) and sociodemographic catchment. A
limitation is that several sampled sites (cats and various environ-
mental 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 house-
hold 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 anti-
biotics used for community-onset S. aureus infection.

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