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Prevalence of *Staphylococcus aureus* carriage among dogs and their owners

M. V. BOOST[1]*, M. M. O'DONOGHUE[2] AND A. JAMES[3]

[1] *Department of Health Technology & Informatics, The Hong Kong Polytechnic University, Hong Kong*
[2] *School of Nursing, The Hong Kong Polytechnic University, Hong Kong*
[3] *Director of the Animal Unit, Chinese University of Hong Kong, Hong Kong*

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SUMMARY

Case reports have indicated transmission of *Staphylococcus aureus* between humans and pets. We investigated associations between level of contact between dog and owner, and *S. aureus* colonization. In a cross-sectional study, nasal carriage and antibiotic susceptibility of *S. aureus* was determined for 830 dogs and 736 owners. Relatedness of isolates was investigated using antibiograms and pulsed-field gel electrophoresis (PFGE). Associations between carriage and demographics or amount of contact between owners and dogs were documented. *S. aureus* was isolated in 24% of humans and 8·8% of dogs. Antibiotic resistance was significantly more common in canine isolates. Of 17 owner/dog colonized pairs, six were indistinguishable by PFGE. Colonization of dogs was not associated with close human contact, but was strongly associated with health-care occupations (OR 3·29, 95% CI 1·49–7·26, $P=0·002$). In outbreak situations health-care workers' pets should be considered as a source of *S. aureus*. High rates of resistance indicate increased monitoring of antibiotic use in veterinary practice is needed.

INTRODUCTION

About 25% of humans carry *Staphylococcus aureus* in the nasal cavities, which act as both its major reservoir, and the most important source for infection [1]. Carriage of *S. aureus* is influenced by genetic and environmental factors, including cell-wall lipotechoic acid, hormonal status, and antimicrobial activity of nasal secretions [2]. The pathogenicity of *S. aureus* has been exacerbated by increased resistance to antibiotics, and methicillin-resistant *S. aureus* (MRSA), encoded for by the *mec*A gene, is associated with increased morbidity and mortality compared to methicillin-sensitive *S. aureus* (MSSA) [3]. Previously MRSA was largely confined to health-care settings and its acquisition associated with established risk factors [4]. More recently, it has spread into the community (community-associated MRSA, CA-MRSA), and been implicated in reports of severe infections in otherwise healthy persons [5–7]. Exposure to health care, including surgery, immunosuppression, antibiotic use, and long-term hospitalization, and health-care workers (HCWs) is recognized as a risk factor for hospital-associated MRSA colonization [6, 8, 9], but further work is required to identify reservoirs for CA-MRSA in the community, and their importance as a source of strains imported into the hospital.

Although case reports of human infection or colonization from companion animals [10–14] have

* Author for correspondence: Dr M. V. Boost, Associate Professor, Department of Health Technology and Informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.
(Email: htmboost@polyu.edu.hk)
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shown the potential of animals to act as reservoirs for transmission of MRSA [15], there appear to be no published reports on the prevalence of carriage of *S. aureus* in owners and their dogs. Reported rates of canine carriage vary widely, but higher levels reported in early studies may be due to the inability to distinguish between *S. aureus* and *S. intermedius*, the staphylococcal species most frequently isolated from dogs [15, 16]. Although $<10\%$ of dogs may carry *S. aureus* [15], canine infections with MRSA have been reported [17, 18]. Increasing concern about MRSA in the community has led to recommendations for surveillance, including carriage rates in healthy dogs and cats [15]. *S. aureus* has been isolated from several sites on dogs, including the anterior nares, skin and anal region, although most studies of carriage sites have focused on *S. intermedius* [19, 20]. It has been suggested that staphylococci are transferred from the nose and mouth of the dog to its coat by grooming and pruritic behaviours, and studies have reported *S. aureus* in the nares of dogs colonized at other sites [10, 19]. In case reports of transmission, the dog's nares is the most frequently identified site of colonization when cultures from several sites are performed [10]. It has been suggested that antibiotic resistance is more frequent in canine isolates of *S. aureus* [21], but this has not been demonstrated in paired dogs and owners.

This study, which is the first to determine the frequency of nasal colonization in healthy dogs and their owners, also investigated the antibiotic resistance patterns of isolates, and strain relatedness between isolates recovered from owners and their dogs. A small subset of stray dogs were examined to compare carriage in dogs with minimal human contact. Risk factors for carriage, including the extent of contact with the dog, were examined. As levels of MRSA carriage in the community remain low [6], levels of colonization with both MSSA and MRSA were recorded.

METHODS

Subjects

A cross-sectional study of nasal colonization of dogs and their owners with *S. aureus* was performed. Adult owners of dogs kept as companion animals and their dogs were recruited at seven veterinary practices over a 6-week period. All owners were invited to participate but, as the study focused on carriage rather than infection, seriously ill dogs, and those with obvious infections were excluded. Most owners were willing for samples to be collected from both themselves and their dogs, with a small number restricting permission to collection only from their dog. The sample size of 800 was based on a carriage level of 25% in adult humans [6], and an assumed 25% carriage frequency in dogs belonging to colonized subjects with a 2% error. For comparison of carriage levels in dogs with limited human contact, 30 stray dogs were sampled for nasal colonization. These dogs had been captured by the Society for Prevention of Cruelty to Animals for de-sexing and release.

Specimen collection

Owners were given clear spoken and written instructions, including a diagram, for self-collection of nasal swabs which involved inserting a sterile swab moistened with normal saline, into the nares and gently rotating it to make contact with the nasal septum. As the nostrils of dogs are smaller and more sensitive, veterinarians inserted smaller swabs to a distance of about 0·5–1 cm. All swabs were placed in transport medium and stored at 4 °C until culture within 8 h of collection. Owners completed a questionnaire about owner and dog, amount of contact with their dog, and antibiotic use in the dog within the last 3 months.

Laboratory investigation

Swabs were inoculated onto Columbia agar with 5% horse blood (BA), and mannitol salt agar (MSA), and finally placed into cooked meat broth with 5% salt (all media were purchased from Oxoid Ltd, Basingstoke, UK) for enrichment culture, which was subcultured onto BA and MSA after 48 h incubation at 37 °C in ambient air. Plates were examined after 48 h and colonies resembling staphylococci were tested with the Murex Staphaurex test (Murex Biotech Ltd, Dartford, UK) for presence of clumping factor. Positives were differentiated from other coagulase-positive staphylococci, including *S. intermedius* and *S. schleiferi*, by tube coagulase, pigment production on BA, acetoin production, polymyxin resistance [zone size <10 mm with a 300 U polymyxin B disc (Oxoid)], ortho-nitrophenyl-b-D-galactopyranoside breakdown, and trehalose and mannitol fermentation [22]. At least five colonies of each isolate were screened for resistance to methicillin by culture on oxacillin-resistance screening agar (ORSAB). Susceptibility to penicillin G (10 U), oxacillin (1 μg), cefoxitin (30 μg), moxalactam (30 μg), tetracycline

Table 1. *Isolation of* S. aureus *from owners and their dogs at various veterinary clinics*

Veterinary practice	No. of owner samples	*S. aureus* positive (%)	No. of dog samples	*S. aureus* positive (%)
A	107	25 (23·4)	127	9 (7·1)
B	123	39 (31·7)	135	15 (11·1)
C	228	45 (19·7)	242	23 (9·5)
D	102	24 (19·7)	108	9 (8·3)
E	135	35 (25·9)	140	8 (5·7)
F	13	2 (15·4)	50	7 (14)
G	28	4 (14·3)	28	2 (7·1)
Total	736	174 (23·6)	830	73 (8·8)

Locations of veterinary clinics: A, Shatin; B, Hong Kong; C, Kowloon; D, Kowloon; E, Hong Kong; F, Sai Kung; G, Tai Wai.

(30 μg), erythromycin (15 μg), fusidic acid (10 μg), gentamicin (10 μg), vancomycin (30 μg), clindamycin (2 μg), ciprofloxacin (5 μg), rifampicin (5 μg), chloramphenicol (30 μg) and trimethoprim–sulphamethoxazole (1·25/23·75 μg) (Oxoid) was determined by disc diffusion following Clinical and Laboratory Standards Institute guidelines [23], except for fusidic acid, when British Society for Antimicrobial Chemotherapy guidelines were used [24]. Methicillin resistance was confirmed by detection of *mec*A using PCR [25]. If *S. aureus* was isolated from both owner and dog and the antimicrobial susceptibility patterns differed by more than two antibiotic susceptibilites, isolates were typed by pulsed-field gel electrophoresis (PFGE) [26], using *Sma*I digestion of the bacterial DNA. Chromosomal relatedness was determined by comparison of the banding patterns of the resulting fragments on an agarose gel [27]. PFGE typing was also performed on MRSA isolates from dogs or their owners attending the same clinic.

Ethical considerations

Ethical approval was obtained from the Human Subjects and the Animal Subjects Ethics Committees of The Hong Kong Polytechnic University confirming that the research was in accordance with the Helsinki Declaration. Owners were given an information sheet about the study and asked to sign consent forms.

Statistical analysis

Prevalence of canine and human carriage was calculated by use of standard equations and included data from all human and dog specimens collected that yielded growth. For determination of association between contact and colonization, only data from dog/owner pairs was considered, each dog and owner being considered as a pair in those cases in which an owner brought more than one dog. The subjects who failed to complete sections of the questionnaire were omitted from these calculations. Differences in proportions of antibiotic resistance were investigated by the χ^2 test. Significant associations between categorical variables were determined by Fisher's exact test. Stepwise multivariate logistic regression models were then used to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) for variables significant in bivariate analysis using the SPSS statistical software package version 15.0 (SPSS Inc., Chicago, IL, USA). Association between age of the dog and colonization was determined by use of a loglinear logit model.

RESULTS

Carriage of *S. aureus*

A total of 736 owners and 830 owned dogs were sampled for *S. aureus* carriage. Seventy-five owners (9·2%) were unwilling to be sampled themselves, but gave permission for sampling of their dogs. Most owners (93%) completed the questionnaire, but some did not answer all questions. Eight owners brought more than one dog to the clinic (three owners with five dogs each, one with four dogs, and four having two dogs). *S. aureus* was isolated from 174 (24%) humans, and 73 (8·8%) dogs (Table 1). In cases of multiple dogs presenting with one owner, no more than one dog was found to be colonized. Isolation frequencies

Table 2. *Antibiotic resistance in isolates of* S. aureus *from humans and dogs*

Antibiotic	Numbers of resistant isolates (%)			Difference between humans and dogs (*P* value)
	Humans	Dogs	Total	
Penicillin	143 (82)	45 (62)	188 (73)	0·10
Oxacillin	4 (2·3)	6 (8·2)	10 (4·0)	0·03*
Erythromycin	43 (25)	11 (15·1)	54 (23)	0·12
Clindamycin	10 (5·7)	10 (13·6)	20 (7·7)	0·030*
Gentamicin	7 (4·0)	7 (9·5)	12 (5·1)	0·025*
Ciprofloxacin	6 (3·5)	3 (5)	9 (3·9)	0·55
Tetracycline	30 (17·2)	21 (28·8)	51 (19·8)	0·04*
Fusidic acid	3 (1·7)	16 (21·9)	19 (7·4)	<0·001*
Multi-resistant (⩾4 antibiotics)	11 (6·3)	7 (11)	18 (7·0)	0·12

Statistical analysis: χ^2 test.
* Significantly more resistance in dog isolates.

differed between the clinics, but this difference did not reach statistical significance. In 17 cases, both owner and dog were colonized (10% of colonized humans). Based on colony morphology and antibiotic susceptibility pattern, more than one strain of *S. aureus* was isolated from 12 humans. None of the 30 stray dogs sampled were colonized by *S. aureus*.

Antibiotic resistance

Almost 90% of isolates were resistant to at least one antibiotic. Canine *S. aureus* isolates tended to be more resistant than human isolates, with significant differences in frequency of resistance to several antibiotics (Table 2). Only one human isolate was resistant to sulphonamide–trimethoprim, and one dog isolate to rifampicin. Although 15 isolates showed resistance to oxacillin by disc diffusion and growth on ORSAB, PCR did not detect the *mec*A gene in five of these isolates. Cefoxitin testing identified two of these isolates as MRSA, but moxalactam testing confirmed all as MSSA. Overall, four isolates from humans and six from dogs were confirmed as MRSA. One dog and her owner were both colonized with MRSA.

Antibiograms of the paired isolates were similar in 11 pairs indicating that both the owner and the dog may be carrying the same strain. Paired isolates with not more than two differences in antibiogram were further investigated for relatedness using PFGE.

Risk factors for *S. aureus* colonization of owners

Colonization in humans was associated with occupation as a HCW (42% as opposed to 24·9% in non-HCWs) (OR 2·2, 95% CI 1·2, 4·1, $P=0·001$) and the presence of either a cat or a bird in the household ($P=0·001$). These factors remained significant after adjustment for other variables using multivariate analysis. Male gender and number of persons in the household were not associated with colonization. Contact with dogs was not found to be associated with increased colonization of owners (Tables 3 and 4).

Risk factors for *S. aureus* colonization of dogs

Bivariate analysis showed that nasal colonization was significantly more frequent in female (12%) than male dogs (6%) ($P=0·005$). Multivariate analysis reduced the level of significance to 0·05. Size of dog, sex of the owner, and use of antibiotics in the dog were not significantly associated with carriage. Dogs of older subjects were rarely colonized, but this did not reach significance due to the low numbers of elderly owners. Dogs in households of ⩽3 people were more likely to be colonized (OR 1·5, adjusted OR 1·6). Bivariate analysis suggested households with 1–3 dogs were less likely to have a colonized dog than households owning more dogs, but this factor was not significant in the multivariate model. Colonization of the owner was not associated with canine colonization, but dogs of HCWs were more likely to be colonized than those of other workers (OR 3·3, 95% CI 1·5–7·3, $P=0·002$; adjusted OR 2·56, 95% CI 1·1–5·90). Contact with the dog, including stroking, carrying, and kissing or licking the face, did not significantly increase the risk of colonization. Those dogs with access to or sleeping in the bedroom had increased carriage levels,

Table 3. *Risk factors for carriage of* S. aureus *in owners*

Variable	*S. aureus* (%) +	*S. aureus* (%) −	OR	95% CI	*P*
Occupation			2·2	1·2–4·1	0·001
Health care	19 (42·2)	26 (57·8)			
Not health care	151 (24·9)	455 (75·1)			
Sex			1·0	0·92–1·2	0·65
Male	51 (26·4)	142 (73·6)			
Female	117 (24·7)	356 (75·3)			
No. in household			1·0	0·98–1·1	0·99
1 or 2	66 (25)	195 (75)			
>2	108 (25)	323 (75)			
Other animals in the house					0·001
None	135 (23·4)	441 (76·5)			
Cat	20 (35·7)	36 (64·3)			
Bird	16 (48)	17 (52)			
Other	3 (13)	20 (87)			
Number of dogs in household			0·93	0·68–1·2	0·56
1	93 (23·25)	307 (76·7)			
>1	81 (28)	208 (72)			
Size of dog					0·66
Large	21 (21·4)	77 (78·6)			
Medium	54 (23·4)	149 (76·6)			
Small	97 (25·26)	287 (77·8)			
Age of dog					0·94
Puppy	36 (24)	113 (76)			
1–5 yr	58 (25·4)	170 (74·6)			
>5 yr	79 (25·2)	234 (74·8)			
Sex of dog			1·1	0·76–1·5	0·68
Male	95 (24)	297 (76)			
Female	75 (25·6)	218 (74·4)			
Day time location of dog					0·66
Outside	6 (18·7)	26 (81·25)			
Outside & inside	36 (26·5)	100 (73·5)			
Inside only	131 (25)	392 (75)			
Dog has access to bedroom			1·0	0·72–1·4	0·90
Yes	139 (25·1)	414 (74·9)			
No	34 (24·6)	104 (75·4)			
Dog sleeps in bedroom			1·0	0·92–1·1	0·94
Yes	90 (25)	267 (75)			
No	80 (24·5)	247 (75·5)			
Dog lies on bed			1·0	0·84–1·3	0·74
Yes	106 (25·6)	307 (74·3)			
No	69 (24·5)	212 (75·5)			
Frequency of stroking dog			1·1	0·95–1·3	0·48
>3 times/day	167 (25·4)	490 (74·6)			
⩽3 times/day	8 (22·2)	28 (77·8)			
Carrying dog			1·5	0·74–2·0	0·27
Yes	161 (25·6)	468 (74·4)			
Never	11 (18·9)	47 (81·1)			
Kiss dog					0·41
Usually	48 (28·6)	120 (71·4)			
Often	24 (20·5)	93 (79·5)			
Sometimes	78 (25·7)	225 (74·3)			
Never	22 (22·0)	77 (78)			
Dog has chronic disease			0·96	0·65–1·4	0·83
Yes	28 (26)	81 (74)			
No	140 (25)	427 (75)			

Statistical analysis: Fisher's exact test.

Table 4. *Adjusted odds ratios of risk factors for carriage of* S. aureus *in owners*

Variable	aOR	95% CI	*P*
Occupation in health care	2·10	1·11–3·97	0·02
Number of people in the household	1·14	0·79–1·63	0·49
Presence of other animals	1·63	1·04–2·56	0·03

aOR, Adjusted odds ratio; CI, confidence interval.

although not reaching significance ($P=0·077$). Loglinear analysis indicated carriage was associated with the age of the dog, with more colonization in older dogs (10%) in comparison with puppies (5%) and younger dogs (8%) ($P=0·01$). A similar trend was observed if length of ownership was considered (data not shown) (Tables 5 and 6).

Bivariate analysis indicated colonization of the owner, female sex of the dog and access to the bedroom were risk factors for colonization of smaller dogs, but this was not confirmed by the multivariate analysis. Number of people in the household, and an owner employed in health care remained significant risks in this subgroup ($P=0·032$ and 0·034, respectively) (Tables 7 and 8).

Characteristics of owner/dog pairs

Although only 6·6% of respondents reported occupation in health care, of the 17 colonized pairs, five owners (29%) were HCWs, and this was significantly associated with dual-colonization ($P=0·001$). However, only one pair was co-colonized with MRSA. Overall, 11% of HCWs carrying *S. aureus* had colonized dogs, in contrast with 2·3% of other professionals, 0·6% of clerical workers, 2% of artisans, and 1·8% of students and housewives. Recent canine antibiotic use reduced the likelihood of paired colonization ($P=0·022$).

PFGE revealed that of 11 pairs with similar antibiograms, six yielded indistinguishable patterns, of which two owners were HCWs. Three of these pairs are shown in the Figure, together with a pair of non-related isolates. Overall, 4·4% of HCWs were colonized with the same strain as their dog whereas only 0·6% of other dog owners carried the same isolate as their pet.

Risk factors for MRSA colonization

One of the four MRSA-colonized owners was a HCW, as were the owners of two of the six colonized dogs. Five colonized dogs were female, and five were older dogs (>4 years). Overall, 2·2% of human *S. aureus* isolates were MRSA, representing a 0·5% colonization rate in the community. In dogs, 8·2% of isolates were MRSA, a 0·7% overall carriage prevalence.

DISCUSSION

The frequency of carriage of *S. aureus* in owners of 24% was similar to that described previously [1]. The *S. aureus* nasal colonization level in dogs of 8·8% was similar to the 8·2% carriage rate reported by Biberstein *et al*. [28], but much lower than the 90% of an early report [29], which may have suffered from lack of discrimination of S. *intermedius*. Sampling of multiple sites on the dog may have increased isolation yield, but recent work on carriage of staphylococci in dogs suggests that the same strain tends to colonize the nasal mucosa, the anal region, and the skin of dogs, and that isolation frequencies from the nasal mucosa and anal region are similar, and are higher than from the skin [21]. As one aim of our study was to investigate factors influencing transfer of *S. aureus* between dogs and owners and vice versa, close contact with the facial region would appear to be the most likely, making nasally carried organisms most relevant. Only 10% of the 174 owners with nasal colonization had nasally colonized dogs. Fifty-six non-colonized owners had colonized dogs, suggesting other sources of *S. aureus* such as another family member, other dogs, food or the environment. However, as carriage in humans may be either persistent or transient [30], it is possible that the organism carried by the dog was previously carried transiently by the owner. As a cross-sectional study was performed, colonization could not be categorized in either human subjects or their dogs. The frequency of persistent colonization in dogs is not known, and can only be determined by a large-scale longitudinal study which poses logistical problems. Studies have shown that some dogs, like some humans, never seem to be colonized [31, 32]. In humans this is thought to reflect the lack of a receptor site on nasal epithelial cells [30], and a similar mechanism may also apply in dogs and other animals. The absence of *S. aureus* in stray dogs suggests that human contact is important, although clearly other factors may affect carriage in stray animals.

The proportion of isolates displaying antibiotic resistance, especially to penicillin and erythromycin was high. The number of isolates exhibiting resistance to

several agents was significantly higher among those from dogs than from humans, possibly reflecting higher use of antibiotics in veterinary practice [33]. To our knowledge, this is the first report comparing prevalence of antimicrobial resistance in these two populations of *S. aureus*. The higher proportion of oxacillin resistance in canine isolates may be due to selection of MRSA by use of first-generation cephalosporins, which are used in the treatment of pyoderma. As the parenteral administration route leads to infrequent use of aminoglycosides in veterinary practice, resistance to these agents is probably co-selected for by use of other antimicrobials. Resistance to two or more antibiotics detected in 54% of canine isolates in our study, was comparable to the 67% multi-resistant clinical *S. aureus* isolates reported previously [21]. High rates of resistance in the present study to both tetracycline (29%) and fusidic acid (22%) seen in canine isolates, may reflect the frequent use of fusidic acid for canine skin and eye infections [33], whilst tetracyline is used as a first-line antibiotic for respiratory infections in veterinary practice. Most antibiotic therapy in companion animals is empirical and pressure from owners may increase antibiotic use [33].

Of isolates phenotypically demonstrating oxacillin resistance, genetic analysis revealed that five did not harbour the *mec*A gene. Phenotypic false-positives can occur for several reasons, including hyper β-lactamase production, and the results emphasize the importance of confirming phenotypic tests for methicillin resistance with molecular or more sensitive phenotypic methods.

Previous studies have reported isolation of MRSA from infected dogs [34, 35], and case studies have shown that dogs of both infected patients and colonized subjects may be colonized with MRSA [10–13]. MRSA colonization has also been reported in healthy dogs belonging to healthy MRSA-negative members of veterinary clinic staff [35].

The increased risk of nasal colonization of healthcare personnel observed in this study has been documented previously [1, 36]. Employment in clinical settings leads to increased risk for MSSA and MRSA colonization. The presence of a cat or a bird was associated with increased risk of *S. aureus* colonization in human subjects. Cleaning of animal excreta in cat litter trays and bird cages generates dust, possibly increasing respiratory exposure to *S. aureus* from the faeces of these animals. Unexpectedly, neither the presence of multiple dogs, nor increased numbers of persons in the household, increased the likelihood of carriage in owners. It has generally been assumed that close contact with dogs would increase the likelihood of transmission between human and pet. Most attention has been on the risk of transmission to humans from animals, and people are routinely advised to avoid animals licking their faces. Despite this, owners who admitted frequent close contact with their animals, including kissing the dog and allowing it to lick their face or sleep on their bed, appeared to have no higher risk of colonization with *S. aureus* than those who did not.

Our finding that nasal colonization with *S. aureus* was higher in female dogs agrees with data previously published both for *S. aureus* [21] and *S. intermedius* [20], and contrasts with human carriage which is higher in males [30]. Hormonal factors may influence colonization, although most female dogs in Hong Kong are de-sexed leading to reduced hormone levels. Behavioural differences between genders may also play a role.

The effect of age on canine colonization, also reported previously [21], may be due to immune or other changes in older dogs, but probably reflects increased duration of human exposure.

Increased *S. aureus* colonization risk for dogs in multi-dog households, although not reaching significance, may be linked to canine social behaviour and has been previously reported for *S. intermedius* [20], as well as to possibly reduced hygiene in these households. Sampling of multiple dogs from one household did not reveal more than one being colonized, but such samples were limited.

The dogs of HCWs were at much higher risk of colonization, with nasal carriage observed in dogs of both currently colonized and non-colonized HCWs. HCWs may carry the organism not only in the nares, but also on their skin and clothing to which the dog is exposed, allowing dogs of transient carriers or even non-carriers to become colonized. Access to the bedroom also appeared to increase risk of colonization as opposed to other living areas. During dressing, undressing, and bed-making contaminated skin scales are shed and are possibly picked up by the dog.

Although the low numbers of colonized dog/owner pairs detected may be affected by transient carriage, it does indicate that transmission between owners and dogs may indeed be low. Of these paired colonizations, again occupation in health care seemed to be the major risk factor. Use of antibiotics in dogs was not a risk factor for colonization, but antibiotic

Table 5. *Risk factors for carriage of* S. aureus *in dogs*

	S. aureus (%)				
Variable	+	−	OR	95% CI	*P*
Owner's occupation			3·3	1·5–7·3	0·002
Health care	9 (20)	36 (80)			
Not health care	45 (7·1)	593 (92·9)			
Sex of owner			1·0	0·85–1·2	0·77
Male	17 (8·5)	183 (91·5)			
Female	37 (7·8)	436 (92·2)			
Owner *S. aureus* positive			1·1	0·93–1·3	0·22
Yes	19 (10·8)	156 (89·2)			
No	41 (7·8)	482 (92·1)			
Age of owner			0·99	0·92–1·2	0·91
⩽50 yr	48 (9·8)	438 (90·2)			
>50 yr	9 (10)	81 (90)			
No. in household			1·5	1·0– 2·2	0·027
1–3	43 (10·5)	365 (89·5)			
>3	19 (6)	301 (94)			
Other animals in the house					0·9
None	50 (8·3)	551 (91·7)			
Cat	5 (8·5)	54 (91·5)			
Bird	4 (12·1)	29 (87·8)			
Other	2 (9·0)	20 (91)			
No. of dogs in household			0·50	0·26, 0·96	0·04
1–3	53 (7·8)	619 (92·2)			
>4	9 (15·8)	48 (84·20)			
Size of dog					0·84
Large	10 (10)	90 (90)			
Medium	17 (8)	196 (92)			
Small	34 (8·5)	365 (91·5)			
Age of dog					0·21
Puppy	9 (5·7)	48 (94·3)			
1–5 yr	20 (7·9)	233 (92·1)		Trend*	0·03
>5 yr	34 (10·4)	293 (89·6)			
Sex of dog			0·69	0·55–0·86	0·005
Male	24 (6)	378 (94)			
Female	36 (12)	266 (88)			
Day time location of dog					0·39
Outside	1 (3)	32 (97)			
Outside & inside	10 (7·2)	129 (92·8)			
Inside only	50 (9·1)	496 (90·8)			
Dog has access to bedroom			1·8	0·9–3·7	0·076
Yes	54 (9)	519 (91)			
No	7 (4·8)	138 (95·2)			
Dog sleeps in bedroom					
Yes	39 (10·3)	340 (89·7)			
No	21 (6·3)	311 (93·7)			
Dog lies on bed			1·2	0·82–1·7	0·35
Yes	40 (9·2)	392 (90·8)			
No	21 (7·2)	268 (92·8)			
Frequency of stroking dog			1·0	0·95–1·1	0·61
>3 times/day	58 (8·4)	632 (91·6)			
⩽3 times/day	4 (11)	33 (89)			
Carrying dog			1·3	0·45–3·7	0·63
Yes	58 (8·7)	605 (91·3)			
Never	4 (6·4)	54 (93·6)			

Table 5 (*cont.*)

Variable	*S. aureus* (%) +	*S. aureus* (%) −	OR	95% CI	*P*
Kiss dog					0·54
Usually	17 (9·5)	161 (90·5)			
Often	13 (10·8)	107 (89·2)			
Sometimes	22 (6·9)	297 (93·1)			
Never	9 (8·6)	95 (91·4)			
Dog has chronic disease			1·0	0·9–1·1	0·85
Yes	10 (8·9)	102 (91·1)			
No	50 (8·3)	547 (91·7)			
Dog taken antibiotic			0·94	0·8–1·1	0·45
Yes	15 (6·9)	201 (93·1)			
No	43 (8·6)	456 (91·4)			

Fisher's exact test.
* Loglinear logit analysis for trend.

therapy for infection at another site may have also eradicated the colonizing organism. Investigation of the 17 isolate pairs revealed that 11 pairs had indistinguishable antibiograms, but PFGE analysis revealed that five of these pairs were unrelated. In one case, owner and dog were colonized with different strains of MRSA. Thus, only six pairs were indistinguishable by PFGE, although over 90% of owners attending the veterinary clinic with the animal claimed to be the person having most contact with the dog. This again suggests that transfer between owner and dog, or vice versa, does occur, but may be more unusual than indicated by case reports [10–13]. The canine strains may have originated from other family members, but other sources, in particular veterinary practices, may be involved in the transfer of *S. aureus* to dogs. Although other studies have reported dogs colonized with strains indistinguishable from those recovered from veterinary personnel [34, 35], in our study PFGE analysis showed that MRSA from dogs attending the same practice differed from each other.

Although MRSA carriage was low, it was noteworthy that of the four owners colonized with MRSA, one was a HCW, whilst two of the six colonized dogs were owned by HCWs. This emphasizes the role HCWs may play in bringing MRSA into the community. The transmission of MRSA to close contacts of HCWs has been previously documented, and previous case reports have implicated dogs of HCWs as reservoirs of MRSA [12, 14]. This study confirmed that dogs of HCWs may be more frequently colonized with either MRSA or MSSA. Of the MRSA-colonized dogs, the preponderance of female dogs is of note, although there is no obvious explanation as to why female gender is a risk factor for colonization.

Table 6. *Adjusted odds ratios of risk factors for carriage of* S. aureus *in dogs*

Variable	aOR	95% CI	*P*
Occupation in health care	2·56	1·11–5·90	0·028
No. of people in the household	1·4	1·04–2·13	0·013
No. of dogs in the household	1·69	0·72–4·00	0·23
Sex of the dog	1·63	1·04–2·56	0·05

aOR, Adjusted odds ratio; CI, confidence interval.

The primary aim of this study was to investigate the role of dogs as reservoirs for *S. aureus*, in particular MRSA, following increasing evidence of MRSA colonization in animals [18, 32]. This has been a cause of concern particularly as levels of MRSA have continued to increase in the community, most notably in the United States [37] and Australia [38]. Although the prevalence of carriage of CA-MRSA remains low in Hong Kong [6], there is still a need for vigilance as infections with community strains of MRSA have recently occurred [39]. In our study, nasal carriage in dogs was assessed, and it was shown that dogs, in particular those owned by HCWs, can act as an important reservoir of the organism.

Whilst this study investigated the association between nasal colonization and close contact with

Table 7. *Risk factors for carriage of* S. aureus *in small dogs*

	S. aureus (%)				
Variable	+	−	OR	95% CI	*P*
Owner's occupation			5·4	2·2–13·6	0·0001
Health care	8 (27·6)	21 (72·4)			
Not health care	23 (6·5)	329 (93·5)			
Owner *S. aureus* positive			2·1	0·91–4·4	0·048
Yes	13 (13·5)	83 (86·5)			
No	20 (7·0)	226 (93)			
No. in household			1·6	0·95–2·7	0·044
1–3	24 (11)	193 (89)			
>3	10 (5·4)	174 (94·6)			
No. of dogs in household			0·7	0·26–1·9	0·47
1–3	30 (8·1)	337 (91·9)			
>3	4 (11·8)	30 (88·2)			
Sex of dog			2·3	1·1–4·8	0·023
Female	21 (11·9)	155 (88·1)			
Male	12 (5·4)	205 (94·6)			
Dog has access to bedroom			7·04	1·0–49	0·012
Yes	33 (10)	291 (90)			
No	1 (1·2)	76 (98·8)			

Statistical analysis: Fisher's exact test.

Table 8. *Adjusted odds ratios of risk factors for carriage of* S. aureus *in dogs*

Variable	aOR	95% CI	*P*
Occupation in health care	2·51	1·07–5·90	0·034
No. of people in the household	1·43	1·03–2·04	0·032
Colonization of the owner	1·28	0·68–2·42	0·45
No. of dogs in the household	1·47	0·59–3·68	0·41
Sex of the dog	1·54	0·86–2·77	0·15
Access to the bedroom	3·53	0·87–4·56	0·28

aOR, Adjusted odds ratio; CI, confidence interval.

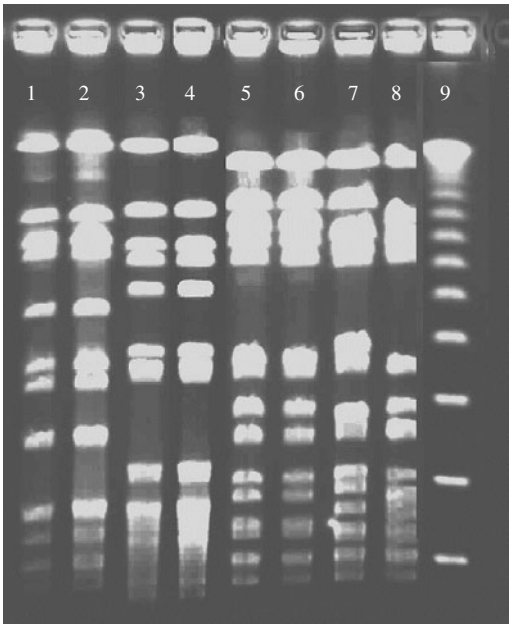

Fig. PFGE of isolates from dogs (D) and their owners (H). Lane 1, K31D; lane 2, K31H; lane 3, K85H; lane 4, K85D; lane5, M113H; lane 6, M113D; lane 7, M203H; lane 8, M203D; lane 9, molecular size ladder. Dogs and humans K31, K85 and M113 appear to be colonized by the same strain, whereas M203 dog and human are colonized by different strains. M203H appears similar to the strain from M113.

companion animals and their owners in broad terms, its setting conveniently assessed this contact at an extreme level, as Hong Kong is highly urbanized and densely populated, with dogs primarily kept indoors. The majority of the population live in high-rise accommodation and dogs are frequently carried when being taken outside for exercise.

This study has shown that colonization of dogs is primarily associated with occupation of the owner and dog ownership is unlikely to significantly increase the risk of infection in healthy subjects, in particular as kissing and carrying of the dogs was not associated with an increased risk of colonization of either owner or dog. It is recognized that companion animals may serve as a reservoir for infection in immunocompromised humans. As dogs of HCWs are more likely to be colonized, if decolonization of HCWs in outbreak situations is to be performed, consideration

should also be given to decolonization of their dogs. Both topical mupiricin or vancomycin have been shown to eliminate carriage in colonized dogs [12], but as topical application of antimicrobial drugs may be impractical, an oral course of rifampcin and either doxycycline or clarithromycin may be employed [10]. However, care must be exercised in the use of these antimicrobials to prevent increasing risk of resistance and subsequent adverse consequences as these drugs are used in human therapy. The high frequency of resistance in isolates from dogs to antibiotics used for humans is of concern, and indicates a need to re-examine the use of antibiotics in veterinary practice.

This study suggests that transmission is generally from owner to dog, although it may also occur from dog to owner. A large-scale longitudinal study is required to confirm this observation.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Kluytmans JAJW, Wertheim HFL.** Nasal carriage of *Staphylococcus aureus* and prevention of nosocomial infections. *Infection* 2005; **33**: 3–8.
2. **Weidenmaier CJF, *et al.*** Role of teichoic acids in *Staphylococcus aureus* nasal colonization, a major risk factor in nosocomial infections. *Nature Medicine* 2004; **10**: 243–245.
3. **Katayama Y, Ito T, Hiramatsu K.** A new class of genetic element, Staphylococcus cassette chromosome *mec*, encodes methicillin resistance in *Staphylococcus aureus*. *Antimicrobial Agents and Chemotherapy* 2000; **44**: 1549–1555.
4. **Chambers HF.** The changing epidemiology of *Staphylococcus aureus*. *Emerging Infectious Diseases* 2001; **7**: 178–182.
5. **Shopsin B, *et al.*** Prevalence of methicillin-resistant and methicillin-susceptible *Staphylococcus aureus* in the community. *Journal of Infectious Diseases* 2000; **182**: 359–362.
6. **O'Donoghue MM, Boost MV.** The prevalence and source of methicillin-resistant *Staphylococcus aureus* (MRSA) in the community in Hong Kong. *Epidemiology and Infection* 2004; **132**: 1091–1097.
7. **Hisata K, *et al.*** Dissemination of methicillin-resistant staphylococci among healthy Japanese children. *Journal of Clinical Microbiology* 2005; **43**: 3364–3372.
8. **Scanvic A, *et al.*** Duration of colonization by methicillin-resistant *Staphylococcus aureus* after hospital discharge and risk factors for prolonged carriage. *Clinical Infectious Diseases* 2001; **32**: 1393–1398.
9. **Boyce JM.** Methicillin-resistant *Staphylococcus aureus* in hospitals and long term facilities: microbiology, epidemiology and preventive measures. *Infection Control and Hospital Epidemiology* 1992; **13**: 725–737.
10. **van Duijkeren E, *et al.*** Human-to-dog transmission of methicillin-resistant *Staphylococcus aureus*. *Emerging Infectious Diseases* 2004; **10**: 2235–2237.
11. **Cefai C, Ashurst S, Owens C.** Human carriage of methicillin-resistant *Staphylococcus aureus* linked with pet dog. *Lancet* 1994; **344**: 539–540.
12. **Manian FA.** Asymptomatic nasal carriage of mupiricin-resistant methicillin-resistant *Staphylococcus aureus* (MRSA) in a pet dog associated with MRSA infection in household contacts. *Clinical Infectious Diseases* 2003; **36**: E26–28.
13. **Simoons-Smit AM, *et al.*** Transmission of *Staphylococcus aureus* between humans and domestic animals in a household. *European Journal of Clinical Microbiology and Infectious Diseases* 2000; **19**: 150–152.
14. **Enoch DA, *et al.*** MRSA carriage in a pet therapy dog. *Journal of Hospital Infection* 2005; **60**: 186–188.
15. **Duquette RA, Nuttall TJ.** Methicillin-resistant *Staphylococcus aureus* in dogs and cats: an emerging problem? *Journal of Small Animal Practice* 2004; **45**: 591–597.
16. **Guardabassi L, Loeber ME, Jacobson A.** Transmission of multiple antimicrobial-resistant *Staphylococcus intermedius* between dogs affected by deep pyoderma and their owners. *Veterinary Microbiology* 2004; **98**: 23–27.
17. **Pak SI, Han HR, Shimuzu A.** Characterisation of methicillin-resistant *Staphylococcus aureus* isolated from dogs in Korea. *Journal of Veterinary Medical Science* 1999; **60**: 1526–1530.

18. **Tomlin J, *et al.*** Methicillin-resistant *Staphylococcus aureus* infections in 11 dogs. *Veterinary Record* 1999; **144**: 60–64.
19. **Pinchbeck LR, *et al.*** Genotypic relatedness of staphylococcal strains isolated from pustules and carriage sites in dogs with supeficial bacterial folliculitis. *American Journal of Veterinary Research* 2006; **67**: 1337–1346.
20. **Harvey RG, Noble WC.** Aspects of nasal, oropharyngeal and anal carriage of *Staphylococcus intermedius* in normal dogs and dogs with pyoderma. *Veterinary Dermatology* 1998; **9**: 99–104.
21. **Hoekstra KA, Paulton RJL.** Clinical prevalence and antimicrobial susceptibility of *Staphylococcus aureus* and *Staph. intermedius* in dogs. *Journal of Applied Microbiology* 2002; **93**: 406–413.
22. **Bannerman TL.** Staphylococcus, Micrococcus, and other catalase-positive cocci that grow aerobically. In: Murray PR, Baron EJ, Jorgensen JH, Pfaller MA, Yolken RH, eds. *Manual of Clinical Microbiology*, 8th edn. Washington, DC: ASM Press, 2003, pp. 384–404.
23. **Clinical and Laboratory Standards Institute.** Performance standards for antimicrobial susceptibility testing, Fifteenth international supplement M100-S15. 2005. Clinical and Laboratory Standards Institute, Wayne, PA.
24. **Andrews J, and BSAC Working Party Report on Susceptibility Testing.** Determination of inhibitory concentrations. *Journal of Antimicrobial Chemotherapy* 2001; **48** (Suppl. 1): 48–71.
25. **Ryffel C, *et al.*** Sequence comparison of *mec*A genes isolated from methicillin-resistant *Staphylococcus aureus* and *Staphylococcus epidermidis*. *Gene* 1990; **94**: 137–138.
26. **Prevost G, Jaulhac B, Piemont V.** DNA fingerprinting by pulsed-field gel electrophoresis is more effective than ribotyping in distinguishing amongst methicillin-resistant *Staphylococcus aureus* isolates. *Journal of Clinical Microbiology* 1992; **30**: 967–973.
27. **Tenover FC, *et al.*** Interpreting chromosomal DNA restriction patterns produced by pulsed-field gel electrophoresis: criteria for bacterial strain typing. *Journal of Clinical Microbiology* 1995; **33**: 2233–2239.
28. **Biberstein EL, Jang SS, Hirsh DC.** Species distribution of coagulase-positive staphylococci in animals. *Journal of Clinical Microbiology* 1994; **19**: 610–615.
29. **Krogh HV, Kristensen S.** A study of skin diseases in dogs and cats. II. Microflora of the normal skin of dogs and cats. *Nordisk veterinaermedicin* 1976; **28**: 459–463.
30. **Wertheim HFL, *et al.*** The role of nasal carriage in *Staphylococus aureus* infections. *Lancet Infectious Diseases* 2005; **5**: 751–762.
31. **Cox HU, *et al.*** Temporal study of staphylococcal species on healthy dogs. *American Journal of Veterinary Research* 1988; **49**: 747–751.
32. **Rich M, Roberts L.** Methicillin-resistant *Staphylococcus aureus* isolates from companion animals. *Veterinary Record* 2004; **154**: 301.
33. **Guardabassi L, Schwarz S, Lloyd DH.** Pet animals as reservoirs of antimicrobial-resistant bacteria. *Journal of Antimicrobial Chemotherapy* 2004; **54**: 321–332.
34. **O'Mahony R, *et al.*** Methicillin-resistant *Staphylococcus aureus* (MRSA) isolated from animals and veterinary personnel in Ireland. *Veterinary Microbiology* 2005; **109**: 285–296.
35. **Loeffler A, *et al.*** Prevalence of methicillin-resistant *Staphylococcus aureus* among staff and pets in a small animal referral hospital in the UK. *Journal of Antimicrobial Chemotherapy* 2005; **56**: 692–697.
36. **Kalmeijer MD, *et al.*** Surgical site infections in orthopaedic surgery: the effect of mupiricin nasal ointment in a double-blind randomised placebo-controlled study. *Clinical Infectious Diseases* 2002; **35**: 353–358.
37. **Fridkin SK, *et al.*** Methicillin-resistant *Staphylococcus aureus* disease in three communities. *New England Journal of Medicine* 2005; **352**: 1436–1444.
38. **Vandenesch F, *et al.*** Community acquired methicillin-resistant *Staphylococcus aureus* carrying Panton-Valentine leukocidin genomes: worldwide emergence. *Emerging Infectious Diseases* 2003; **9**: 978–984.
39. **Ho PL, *et al.*** Community-acquired methicillin-resistant *Staphylococcus aureus* arrives in Hong Kong. *Journal of Antimicrobial Chemotherapy* 2004; **54**: 845–846.