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Review

Meticillin-resistant *Staphylococcus aureus* in animals: A review

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Abstract

The objectives of this paper are to review published data on the prevalence and epidemiology of meticillin-resistant *Staphylococcus aureus* (MRSA) infection and colonization in animals and to provide suggestions for preventing and controlling the problem in veterinary practice. MRSA first emerged as a serious pathogen in human medicine during the late 1970s and has been increasingly reported in animals during the past 10 years. The prevalence of MRSA in human infections varies markedly between geographical areas, being as high as 60% in parts of the USA, 40% in southern Europe but <1% in northern Europe. Epidemiological evidence, including phenotypic and molecular typing data, suggests that MRSA isolates from dogs and cats are indistinguishable from human healthcare isolates, whereas strains of MRSA isolated from horses and associated personnel are different. There is evidence that transfer of MRSA strains can occur between animals and humans and vice versa. Guidelines for the control of MRSA in animals have been drawn up by individual institutions based on those available for human MRSA infection. Risk factors for MRSA infection in animals are currently under investigation and such data are essential for the preparation of specific guidelines for control of MRSA in veterinary practice.

Keywords: Meticillin-resistant *Staphylococcus aureus*; MRSA; Animals; Prevalence; Epidemiological typing; Control

1. Introduction

Staphylococcus aureus is well recognised as a significant pathogen in both human and animal medicine. It can cause a wide range of conditions in humans and animals, from mild skin infections to life-threatening bacteraemia. More than 80% of *S. aureus* strains produce penicillinases and thus β-lactam antibiotics such as meticillin,[1] which are resistant to penicillinases were widely used to treat *S. aureus* infections. Meticillin was first introduced in human medicine in the late 1950s when it was used for treating penicillin-resistant staphylococcal infections.

Jevons (1961) reported meticillin-resistance as early as 1961 while Barber (1961) demonstrated that repeated passage of *S. aureus* (*pyogenes*) in the presence of meticillin resulted in the development of resistance. During the 1970s, meticillin-resistant *S. aureus* (MRSA) emerged as a serious problem in the USA and caused sporadic problems in individual hospitals elsewhere (Cooke et al., 1986; Panlilio et al., 1992). By the 1990s, MRSA had become a serious nosocomial infection worldwide (Anon, 2001; Ayliffe, 1997).

MRSA strains are resistant to β-lactam antibiotics, including all penicillinase-stable β-lactams, with resistance most commonly mediated by the *mecA* gene. This gene encodes for a penicillin-binding protein (PBP2a) which is expressed in the bacterial cell wall and which has a low affinity for β-lactam antibiotics. Thus, this group of antibiotics are ineffective against bacteria expressing this gene. In addition, most MRSA isolates are resistant to many other antimicrobial classes. There is evidence that meticillin-sensitive strains of *S. aureus* became meticillin resistant through the acquisition of the SCC*mec* element, probably from coagulase-negative staphylococcal strains, and that this has occurred on multiple occasions (Robinson and Enright, 2004). In recent years MRSA has been increasingly reported as an emerging problem in veterinary medicine, particularly in small animal and equine practices.

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[1] The spelling 'meticillin' has been used in place of 'methicillin' in accordance with International Pharmacopoeia guidelines.

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2. Typing of MRSA strains

MRSA strains can be typed using both phenotypic and molecular methods. Phenotypic typing methods include the use of colonial characteristics, biochemical reactions, antibiotic susceptibility pattern, susceptibility to various phages and toxin production. The most important molecular typing methods in current use comprise pulsed field gel electrophoresis (PFGE), multilocus sequence typing (MLST), SCC*mec* and *spa* typing.

2.1. PFGE typing

PFGE separates DNA under conditions of alternating polarity allowing for the resolution of DNA fragments nearly 20-times larger than those separated by traditional agarose gel electrophoresis. PFGE is used in conjunction with restriction enzymes to provide a DNA fingerprint of the bacterial genome. The advantage of this method is that it provides great discrimination between strains and is useful in the investigation of outbreaks by allowing differentiation of unrelated strains. Disadvantages associated with the method relate principally to difficulties with inter-laboratory comparison of results. Thus reliable comparison of strains between regions and internationally is not always possible.

2.2. MLST and SCCmec typing

Investigation of the genetic relatedness of MRSA isolates in international epidemiological studies is carried out using results of MLST and SCC*mec* typing.

MLST involves sequencing DNA fragments of seven housekeeping genes (Maiden et al., 1998). The sequences of the genes are compared to known alleles via the MLST website (http://www.mlst.net) and thus every isolate can be described with a seven integer profile. The MLST scheme for *S. aureus* was developed in 2000 and the details of more than 1500 isolates are available at the *S. aureus* MLST website http://saureus.mlst.net (Enright, 2006).

The gene encoding meticillin resistance, *mecA*, is part of a larger genetic element known as the staphylococcal chromosomal cassette (SCC) *mec*. This element contains the *mecA* gene, chromosomal cassette recombinase genes, *mec* regulatory genes and a junkyard region which contains non-essential components of SCC*mec*. There are five SCC*mec* types currently described, which are characterized using PCR-based techniques. Each type is differentiated by the class of the *mec* gene and the type of recombinase genes (Ito et al., 2001, 2004). Differences in the junkyard region define variants of each SCC*mec* type.

Enright et al. (2002) described a system whereby MRSA clones could be described using the MLST profile of a strain combined with a description of the antimicrobial resistance phenotype and SCC*mec* type. This system was agreed by a subcommittee of the international union of microbiology societies in Tokyo, 2002. For example, one of the previous epidemic clones known as the New York/Japan clone is now known as ST5-MRSA-II. There are five pandemic MRSA lineages or clonal complexes. These have evolved from epidemic meticillin-sensitive *S. aureus* (MSSA) strains which acquired SCC*mec* elements. It is suggested that acquisition of these elements by MSSA has occurred on at least 20 separate occasions (Feil and Enright, 2004).

Published data on ST and SCC*mec* types of animal isolates are limited although some recent publications include this information. These data suggest that MRSA strains found in companion animals such as dogs and cats are identical to epidemic strains found in human hospitals whereas those found in other animal species tend to be distinct from strains causing widespread problems in humans. Recent studies by Baptiste et al. (2005), Loeffler et al. (2005), O'Mahony et al. (2005) and Strommenger et al. (2006) have shown that isolates from pets in the UK, Ireland and Germany were similar to human isolates of the epidemic lineage EMRSA-15 (ST22-MRSA-SCC*mec*IV). The other strain of MRSA, which is widespread in hospitals in the UK, EMRSA-16, has also been isolated from pets, but to a lesser extent (Rich et al., 2005; Waller, 2005).

Recent reports of MRSA in pets in the USA have described the isolates using PFGE patterns but do not characterize the isolates using MLST or SCC*mec* typing (Middleton et al., 2005; Rankin et al., 2005). However, a recent survey of MRSA carriage in small animal veterinary practitioners identified MRSA of type ST5-MRSA-II, similar to USA 100, in 12 small animal personnel in the USA (Hanselman et al., 2006).

Malik et al. (2006) reported another technique in which partial nucleotide sequencing of the *mecA* genes of *S. aureus* isolates was undertaken. These data were used to compare human isolates and a small number of isolates from dogs and cats. As in other typing studies the data strongly suggested that transmission of MRSA occurs between humans and companion animals and vice versa.

Epidemiological typing of equine isolates of MRSA and MRSA strains from equine-associated personnel shows that these isolates are distinct from MRSA strains which commonly cause infections in humans (Baptiste et al., 2005; O'Mahony et al., 2005; Weese et al., 2005a; Cuny et al., 2006). Equine MRSA strains of differing MLST types appear to be prevalent in different countries although there is evidence that strains of Canadian epidemic MRSA-5 may occur in both North America and Europe (Weese, 2006). Typing data on isolates from pigs and associated human infections (Voss et al., 2005; Van Dijke et al., 2006) and on isolates from cattle (Kwon et al., 2005) suggest MRSA from these species may represent different lineages from those present in humans.

2.3. spa typing

DNA sequence analysis of the variation in region X of the protein A gene, *spa* typing, is a useful rapid method

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for typing MRSA isolates (Frenay et al., 1996; Shopsin et al., 1999). Typing of a limited number of animal isolates has been carried out using this method (Voss et al., 2005; Strommenger et al., 2006; Moodley et al., 2006). Results support those of the other typing methods that isolates from pets are similar to human epidemic strains whereas those from horses are different. In addition, it is possible in some cases to use *spa* typing to differentiate strains that are indistinguishable using PFGE (Moodley et al., 2006).

2.4. VNTR typing

In recent years, a typing method, which analyses the variation in short sequence repeat motifs, has been developed for use with *S. aureus*. Following the sequencing of the genomes of a number of *S. aureus* strains, several variable number tandem repeat (VNTR) sequences have been identified and can be used for typing purposes (Sabat et al., 2003; Hardy et al., 2004). It has been suggested that this method gives good discrimination of strains and allows epidemiological tracing in both epidemic and endemic settings (Hardy et al., 2006). No published data are available on VNTR typing of animal MRSA isolates to date.

3. Epidemiology of MRSA in humans

In humans, the anterior nares are considered the ecological niche of *S. aureus* (Kluytmans et al., 1997). Other sites of carriage include the throat, axilla, perineum and groin. Intermittent carriage of *S. aureus* is thought to occur in as many as 60% of the population while approximately 20% of people are persistent carriers of a single strain (Williams, 1963). Nasal carriage rates vary according to the population studied, for example being higher in children than adults (Armstrong-Esther and Smith, 1976). In a comprehensive review of published cross-sectional surveys Kluytmans et al. (1997) reported a mean carriage rate of 37.2%. In a recent US survey of non-institutionalized people a prevalence rate of *S. aureus* colonization of 31.6% was reported (Graham et al., 2006). In the same study the prevalence of colonization with MRSA was 0.84%.

Traditionally MRSA has been considered a healthcare-associated pathogen with established factors associated with increased risk of nosocomial acquisition of infection including prolonged antimicrobial therapy, surgery, prolonged hospitalization, treatment in an intensive care unit and close proximity to other patients infected or colonized with MRSA (Thompson et al., 1982; Brumfitt and Hamilton-Miller, 1989). The skin is often colonized by *S. aureus* in nasal carriers and transmission is considered to occur principally by means of hands (Mulligan et al., 1993). Studies have shown that elimination of nasal carriage by the use of topical mupirocin will also eliminate hand carriage (Reagan et al., 1991). Surveys of hospital personnel and of outpatients suggest nasal carriage rates for MRSA of approximately 6% and 2%, respectively (Kenner et al., 2003; Cesur and Cokca, 2004).

Worldwide MRSA rates have increased dramatically in recent decades. In the United States, MRSA prevalence among all hospital *S. aureus* isolates has increased from 2.4% in 1975 to 29% in 1991 (Panlilio et al., 1992). Between 1992 and 2003, the proportion of *S. aureus* isolates from patients in intensive care units that were meticillin-resistant rose from 35.9% to 64.4% (Klevens et al., 2006). In England and Wales, the proportion of *S. aureus* bacteraemia due to MRSA increased from 1% to 2% in 1990–1992 to approximately 40% in 2000 (Johnson et al., 2001).

Infections with MRSA are considered to cause substantial illness and add to health care costs. It has been estimated that from 1999 to 2000 in the US 125,969 hospitalizations with a diagnosis of MRSA occurred annually, equating to 3.95 per 1000 hospital discharges (Kuehnert et al., 2005).

The prevalence of meticillin resistance among *S. aureus* isolates varies markedly between health care institutions and geographic areas. Analysis of data supplied by 26 countries participating in the European Antimicrobial Resistance Surveillance System between 1999 and 2002 indicated that MRSA prevalence among *S. aureus* isolates from blood varied from <1% in northern Europe to >40% in Southern and Western Europe (Tiermersma et al., 2004). Control programmes have been successfully designed and implemented in several countries. In Denmark, MRSA prevalence fell from 15% of *S. aureus* isolates in 1971 to 0.2% in 1984 (Rosdahl and Knudsen, 1991), while in the Netherlands, as a result of a national 'search-and-destroy' policy, <1% of clinical *S. aureus* strains are MRSA and only 0.03% of non-risk patients admitted to hospital are nasal MRSA carriers (Wertheim et al., 2004).

In recent years, a change in the epidemiology of MRSA has been documented with infections also appearing in healthy individuals in the community without health care-associated risk factors (Kluytmans-VandenBergh and Kluytmans, 2006). Prevalence rates of community acquired MRSA (CA-MRSA) are difficult to ascertain due to the different definitions used and the different settings in which the studies have been carried out. Molecular epidemiological definitions of CA-MRSA and hospital acquired MRSA (HA-MRSA) isolates are considered the most reliable. An MRSA isolate is currently considered community acquired if it contains the SCC*mec* type IV gene and if it is not related phylogenetically to known HA-MRSA clonal lineages (Robinson and Enright, 2003).

A fifth allotype of SCC*mec* has now been described, also associated with CA-MRSA isolates (Ito et al., 2004; Boyle-Vavra et al., 2005). Solgado et al. (2003) reported a meta-analysis of studies reporting the prevalence of CA-MRSA. In 27 retrospective studies, the pooled prevalence of CA-MRSA among MRSA isolates was 30.2% and 37.3% in five prospective studies. The pooled MRSA colonization rate among community members was 1.3% but this reduced to 0.2% when persons with health care contacts were excluded.

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4. Epidemiology of MRSA in animals

Given the importance of *S. aureus* as a cause of mastitis in cattle and the widespread usage of intramammary antibiotics in that species it is perhaps not surprising that the first isolations of MRSA from animals were in milk from mastitic cows (Devriese et al., 1972; Devriese and Hommez, 1975). Since then MRSA has been found in a variety of other domestic species including dogs (Pak et al., 1999; van Duijkeren et al., 2004), cats (Bender et al., 2005), horses (Anzai et al., 1996; Hartmann et al., 1997), sheep (Goni et al., 2004) pigs (Voss et al., 2005) and chickens (Lee, 2003) leading to an upsurge of reports and interest in MRSA colonization and infection in animals.

A recent survey of *S. aureus* isolates recovered from 65 patients attending seven veterinary teaching hospitals revealed that 14% of patients were infected with MRSA and that MRSA infections were most prevalent among

Table 1
Summarized chronology of publications reporting MRSA infections in animals

Year	Authors	Comments
1972	Devriese et al.	Isolation of MRSA from cows with mastitis
1975	Devriese and Hommez	Further isolations of MRSA from dairy cows, suggested to be of human origin
1988	Scott et al.	Cat suspected to be source of MRSA outbreak in geriatric ward
1989	Smith et al.	Isolation of coagulase-positive Staphylococcus sp. (12% of isolates were oxacillin resistant) from orthopedic implant sites in dogs
1994	Cefai et al.	Repeated nasal carriage of MRSA in two nurses linked to pet dog
1996	Anzai et al.	Isolation of MRSA from 13 mares with metritis and a stallion with a skin lesion
1997	Hartmann et al.	MRSA isolated from leg wound of horse
	Shimizu et al.	PGFE typing of equine MRSA isolates reveals pattern distinct from human isolates
1998	Lilenbaum et al.	Isolation of MRSA from skin scrapings from clinically normal cats
1999	Sequin et al.	MRSA outbreak in equine patients attending a veterinary hospital. Closely related MRSA isolates also obtained from hospital personnel
	Pak et al.	Isolation of MRSA from 12 dogs hospitalized due to a variety of clinical conditions
	Tomlin et al.	MRSA infection in 11 dogs associated with surgery, traumatic wounds or recurrent pyoderma
	Gortel et al.	MRSA isolates from wounds and skin lesions in dogs
2003	Lee	MRSA isolated from dairy cows (milk samples) and chickens (muscle or joint samples)
	Manian	Identical PGFE type of MRSA isolated from pet dog of owners with recurrent MRSA infection
2004	Goni et al.	MRSA isolated from case of ovine mastitis
	Van Duijkeren et al.	MRSA isolated from two dogs with wounds
	Rich and Roberts	95 MRSA isolates reported from dogs (69), cats (24), a horse and a rabbit. Most isolates obtained from wound infections, postoperative infections or from the skin
	Boag et al.	12 MRSA isolates from dogs (7) and cats (5)
	Weese et al.	Environmental contamination suggested as important source of MRSA in veterinary teaching hospital
2005	Voss et al.	Association between pig farming and high MRSA carriage rates
	Bender et al.	Isolation of MRSA from non-healing abscess in a cat
	O'Mahony et al.	MRSA isolated from dogs (14), horses (8), a cat, a rabbit and a seal. Isolates were also obtained from attendant veterinary personnel. Non-equine MRSA isolates had PGFE pattern indistinguishable from most prevalent MRSA strain in human population. Distinct PGFE pattern for equine MRSA isolates
	Kwon et al.	SCC *mec* characterization of MRSA from bovine milk
	Loeffler et al.	MRSA isolated from staff, dogs and environment of a small animal referral hospital
	Middleton et al.	14% of patients (65) with *S. aureus* infection at 7 veterinary teaching hospitals infected with MRSA
	Hanselmann et al.	1% nasal MRSA carriage rate in dogs in referral hospitals
	Weese et al. (a)	MRSA isolates from horses and horse personnel typed as SCCmecIV and distinct from epidemic MRSA types predominant in human population
	Weese et al. (b)	4.7% isolation rate of MRSA in screened horses rising to 12% using targeted surveillance
	Baptiste et al.	MRSA isolates from dogs and staff at veterinary hospital identical by PFGE analysis to epidemic MRSA type prevalent in human population. Five distinct MRSA strains isolated from horses
2006	Abbott et al.	0.6% MRSA carriage in dogs rising to 8% in dogs clinically assessed as suspect cases
	Leonard et al.	MRSA isolates from postoperative infection sites in five dogs and from nares of veterinary surgeon indistinguishable by PFGE
	Cuny et al.	Approx. 0.48% of equine cases presented at veterinary teaching hospital infected with MRSA. Long term nasal carriage of MRSA in two attending veterinarians
	Strommenger et al.	MRSA isolates from dogs and cats closely resemble hospital-derived isolates in local human population
	Weese et al. (a)	Skin infections and nasal carriage reported in personnel attending a foal with MRSA infection
	Weese et al. (b)	Animal to human and human to animal transmission of MRSA suspected following investigation of six instances of MRSA infection in pets
	Weese et al. (c)	Community-associated MRSA colonization rate of 27 per 1000 equine admissions to veterinary teaching hospital. Incidence rate of nosocomial MRSA infection of 1.8 per 1000 admissions
	Malik et al.	*mecA* gene in MRSA isolates from dogs and cats shown to be identical to that found in human strains
	Rich and Roberts	Culture of 561 isolates of MRSA from clinical infections in animals between January 2003 and August 2006. One of 255 healthy dogs sampled found to carry MRSA

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canine and equine patients (Middleton et al., 2005). Although it is possible that part of the perceived increase in MRSA cases is due to increased awareness and testing, it does appear likely that MRSA infection is a disease of emerging importance in dogs, cats and horses (Duquette and Nuttall, 2004; Weese et al., 2005a). Table 1 summarizes the publications reporting MRSA infections in animals to date.

4.1. MRSA in dogs and cats

Most studies indicate that *S. intermedius* is the most prevalent coagulase-positive staphylococcal species isolated from dogs (Medleau et al., 1986; Saijonmaa-Koulumies and Lloyd, 1996; Rich and Roberts, 2004) and cats (Lilenbaum et al., 1998). *S. aureus* is capable of colonizing the healthy canine hair coat (White et al., 1983) but the frequency of *S. aureus* isolation from dogs and cats is generally low, typically being recovered from <10% of samples (Cox et al., 1984; Medleau et al., 1986; Saijonmaa-Koulumies and Lloyd, 1996; Lilenbaum et al., 1998; Duquette and Nuttall, 2004).

With regard to MRSA carriage, a recent study of healthy dogs and cats presented at primary care veterinary clinics did not identify MRSA in 188 dogs and 39 cats sampled (Murphy et al., 2005) while a study of dogs presented at a tertiary care veterinary hospital only found MRSA nasal colonization in 2/203 (1%) dogs (Hanselman et al., 2005). Boag et al. (2004) found MRSA colonization of the nasopharynx in five canine cases with MRSA infections. However, it was unclear if this colonization was present before or after the establishment of infection. A year long survey of 6519 samples submitted to a UK diagnostic laboratory identified 95 MRSA isolates (Rich and Roberts, 2004). In a more recent publication the same authors reported that by August 2006, the number of MRSA isolates confirmed had risen to 561, the vast majority from dogs and cats (Rich and Roberts, 2006). A recent survey of Irish veterinary practices revealed MRSA carriage in 0.6% of dogs presented while evidence of carriage was found in 8% of dogs suspected of MRSA infection on clinical grounds (Abbott et al., 2006).

Several reports have documented an apparent increase in the number of MRSA infections in companion animals in recent years (Boag et al., 2004; O'Mahony et al., 2005). The majority of these infections are associated with postoperative infections and open wounds (Tomlin et al., 1999; Rich and Roberts, 2004; Leonard et al., 2006). The presence of implants such as suture material or orthopaedic devices appears to be associated with the persistence of MRSA infection (Leonard et al., 2006). A bacterial isolation rate of 38% has been reported from the fixation site of orthopaedic implants removed following union from dogs with closed fractures (Smith et al., 1989). Foreign bodies with large surface area are thought to increase the potential for bacterial adherence and perpetuation due to the tissue trauma and devitalisation caused during application, the large surface area for bacteria to adhere to, the polysaccharide mucoid peribacterial film that can form on metallic implants after contamination and the provision of a large mechanical barrier to the immune system (Smith et al., 1989).

4.2. MRSA in horses

Significant clusters of MRSA infection have been documented in horses in veterinary hospitals in North America (Seguin et al., 1999; Weese et al., 2004). Equine MRSA infections have also been recorded in Ireland (O'Mahony et al., 2005), Japan (Anzai et al., 1996; Shimizu et al., 1997), Austria (Cuny et al., 2006) and the United Kingdom (Baptiste et al., 2005). Wound infections and postoperative infections tend to be the most common manifestations similar to the situation in dogs. Transmission of infection on the hands of veterinary personnel is considered to be the principal route of transmission within the veterinary hospital setting. However, a Canadian study found widespread contamination of the veterinary hospital environment suggesting that this may be an important source of MRSA infection (Weese et al., 2004).

Cuny et al. (2006) reported an MRSA infection rate of about 4.8 cases per 1000 equine cases presented at a veterinary teaching hospital in Austria. A North American study reported MRSA isolation rates in horses of 4.7% using non-targeted surveillance compared with 12% using targeted surveillance (Weese et al., 2005b). An MRSA screening programme established at a Canadian veterinary teaching hospital whereby nasal swabs were collected at admission, weekly during hospitalization and at discharge isolated MRSA from 5.3% of equine admissions; 50.8% of these isolates being obtained at the time of admission (Weese et al., 2006c).

5. Public health significance

The possibility that dogs and cats could act as the source for zoonotic staphylococcal infections in humans was suggested many years ago (Mann, 1959). Recent reports suggest that pig farmers are at increased risk of nasal *S. aureus* colonization including MRSA colonization (Armand-Lefevre et al., 2005; Voss et al., 2005). Several reports have presented information suggesting that animals may serve as reservoirs for MRSA infection of humans. In one case, a dog was implicated as a reservoir for the re-infection of two nurses after their treatment to eliminate carriage of MRSA (Cefai et al., 1994) while in another a cat was implicated as the source of MRSA for nurses in a geriatric nursing facility (Scott et al., 1988).

Manian (2003) reported recurrent MRSA infection in a patient with diabetes and in his wife. Sampling of the nares of the family dog revealed MRSA colonization with an identical PFGE type of MRSA. Recurrence of MRSA infection and nasal colonization in the couple was only halted following successful eradication of MRSA from the dog's nares.

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The resistance patterns and genetic make-up of MRSA isolates from dogs and cats are generally indistinguishable from the most prevalent hospital-associated MRSA strains in the human population (O'Mahony et al., 2005). A cluster of five canine postoperative wound cases infected with MRSA were found to be associated with asymptomatic carriage of MRSA in one of the attending veterinary surgeons (Leonard et al., 2006). The human and canine isolates were typed as AR06, which corresponds to epidemic MRSA-15, the predominant strain prevalent in Irish hospitals at this time. In a survey of the nasal and oral mucosae of staff and pets in a small animal referral hospital, MRSA was isolated from 14 staff and four dogs (Loeffler et al., 2005). Typing of the isolates by PFGE showed that the majority were indistinguishable or closely related to EMRSA-15, one of the two EMRSA strains (EMRSA-15 and EMRSA-16) currently prevalent in UK hospitals (Combined Working Party Report, 1998).

A recent study in Canada investigated six reports where MRSA had been recovered from one or more animals in a household or veterinary facility (Weese et al., 2006b). In each case an MRSA isolate, indistinguishable by PFGE from the animal MRSA isolate, was recovered from at least one in-contact person. All the isolates were typed as Canadian epidemic MRSA-2, which is the predominant community-associated MRSA human clone in Canada. The identification of indistinguishable MRSA isolates in both pets and humans in contact with them strongly suggests interspecies transmission but it does not indicate the direction of transmission (Baptiste et al., 2005). However, given the preponderance of common human MRSA clones in household pets, it is likely that animals become colonized through contact with colonized or infected humans and that they in turn serve as a source of re-infection or re-colonization.

In contrast to small animals, equine MRSA strains tend to differ from the common hospital MRSA strains (O'Mahony et al., 2005; Waller, 2005; Weese et al., 2005a, Cuny et al., 2006). The study by O'Mahony et al. (2005) in Ireland found that MRSA isolates from clinical specimens from a variety of veterinary species and from veterinary personnel associated with them, could be divided into two strains by AR and PFGE typing. One strain was associated with small animals and was indistinguishable from the most common human hospital strain in Ireland. The other stain, recovered from horses and equine veterinary personnel, had not previously been reported in Irish studies of human MRSA isolates.

A Canadian study of 79 horses and 27 persons colonized or infected with MRSA between 2000 and 2002 revealed that 96% of the equine and 93% of the human isolates were subtypes of Canadian epidemic MRSA-5, *spa* type 7 and possessed SCC*mec* type IV (Weese et al., 2005a). This human strain is a relatively uncommon isolate in Canada but is able to colonise the nose of horses and to spread between horses and between horses and persons in contact with them (Weese et al., 2006a).

6. Control of MRSA in animals

Numerous documents on the control of MRSA in people have been published (e.g. CDC MRSA guidelines, available at www.cdc.gov/ncidod/dhap/ar_mrsa.html, Coia et al., 2006) and many of the principles may be applied to control in animals also. However, caution should be exercised in extrapolating guidelines for MRSA control in people to animals because there may be significant differences in the epidemiology of the disease (Weese, 2006). At present no controlled studies have been conducted to provide data on key questions such as prevalence and persistence of colonisation and infection in animals, ease of transmission between animals and humans and efficacy of decolonisation procedures in animals.

Limited results of studies examining risk factors for MRSA infection in horses suggest that farm size, prior antimicrobial administration, previous colonisation, previous identification of infection or colonisation in horses on the same farm and previous admission to a veterinary hospital were risk factors for MRSA colonisation (Weese et al., 2005b; Weese, 2006). In addition, although transmission of infection on the hands of veterinary personnel caring for horses is likely to be a major route of infection, a recent Canadian study found that widespread contamination of the veterinary hospital environment can occur and that this may be an important source of MRSA infection (Weese et al., 2004). Risk factors for MRSA infection in pets are currently under investigation (Loeffler, 2006).

Guidelines for control and prevention of MRSA infection in animals have been prepared for individual institutions (Nutall, 2006; Weese, 2006) and the British Small Animal Veterinary Association has drawn up guidelines which are available on its website, www.bsava.com. A summary of control measures for MRSA infection in animals is presented in Table 2.

As in human medicine, hand hygiene is an integral part of the prevention of the spread of MRSA between animals and between animals and humans. Hand washing and disinfection of surfaces and equipment should be carried out between patients. Alcohol gel pouches provided in consulting rooms, on kennels and for wearing on uniforms help to remind staff of the need for hand hygiene and can be used as a rapid, frequent and convenient method of hand sanitising.

Other routine measures to prevent infection include the wearing of uniforms that can be laundered on site and the wearing of gloves, disposable aprons and masks for contact with body fluids or contaminated materials such as are encountered when changing dressings on infected wounds. Eye protection may be worn if splashing or aerosols are expected. Excellent aseptic technique during surgery is essential and high standards of cleaning throughout veterinary premises are important. Although microbiological cleanliness of floors does not appear to be as important as hand-touch sites in the control of human MRSA infections, the situation may be different in veterinary medicine.

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Table 2
Summary of control measures for MRSA infection and colonization in animals

Control principle	Control measure	Comment
Prevent introduction of infection	Screen all incoming cases for infection and/or nasal carriage at admission to veterinary hospital and isolate until negative status established	May be possible in referral practices but only screening of suspect cases is practical in first opinion clinics
Prevent transmission from animal-to-human and human-to-animal	Hand hygiene and related measures • Correct hand washing • Alcohol-based hand sanitizers • Cover wounds and skin lesions • Use gloves, masks, eye protection, disposable aprons for contact with wounds, body fluids or other contaminated materials	These measures are among the most important as transmission via human hands is highly significant based on findings in human medicine
	Strict asepsis during surgery	
	Screening staff for MRSA colonization	This may be required where clusters of infection in animals are identified but should be carried out with sensitivity and in collaboration with the medical profession
Prevent transmission from animal to animal	Isolation of all suspect cases of MRSA infection • No entry to waiting room • Hospitalize in isolation area as far as possible	
	Elimination of carriage may be a possibility but limited data available	
Prevent indirect transmission	High standards of cleaning and disinfection • Hand touch surfaces including doors, pens, stethoscopes, keyboards • Consulting rooms/isolation kennels/stables or other areas following boarding of known infected animals	Environmental transmission may be of greater importance than in human medicine, especially in horses
	Dedicated thermometers, leads, head collars and other handling equipment for known positive or suspect cases	

Transmission of MRSA infection between two dogs in the University Veterinary Hospital, University College Dublin was apparently associated with contamination of the floor in the room where dressings on an infected wound were changed (Y. Abbott and F.C. Leonard, unpublished data).

Identification of colonised or infected animals is important but routine screening of animals before admission to first opinion practices is probably not practical. Thus, it is likely that a small number of colonised animals will remain undetected. Few data on MRSA colonisation rates in non-clinically affected animals are available. The reported admission colonisation incidence rate in horses in a veterinary teaching hospital was 27/1000 admissions (Weese et al., 2006c) and Abbott et al. (2006) reported a prevalence of MRSA colonisation of 0.6% in non-clinically infected dogs in first opinion practices and an equivalent figure of 0.9% in a referral hospital. However, identification of infection in MRSA suspect cases is important. Samples for microbiological analysis should be collected from animals with non-healing wounds, with non-antibiotic responsive infections or with nosocomial infections. Animals from known MRSA-positive households or those belonging to healthcare workers should be screened also. In addition, testing of hospitalised animals may be required if transmission of MRSA infection has been demonstrated within a practice or if veterinary personnel are known to be colonised.

Animals identified as, or suspected to be, positive should be admitted directly into a consultation room to prevent contact with other animals in the waiting room. The consulting room must be cleaned and disinfected before other patients are admitted. Following admission to a veterinary hospital, known or suspected MRSA-infected animals should be isolated and nursed using barrier nursing precautions (Nutall, 2006). Antimicrobial therapy should be based on in vitro susceptibility testing but may need to be coupled with other treatments such as removal of implants (Leonard et al., 2006). Data on methods for eradication of infection and/or colonisation in animals are not available. However, Weese and Rousseau (2005) suggest that decolonisation of horses may be possible using segregation and repeated screening rather than the use of antimicrobial therapy.

Surveillance of veterinary staff for MRSA carriage is controversial and issues pertaining to confidentiality and stigmatisation must be recognised. Both colonisation and transient contamination may be important for transmission of infection in the absence of good infection control procedures. Transient contamination has been identified where MRSA can be isolated from a nasal swab collected in the evening but swabs collected from the same person in the morning are negative (Nutall, 2006). Close co-operation between the medical and veterinary professions is required to identify human carriers and to implement effective control measures in veterinary practices.

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