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A Review on Assessment of Public Health Hazards of Methicillin Resistance *Staphylococcus Aurous* (MRSA) in Animals and Foods

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Abstract
Staphylococcus aureus is a common bacterium present on skin and in mucous membranes in 20-30% of healthy people. It may sometimes cause infections in humans, typically local skin and wound infections but occasionally more severe infections in the body. Some strains of this bacterium have, however, developed a resistance to beta-lactam antibiotics which includes penicillins and are used for the treatment of many infections. These are called Methicillin-resistant *Staphylococcus aureus* (MRSA). Humans mainly acquire MRSA through direct contact between infected humans or contact with medical devices and equipment. MRSA is especially problematic in hospitals where patients with weakened immune systems are at greater risk of infection than the general public. A specific MRSA strain has been reported to occur in food-producing animals, most often in intensively reared pigs, veal calves and chickens, and has also been found in horses and companion animals. Reports on Biological Hazards found that food may be contaminated by MRSA, but it has not been associated with food-borne intoxications. However, in areas where MRSA prevalence in food-producing animals is high, people in contact with live animals are at greater risk of acquiring MRSA than the general population, although infections are rare.
Keywords: MRSA, Health hazard, animals, Food

INTRODUCTION

Staphylococcus aureus is a Gram-positive bacterium and important opportunistic pathogen in various species. Historically it has been a leading cause of both skin and invasive infections in humans, and its impact is no less today. One reason for the continuing important role of *S. aureus* in disease is its propensity to become resistant to antimicrobials. The introduction of penicillin had a profound effect on staphylococcal infections, but penicillin resistance soon followed. Similarly, after the introduction of new antimicrobials such as methicillin, it was not long before methicillin-resistant *S. aureus* (MRSA) developed (Weese, 2010).

Staphylococcus aureus is frequently present on the skin, in the nose or in the mouth of human hosts without causing illness. However, in some instances, *S. aureus* can cause disease when it enters wounds or damaged skin, and can cause abscesses, pneumonia, meningitis, endocarditis and septicaemia (EFSA, 2009).

Methicillin-resistant *S. aureus* (MRSA) is considered to be resistant to virtually all available beta-lactam antimicrobials. This resistance is mediated by the *mec*A gene, chromosomally located in the staphylococcal cassette chromosome, which codes for a penicillin binding protein with a low affinity for beta-lactams. MRSA first emerged in hospitals in the 1970s, and by the 1990s increased dramatically worldwide, becoming a serious clinical problem in hospital environments. In recent years a major change in epidemiology of MRSA has been observed, with the appearance of cases in the community affecting people having no epidemiological connection with hospitals. The strains isolated from such cases are referred to as Community-acquired or Community-associated MRSA (CA-MRSA). Isolates from these cases have clear phenotypic and genotypic differences from the strains isolated from classically health-care associated MRSA cases (EFSA, 2009).

The hazard of animal-associated MRSA has also been recently identified. In this case, it is important to distinguish between MRSA isolated from pet animals, and MRSA from animals used in food production. Since the 1990s, an increasing number of studies have reported MRSA infections in pet animal patients at veterinary clinics and hospitals. Strains isolated from these cases are usually indistinguishable from those isolated from human contacts. It is generally accepted that pets become infected through contact with infected or colonized people, and that pets in turn pass MRSA back to humans. MRSA is not only carried by pet animals but can also cause clinical disease in a number of such animals. Most of the cases of MRSA in pets are reported in dogs and horses, and the majority of such clinical cases have been due to post-operative infections (EFSA, 2009).

With the current knowledge the EFSA assume that MRSA can be transmitted from production animals to humans. Animals in food production and their products are therefore a potential source of community-acquired MRSA. There is increasing concern about the public health impact of MRSA associated with food producing animals. Accordingly, attention requires to be paid to the epidemiology, prevalence and virulence of food and animal derived MRSA strains.

Characteristics of S. aureus and MRSA

S. aureus

Staphylococcus aureus is a Gram-positive bacterium that can colonize and infect humans. *Staphylococcus* *aureus* is often found closely associated with the human body. It may also be found in many parts of our environment, including dust, water, air and faeces and on clothing or utensils. Although *S. aureus* is an important pathogen, many healthy people carry it as part of the normal population of micro-organisms associated with the nose, throat, perineum or skin. The carrier rate varies in different populations. The nasal passages are reported to harbour *S. aureus* in 10-50% of the healthy population. It can be carried harmlessly in the nostrils, throat, and skin Safety because of their frequency and the fact that they do not necessarily prevent the infected person from working. Various types of skin eruptions and inflammations (boils, acne, styes, etc.) and wounds, sometimes as small as minor damage around fingernails, can harbour large numbers of the organisms. *Staphyloccocus aureus* can also cause respiratory infections or may become established in the gut, causing enteritis (Bremer *et al*., 2004). In addition, *S. aureus* is a major cause of food poisoning, due to the production of heat resistant enterotoxins, which when consumed cause vomiting and diarrhea (Rieman and Cliver, 2006).

Methicillin resistant *Staphylococcus aureu*

Antibiotic resistance first became apparent in *S. aureus* in the 1950s when strains of bacteria emerged that possessed penicillin destroying ß-lactamase enzymes and became widespread. This led to the development and use of semi-synthetic penicillins such as methicillin and flucloxacillin that were resistant to the penicillin-destroying enzymes produced by *S. aureus* and other bacteria. Methicillin resistant *Staphylococcus aureus* (MRSA) was first described in 1961, almost immediately after the agent was introduced into clinical practice. It is interesting to note that MRSA also emerged in countries where methicillin had not yet been used. Staphylococci would have likely encountered penicillin-producing moulds in various environments over several million years and MRSA resistance probably represents a more primitive type of penicillin resistance compared to the *S. aureus* penicillin-destroying enzymes that appeared later on. This may also account in part for the appearance of community MRSA where there is no history of interactions with healthcare delivery (Cookson, 2000). Widespread use of antibiotics throughout the 1970s led to the development of resistance, predominately in MRSA, to many other antibiotics such as erythromycin, gentamicin, trimethoprim and, more recently, vancomycin.

Hazard Characterization

Occurrence of MRSA in humans

When MRSA emerged in international hospitals in the 1960s, there was initially limited concern because of the relatively low incidence of disease. It was not until the late 1970s and early 1980s that MRSA rates in hospitals increased dramatically, starting a pandemic phase (Chambers and DeLeo 2009). MRSA had (and continues to have) a tremendous impact on morbidity and mortality in hospitals, but another major epidemiological shift occurred in the 1990s with the widespread emergence of community-associated MRSA (CA-MRSA) infections.

MRSA in hospital staff

Carriage rates in hospital staff vary widely depending on the geographical region. In a recent review of 127 investigations worldwide, an overall prevalence rate of MRSA colonization in hospital staff was 4.6 % (Albrich, and Harbarth, 2008).

MRSA in the community

Early reports of CA-MRSA were associated with strains most commonly found in hospitals and typically involved people with prior healthcare exposure and other health care associated risk factors. Subsequent reports described infections (sometimes fatal) in people with little to no healthcare contact or other recognized risk factors (Diederen and Kluytmans 2006; Frazee *et al*. 2005a). These infections were often associated with strains different from those that predominated in healthcare facilities, demonstrating a unique Community-associated disease, not a hospital-associated infection. Now MRSA is a leading cause of community associated skin and soft tissue infections in some regions, with rare but dramatic serious infections such as necrotizing fasciitis and necrotizing pneumonia (Frazee *et al*. 2005a; Miller *et al*. 2005).

Occurrence of MRSA in animals

Companion animals

In 1988 Scott et al. (Scott *et al*., 1988) reported the first companion-animal related outbreak of MRSA in a rehabilitation geriatric ward where the ward cat was colonized and was implicated as reservoir for re-infection. Infection control measures and removal of the cat led to rapid resolution of the outbreak. Since, the number of reports on infections and colonization with MRSA from companion animals has increased (Leonard and Markey, 2008). MRSA colonization is increasingly found in pets, including cats and dogs, and is known to cause infections. Although there is good evidence to suggest that the MRSA in pets come from contact with humans, pets can form a reservoir of MRSA for reinfecting humans (Coilin and Richard, 2007).

Several studies have examined the prevalence of MRSA in veterinary hospitals in the United Kingdom (Hanselman *et al*., 2008; Loeffler *et al*., 2005; O'Mahony *et al*., 2005). These studies have shown that veterinary staff and their pets have a higher prevalence of MRSA, although they mostly are asymptomatic carriers. A recent study (Moodley *et al*., 2008) showed that MRSA carriage was higher among the veterinary practitioners (3.9%) than among the participants not professionally exposed to animals (0.7%). The results from this study indicate that veterinary professionals are at risk of MRSA carriage and thus should be informed about this emerging occupational health risk and educated about preventive measures. MRSA infections in owners with involvement of their companion animals like dogs and cats have been suggested for many years, and evidence for this hazard has increased during recent years (Leonard and Markey, 2008;Morgan, 2008). Larger epidemiological studies are required to provide more information on specific risk factors.

Food-producing animals.

MRSA has been isolated from most food-producing animals and from most meats as well as from milk. Since the emergence of MRSA in Europe, reports of MRSA in farm animals are increasing. The occurrence of MRSA in raw food is generally low with the highest prevalence reported in The Netherlands where MRSA was detected in 11% of meat samples (de Boer *et al*., 2008). In conclusion, MRSA has recently emerged in food production animals and this has spread over many countries in Europe and North America.

Occurrence of MRSA in foods

Considering the increasing evidence of MRSA in food animals, it is logical that concerns would emerge about MRSA contamination of food and to assume that colonized animals were the source of contamination. But this connection has yet to be clearly demonstrated. MRSA has predominated in some, but not all, reports of MRSA in meat. Studies have reported the presence in meat of strains more commonly found in people, including strains not yet reported in food animals (Lozano *et al*. 2009; Weese *et al*. 2009), raising questions about whether contamination is from food animals, other sources such as people involved in food processing, or both. Clearly, more information is required, necessitating research beyond the cross-sectional study of retail food contamination. It is also reasonable to suspect that MRSA food poisoning could become more common with an increase in food contamination and colonization of food handlers. As with methicillin-susceptible staphylococci, staphylococcal “food poisoning” caused by ingestion of preformed enterotoxins can occur. While MRSA isolates can possess various enterotoxin genes there is only one report of staphylococcal food poisoning caused by MRSA (Jones *et al*. 2002). This may be in part because of limited attempts to culture stool for *S. aureus* in cases of suspected food poisoning. Clinically, food poisoning caused by MRSA should be no different from that caused by MSSA, but MRSA-contaminated food could also be a source of intestinal colonization.

In addition to these risks, food may be a concern as a vehicle of MRSA extra intestinal colonization and infection. Contaminated food was implicated as a source of an outbreak in a hospital in the Netherlands, where MRSA was isolated from a banana peeled by a colonized food preparer (Kluytmans *et al*. 1995). Based on that finding and the lack of another identified route of transmission, food was suspected as being a vehicle for MRSA, although definitive proof was lacking. It is certainly plausible that surface contamination of food could lead to colonization if people touch their noses after contaminating their hands. Infection of hand wounds could also be a concern, but neither of these has been proven. Recent attention has largely focused on contamination of meat, based on the presence of MRSA in food animals and on reports of MRSA-contaminated retail meat, involving a range of meat products and with prevalences ranging from 0.4% to 12% (de Boer *et al.* 2009; Lozano *et al*. 2009). Although it is not advisable to compare prevalence data because of varying methods, sample collection schemes, and sample types, these studies indicate that MRSA is present in a varying but generally small percentage of retail meat samples.

Exposure assessment

Transmission route of MRSA

S. aureus is transmitted from human to human, animals to human and vice versa and through viable or inanimate vectors (Roberson, 1999). Skin to skin contact is probably the main route of transmission between humans, humans to animals, animals to human and between animals, however contaminated materials, surfaces, food or dust can play also a role in transmitting the agent (Asoh, *et al.*, 2005; Lee, 2003). This is true for both HA-MRSA and CA-MRSA. Conditions such as overcrowding and understaffing in hospitals can contribute to high colonization pressure and increase the transmission risk (Clements, *et al.*, 2008). Dust is identified as a vehicle for the airborne transmission of *S. aureus* and may play a role in the spread of infections (Shiomori, *et al.*, 2001); therefore the presence of MRSA in air of a positive farm is likely.

Risk factors for the stages of contaminated, carrier and disease in humans.

Serious disease has been reported with the livestock-associated MRSA (Ekkelenkamp, *et al.*, 2006), however the process risks to becoming contaminated, developing carriage or developing diseases after contact with MRSA positive animals are poorly understood. A carriage rate of 29% in persons who worked regularly with pigs, 12% in those entering pig houses at least once per week but not working with pigs and carriage in only 2% of those with no contact with pigs but living on positive farms have been reported. In Denmark, MRSA was isolated from 31 persons between 2003 and 2007 (Lewis, 2008). Further information was obtained on 21 cases, of which 10 had clinical symptoms, mainly skin and soft tissue infections. A study indicated that living or working on farms with animals was an independent risk factor for MRSA. The low carriage rate in those without pig contact suggests that person to person transmission of the MRSA strain occurs infrequently. However, using data from several studies concluded that colonization with MRSA in humans was associated with a four-fold increase in the risk of developing infection. Considerations on the development of disease in healthcare workers colonized with MRSA may be helpful in assessing the risk of disease in colonized animal associated personnel.

Transmission routes between animals and within the food chain.

The highest reported prevalence of MRSA positive swine was found during an investigation in 50 Belgian fattening farms where 68% (n=34) was found to be positive. A marked difference in the number of MRSA positive animals between open (94%) and closed farms (56%) was demonstrated in the Belgian survey (Denis, *et al.*, 2008). This difference might be the result of MRSA transmission within the production chain, e.g. from multiplier to finisher farms. Little is known about the persistence of MRSA in veal calves over consecutive production rounds. In dairy cattle, the number of MRSA among mastitis isolates is very low. However, where carriage in a herd occurs, up to 15% of lactating cows can be positive for MRSA .In poultry, the highest percentage of MRSA positive animals was also found in Belgium; with 2 of 14 randomly selected broiler farms (14.3%) being positive (Persoons, *et al.*, 2009).

Risk Characterization

Carriage versus disease

Carriage of *S. aureus* in the nose, throat, or gastrointestinal tract of humans and animals is asymptomatic. Disease caused by *S. aureus* varies widely, but often involves a breach of the skin or mucosal membranes followed by inflammation, fever and the generation of pus. Many infections in healthy hosts are minor and may not even be recognized or need treatment. At the other end of the spectrum of disease, shock, multi-organ failure and death can occur. Isolation of *S. aureus* is not sufficient to prove causation of disease, although isolation from an otherwise sterile site with symptoms of disease is significant. However the symptoms associated with most *S. aureus* infection are relatively non-specific and can also be caused by a range of other pathogens: indeed the disease will often be referred to on the basis of symptoms rather than by the causative organism, e.g. sepsis, pneumonia, bacteraemia, etc and in cases, such as chronic pneumonia in ventilated humans, defining when a patient is infected versus colonized with *S. aureus* is extremely problematic (EFSA, 2009). There are two main factors determining colonization and/or infection with *S. aureus* (including MRSA) in different animal species and humans, and these are: the degree of host specificity on part of the bacterium and host susceptibility on the part of the host. The anterior nares are the main site which is colonized by *S. aureus*, therefore it represents the main reservoir for dissemination. In humans about 20% of the healthy populations are permanently colonized (Kluytmans, *et al.*, 1997). Nasal colonization in humans and in pigs is usually with one clone of *S. aureus* (Nouwen, *et al.*, 2004). The basis for the mutual exclusion of colonization is unknown. It is likely that antibiotic use is also important e.g. fluoroquinolones clears carriage of susceptible *S. aureus* and allows colonisation with MRSA which are often resistant to this antibiotic. In a study on human volunteers, non-carriers quickly eliminated *S. aureus* following nasal inoculation; however persistent carriers selected their original resident *S. aureus* from the inoculated mixture (Nouwen, *et al.*, 2004).

Host specificity

S. aureus is not only a colonizer of the mucosa of the upper respiratory tract of all mammals but it has also been found in natural population of birds, including industrially raised poultry. Characterization of MSSA isolates suggests the existence of host adaptation including humans, cattle, sheep, and chicken (Devriese, 1984). This hypothesis was later confirmed by multilocus sequence typing (MLST) which identified *S. aureus* clone preferentially associated with cattle, sheep, goats, chicken and pig (Hata, *et al.*, 2008; Rabello, *et al.*, 2007). However animal clone do cause some human infections and *vice versa*.

Conditions predisposing humans to infections with *S. aureus*

In comparison to the wide-spread distribution of this bacterium as a colonizer, infections are rare events. For humans, the following conditions have been identified to predispose to *S. aureus* infections:

• Exposure to the organism, including from colonized individuals (including patients and staff in hospitals).
• Disruption of skin as an external barrier by injuries or surgery.

• Exposure to the organism from the patients own colonization sites.

These factors predispose to HA-MRSA, as well as specific antibiotic usage which is more likely to lead to infection with MRSA. A recent history of hospitalization as well as being hospitalized in specialized care units such as intensive care and burn units have also been identified as risk factors for HA-MRSA infection. In intensive care units, MRSA colonisation and a higher severity of illness at admission are also risk factors for infection. In long-term care facilities, risk factors for infection include persistent MRSA colonization, and diabetes mellitus.

Risk of human disease through food handling or consumption

The risk from contact with contaminated food appears to be small, and certainly much reduced from that following contact with live animals or humans. Experience in countries with a high prevalence of MRSA, such as the UK, shows that hospital environments are often contaminated with MRSA. The major MRSA reservoirs in hospitals are the noses and hands of patients as well as staff and visitors, equipment, clothing, bedding, curtains and floors (Cimolai, 2008). There are however, descriptions of two outbreaks of foodborne disease due to MRSA. In the first, three family members who shared a meal of pork and coleslaw became ill with nausea, vomiting and stomach cramps. The same strain of MRSA with an indistinguishable pattern was isolated from the three family members, the coleslaw and a food handler at the convenience market where the food was purchased (Jones, *et al.*, 2002). In the second outbreak which affected 27 patients and 14 hospital workers in the Netherlands (Kluytmans, *et al.*, 1995), routine testing of food prepared for patients resulted in the detection of MRSA in a piece of banana, leading to the screening of all food handlers. One worker who had prepared food for patients at the start of the outbreak was found to be colonised with MRSA which was the same strain as that recovered from food sample and from the infected patients. This study suggests that food contaminated by the health worker food handler was likely to have caused the first case of MRSA which was subsequently transmitted to other patients in the surgical unit by a colonized nurse (Kluytmans, *et al.*, 1995).

Risk of human infection through contact with companion animals

MRSA infections in companion animals are increasingly reported, and in almost all cases, the strains causing infection in animals were the same as those commonly occurring in hospitals (Loeffler, et *al.*, 2005). More recently study (Faires, and Weese, 2009) found that amongst 18 households in which a pet had been diagnosed with a MRSA infection, colonization in one or more household members was detected in 5 of the households (28%). Therefore, companion animals serve as reservoir of MRSA for human infections.

Control strategies

In comparison to other zoonotic pathogens such as *Salmonella* and *Campylobacter*, *S. aureus* (including MRSA) has some unique characteristics that require consideration of different control options. This is partly because exposure to, and colonization by, MRSA does not normally lead to disease in healthy humans, however severe infection can occur. At-risk human populations particularly occur in hospitals and other health-care settings, and in these settings, risks are related to introduction of MRSA by human carriers. MRSA carriers can be managed by screening and infection control measures. However strategies for screening (together with actions taken following their results) vary considerably among different countries. In the Netherlands and in Denmark, search-and-destroy policies are implemented which appear to be effective MRSA. In the Netherlands and in Germany it is recommended that persons in contact with live pigs or veal calves are screened for MRSA on admission to the hospital and nursed in isolation until screening tests demonstrate the absence of MRSA. Colonization by MRSA outside hospitals is acquired through direct contact with animals, through the environment contaminated by animal reservoirs or by secondary transmission from human carriers originally exposed to animal reservoirs. Transmission of infection by food products appears to be very rare and based on current data does not warrant specific control measures. Since the most important routes of transmission are through direct contact with live animals and their environments, the most effective control options will be at preharvest. MRSA is one aspect of the wider problem of antimicrobial resistance related to the use of antimicrobials in veterinary medicine, and should be addressed as part of an integrated strategy to reduce resistance. Strategies for control of MRSA in companion animals and individual horses are necessary because they reduce the risk of transfer of MRSA back to humans.

Husbandry interventions, management and organization of animal and food production

Animal movement and contact between animals are likely to be important factors for transmission of MRSA. In the absence of specific studies on the spread and persistence of MRSA, general control options on farms, in slaughterhouses and in food production areas are likely to be the same for MSSA as well as MRSA, and include good husbandry practices and HACCP. Monitoring and subsequent restrictions on movement may reduce transmission. Since the most important routes of transmission to humans are through direct contact with live animals and their environments, the most effective control options will be at pre-harvest. In order to avoid airborne transmission of MRSA from farm areas, sufficient "safe distances" to neighbouring farms and residential areas should be achieved. LA-MRSA may also be introduced by contaminated or colonized humans. Reduction of the number of visitors (Ribbens, *et al.*, 2008) and implementation of control measures such as dedicated clothing and other measures for employees and visitors who are allowed entry may help to prevent introduction of MRSA into a herd/flock, or food production area. The wearing of protective clothing and breathing masks are possible options to reduce the risk of contamination and carriage in humans. Testing of potential employees for MRSA carriage and exclusion is one possible control measure. Spreading of MRSA-containing manure on land may pose a risk of transmission to wild or farm animals and may lead to a contamination of feed, vegetables and fresh produce. Preventive measures in order to avoid MRSA transmission via manure may include long storage times, composting, heat treatment or digestion. However, it has not yet been demonstrated how efficient such treatments are at reducing MRSA.

Control options for human food-borne staphylococcal intoxications

Although a variety of animals carry coagulase positive staphylococci, human carriers are the main reservoirs for *S. aureus* (including MRSA and MSSA) responsible for human foodborne staphylococcal intoxication. Control of staphylococcal food poisoning involves temperature and time control as well as the hygienic behaviour of food handlers, and will be identical for all coagulase positive staphylococci, including MRSA and MSSA. Direct handling of cooked foods should be avoided and suitable utensils used wherever possible.

Food handlers with septic lesions should be excluded until treated successfully. Where hand contact is unavoidable, hands should be cleaned thoroughly and disposable gloves used where practical. Foods should be refrigerated, displayed for time periods in line with current food safety legislation, and disposed after such time has elapsed. Finally, food processes should be controlled to prevent the growth of *S. aureus* in raw materials.

Options for control of transfer of MRSA from companion animals to humans

Vulnerable patients (including the immunocompromised, recently hospitalised, postsurgical patients, and known MRSA carriers) that have contact with small animals, especially those who may be infected or colonised with MRSA or have received antibiotics recently, should be educated about potential zoonotic transfer and hygiene. The risk to human health is likely to be equivalent to having a suspected colonized or infected family member. If companion animals are colonized with MRSA it will be found in the nose, as well as other moist areas. Infected animals may have lesions that can potentially disseminate high levels of MRSA. Transfer of MRSA to and from humans is potentially easy, and difficult to control. Basic hygiene measures are key, especially hand washing before and after pet contact, and if possible, avoiding direct contact with nasal secretions, saliva and wounds. In a study of equine veterinary personnel, hand washing between animals and between farms was associated with a reduced risk of MRSA colonisation, emphasizing the importance of this control measure (Anderson, M.E. *et al.*, 2008).

Conclusions

The overall role of animals in human MRSA infections varies tremendously between animal species and regions. And because the epidemiology of MRSA in animals is only superficially understood, it is inappropriate to draw conclusions or take actions based on rather limited data. However, it is clear that MRSA is an excellent example of the "One Health" concept as it can reciprocally affect human and animal populations. Concerns about MRSA in animals are reasonable and require careful study of various aspects to better understand the emergence and dissemination of MRSA in different species and to characterize interspecies transmission. At the same time, it is important to remember that a minority of human MRSA infections are directly associated with animals. Thus, a balanced approach is key in efforts to reduce the implications of MRSA in both animals and humans while avoiding an excessive response that might unnecessarily harm human interactions with pets, food animals, and food. As MRSA becomes (or has become) established in different animal and human populations, elimination of all risk will be impossible. However, proper study of MRSA in animals, characterization of interspecies transmission, identification of true human and animal health risks, and development of evidence-based control measures can surely reduce the impact on animal health and welfare, human health, agriculture, and the human-animal bond.

RECOMMENDATIONS

In order to identify trends in the spread and evolution of zoonotically acquired MRSA, systematic surveillance and monitoring of MRSA in humans and food producing animals is recommended. Harmonized data, including information on risk factors, as well as analysis of a representative sample of isolates for susceptibility to multiple antimicrobial agents, virulence associated traits, should be available from a single location. In order to evaluate the effectiveness of control measures to reduce the carriage of MRSA in livestock, intervention studies should be carried out. The factors responsible for host specificity, persistence in different environments, transmission routes (including airborne transmission) and vectors, should be investigated. In order to evaluate the effectiveness of control measures to reduce the carriage of MRSA in companion animals and their human contacts, intervention studies should be carried out. On the base of already existing control strategy for prevention of MRSA infection, protocols for screening at admission to hospitals should be expanded to include humans exposed to intensively reared livestock.

Reference

Albrich, W.C. and Harbarth, S. (2008). Health-care workers: source, vector, or victim of MRSA? *Lancet Infect Dis* 8 (5), 289-301.

Anderson, M.E., Lefebvre, S.L. and Weese, J.S. (2008). Evaluation of prevalence and risk factors for methicillin-resistant *Staphylococcus aureus* colonization in veterinary personnel attending an international equine veterinary conference. *Vet Microbiol* 129 (3-4), 410-417.

Asoh, N., Masaki, H., Watanabe, H., Watanabe, K., Mitsusima, H., Matsumoto, K., Oishi, K. and Nagatake, T. (2005). Molecular characterization of the transmission between the colonization of methicillin-resistant *Staphylococcus aureus* to human and environmental contamination in geriatric long-term care wards. *Intern Med* 44 (1), 41-45.

Bremer, P.J., Fletcher, G.C. and Osborne, C. (2004). *Staphylococcus aureus*. *New Zealand Institute for Crop & Food Research*

Chambers, H.F, DeLeo FR. (2009). Waves of resistance: *Staphylococcus aureus* in the antibiotic era. Nat Rev Microbiol 7:629-641.

Cimolai, N. (2008). MRSA and the environment: implications for comprehensive control

Clements, A., Halton, K., Graves, N., Pettitt, A., Morton, A., Looke, D. and Whitby, M. (2008). Overcrowding and understaffing in modern health-care systems: key determinants in meticillin-resistant *Staphylococcus aureus* transmission. *Lancet Infect Dis* 8 (7), 427-434.

Cockfield, J.D., Pathak, S., Edgeworth, J.D. and Lindsay, J.A. (2007). Rapid determination of hospital-acquired meticillin-resistant *Staphylococcus aureus* lineages. *J Med Microbiol* 56 (5), 614-619.

Coilin, N., Richard, Y. (2007). MRSA in farm and meat: A new threat to human health. Soil Association series, report no. 5, UK.

Cookson, B.D. (2000). Methicillin-resistant *Staphylococcus aureus* in the community: new battlefronts, or are the battles lost? Infect Control Hosp Epidemiol 21: 398-403.

de Boer, E., Zwartkruis-Nahuis, J.T., Wit, B., Huijsdens, X., de Neeling, A., Bosch, T., van Oosterom, R.A., Vila, A., Heuvelink, A.E. (2009). Prevalence of methicillin-resistant *Staphylococcus aureus* in meat. *Int J Food Microbiol* 134:52-56.

Denis, O., Suetens, C., Hallin, M., Ramboer, I., Catry, B., Gordts, B., Butaye, P. and Struelens, M.J.(2008). High prevalence of "livestock-associated" meticillin-resistant *Staphylococcus aureus* ST398 in swine and pig farmers in Belgium. *18th European Congress of Clinical Microbiology and Infectious Diseases (ECCMIC)*, Barcelona, Spain,

Devriese, L.A., (1984). A simplified system for biotyping *Staphylococcus aureus* strains isolated from animal species. *J Appl Bacteriol* 56 (2), 215-220.

Diederen, B., Kluytmans, J. (2006). The emergence of infections with community associated methicillin resistant *Staphylococcus aureus*. J Infect 52:157-168.

Ekkelenkamp, M.B., Sekkat, M., Carpaij, N., Troelstra, A. and Bonten, M.J. (2006). Endocarditis due to meticillin-resistant Staphylococcus aureus originating from pigs. *Ned Ned Tijdschr Geneeskd* 150 (44), 2442-2447.

Faires, M. and Weese, S. (2008a). Prevalence of methicillin-resistant *Staphylococcus aureus* colonization in people and pets in the same household. *Antimicrobial resistance in zoonotic bacteria and foodborne pathogens*, Cpenhagen, Denmark, American Society for Microbiology

Frazee, B., Lynn, J., Charlebois, E., Lambert, L., Lowery, D., Perdreau-Remington, F. (2005a). High prevalence of methicillin-resistant *Staphylococcus aureus* in emergency department skin and soft tissue infections. *Ann Emerg Med* 45:311-320.

Frazee, B., Salz, T., Lambert, L., Perdreau-Remington, F. (2005b). Fatalcommunity associated methicillin-resistant *Staphylococcus aureus* pneumonia in an immuno competent young adult. *Ann Emerg Med* 46:401-404.

Hanselman, B.A., Kruth, S., Weese, J.S. (2008). Methicillin-resistant staphylococcal colonization in dogs entering a veterinary teaching hospital: *Vet.Microbiol*. 126: 277-281.

Hata, E., Katsuda, K., Kobayashi, H., Nishimori, K., Uchida, I., Higashide, M., Shikawa, E., Sasaki, T. and Eguchi, M. (2008). Bacteriological characteristics of *Staphylococcus aureus* isolates from humans and bulk milk. *J Dairy Sci* 91 (2), 564-569.

Jones, T., Kellum, M., Porter, S., Bell, M., Schaffner, W. (2002). An outbreak of community-acquired foodborne illness caused by methicillin-resistant *staphylococcus aureus*. Emerg Infect Dis 8:82-84.

Kluytmans, J., van Belkum, A. and Verbrugh, H. (1997). Nasal carriage of *Staphylococcus aureus*: epidemiology, underlying mechanisms, and associated risks. *Clin Microbiol Rev* 10 (3), 505-520.

van Leeuwen, N. (1995). Food-initiated outbreak of methicillin-resistant *Staphylococcus aureus* analyzed by phenotypic and genotyping. *J Clin Microbiol* 33:1121-1128.

Lee, J.H., (2003). Methicillin (Oxacillin)-resistant *Staphylococcus aureus* strains isolated from major food animals and their potential transmission to humans. *Appl Environ Microbiol* 69 (11), 6489-6494.

Leonard, F.C., Markey, B.K. (2008). Meticillin-resistant *Staphylococcus aureus* in animals: a review: Vet.J. 175: 27-36.

Lewis, H.C., Molbak, K., Reese, C., Aarestrup, F.M., Selchau, M., Sorum, M. and Skov, R.L. (2008). Pigs as source of methicillin-resistant *Staphylococcus aureus* CC398 infections in humans, Denmark. *Emerg Infect Dis* 14 (9), 1383-1389.

Loeffler, A., Boag, A.K., Sung, J., Lindsay, A., Guardabassi, L., Dalsgaard, A., Smith, H., Stevens, K.B., Lloyd, D.H. (2005). Prevalence of methicillin-resistant *Staphylococcus aureus* among staff and pets in a small animal referral hospital in the UK: *J.Antimicrob.Chemother*. 56: 692-697.

Lozano, C., López, M., Gómez-Sanz, E., Ruiz-Larrea, F., Torres C., Zarazaga, M. (2009). Detection of methicillin-resistant *Staphylococcus aureus* ST398 in food samples of animal origin in Spain. J Antimicrob Chemother, 64:1325-1326

Miller. L., Perdreau-Remington, F., Rieg, G., Mehdi, S., Perlroth, J., Bayer, A., Tang, A., Phung, T., Spellberg, B. (2005). Necrotizing fasciitis caused by community-associated methicillin-resistant *Staphylococcus aureus* in Los Angeles. *N Engl J Med* 352:1445-1453.

Moodley,A., Nightingale, E.C., Stegger, M., Nielsen, S.S., Skov, R.L., Guardabassi, L. (2008). High risk for nasal carriage of methicillin-resistant *Staphylococcus aureus* among Danish veterinary practitioners: *Scand.J.Work Environ.Health*, 34:151-157.

Morgan,M. (2008). Methicillin-resistant *Staphylococcus aureus* and animals: zoonosis or humanosis? J.Antimicrob.Chemother, 62:1181-1187

Nouwen, J., Boelens, H., van Belkum, A. and Verbrugh, H., (2004). Human factor in *Staphylococcus aureus* nasal carriage. *Infect Immun* 72 (11), 6685-6688.

O'Mahony, R., Abbott, Y. Leonard, F.C., Markey, B.K., Quinn, P.J., Pollock, P.J., Fanning, S., Rossney, A.S. (2005). Methicillin-resistant Staphylococcus aureus (MRSA) isolated from animals and veterinary personnel in Ireland: *Vet.Microbiol*. 109: 285-296.

Rabello, R.F., Moreira, B.M., Lopes, R.M., Teixeira, L.M., Riley, L.W. and Castro, A.C. (2007). Multilocus sequence typing of *Staphylococcus aureus* isolates recovered from cows with mastitis in Brazilian dairy herds. *J Med Microbiol* 56, 1505-1511.

Rieman, H.P., and Cliver, D.O. (2006). Foodborne infection and intoxication. 3rd ed. Elsiver Inc, India, pp 523-552.

Roberson, J.R. (1999). The epidemiology of *Staphylococcus aureus* on dairy farms. *National Mastitis Council 38th Annual Meeting. USA.*

Scientific Opinion of the Panel on Biological Hazards on a request from the European Commission on: Assessment of the Public Health significance of meticillin resistant *Staphylococcus aureus* (MRSA) in animals and foods. (2009). *the EFSA Journal* 993, 1-73.

Scott, G.M., Thomson, R., Malone-Lee, J., Ridgway, G.L. (1988). Cross-infection between animals and man: possible feline transmission of *Staphylococcus aureus* infection in humans? J.Hosp.Infect. 12: 29-34.

Shiomori, T., Miyamoto, H. and Makishima, K., (2001). Significance of airborne transmission of methicillin-resistant *Staphylococcus aureus* in an otolaryngology-head and neck surgery unit. *Arch Otolaryngol Head Neck Surg* 127 (6), 644-648.

Strommenger, B., Kehrenberg, C., Kettlitz, C., Cuny, C., Verspohl, J., Witte, W. and Schwarz, S. (2006). Molecular characterization of methicillin-resistant *Staphylococcus aureus* strains from pet animals and their relationship to human isolates. *J Antimicrob Chemother* 57 (3), 461-465.

Weese, J.S. (2005). Emergence of methicillin-resistant *Staphylococcus aureus* in pets: implications for animal and human health. Proceedings of the American College of Internal Medicine.

Weese, J.S., Avery, B., Rousseau, J., Reid-Smith, R. (2009). Methicillin-resistant *Staphylococcus aureus* contamination of retail meat: Canada. American Society for Microbiology (ASM)-ESCMID Conference on Methicillin- Resistant Staphylococci in

Weese, J.S. (2010). Methicilin resistance *Staphylococcus aureus* in animals. *ILAR journal*, 51(3): 233-244. Animals, London

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