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Methicillin Resistant *Staphylococcus aureus* (MRSA) Infection in Canines and its Public Health Importance

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ABSTRACT

This paper reviews about Methicillin-resistant *Staphylococcus aureus* (MRSA) in canines and its influence in public health. This disease could spread from one species to another, including from people to dogs and vice versa. MRSA in pets was reported in the late 1990s. The clonal types that infect people in the same geographic area connect with those seen in dogs and cats. Globally *S. aureus* was the main cause of infections linked to health care and the community. MRSA in dog kennels can cause a number of illnesses, such as pyoderma observed that animals have superficial bacterial infections that cause pus-filled skin lesions and signs like pruritus, discomfort, inflammation crusting, pustules, irritation, and even hair loss and deadly pneumonia in pups, and gangrenous mastitis in bitches. Methicillin was one of the antistaphylococcal penicillins to which *S. aureus* has become resistant. Penicillin binding protein 2a (PBP2a), which had a very low affinity for beta-lactam antibiotics, was encoded by the *mecA* gene and mediates MRSA resistance. For MRSA infections in animals, conventional antibiotics such as doxycycline, rifampin, clindamycin, trimethoprim-sulfamethoxazole, tetracyclines, and vancomycin could be administered. Improving infection control procedures like hospitals and household was a proven and effective way to reduce the spread of bacteria resistant to antibiotics and other diseases. Biosecurity and disease management programs must be implemented to stop the spread of pathogens to humans. Measures to prevent antibiotic resistance and reduce the spread of disease include vaccination campaigns, animal and handler cleanliness, and sanitation.

KEYWORDS: Dog, MRSA, public health, risk factors, *Staphylococcus aureus*

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1. INTRODUCTION

Staphylococcus is a genus that has 81 species and many subspecies and most of them are commensals or opportunistic pathogens on mammals (Haag et al., 2019). *Staphylococcus* is named after two Greek words: "staphyle" which means bunch or cluster, and "kokkos,"which means grapes. When viewed under a microscope, the term "bunch of grapes" is used. "Golden Cluster Seed" or "*Staphylococcus aureus*" is the source of the term "golden staph". As facultative anaerobes, *Staphylococci* belong to the *Staphylococcaceae* family. It can form colonies in a range of colors on different culture media, including yellow colonies on mannitol salt agar, pink colonies on chromogenic agar, and golden or grayish-white colonies on blood agar. *S. aureus* shows development in multiple planes under a microscope, appearing as spherical seeds grouped in bunches. The commensal and opportunistic nature of this organism allows it to colonize a variety of locations on the surfaces of both human and animal bodies. Numerous virulence factors, including different kinds of proteins, enzymes, toxins, and other compounds with high pathogenicity, can be produced by *S. aureus*. Fibronectin-binding protein and protein A are produced by *S. aureus* and help the bacteria to get attached and colonized in cell surfaces. *S. aureus* produces the several types of toxins that include exotoxins, enterotoxins, beta, gamma hemolysins, and Panton-Valentine leukocidin (PVL) toxins. All of these facilitate the spread of *S. aureus* infections, which can lead to serious bloodstream and necrotizing infections in people (Shoaib et al., 2023). Akanbi et al. (2017) recorded that gram-positive *S. aureus* range in size from 0.5 to 1.5 µm. This bacterium is oxidase-negative, catalase-positive, hemolytic, coagulase-positive, non-motile, and non-spore-forming. MRSA is resistant to the majority of β-lactam antibiotics because penicillin-binding proteins (PBPs) are inhibited by antibiotics and PBPs (PBP2a) have a poor affinity for most β-lactam antibiotics. Methicillin-resistant *Staphylococcus aureus*, also referred to MRSA is resistant to the majority of β-lactam antibiotics because penicillin-binding proteins (PBPs) are inhibited by antibiotics and PBPs (PBP2a) have a poor affinity for most β-lactam antibiotics (Rosado et al., 2025). MRSA can cause zoonotic disease. This disease can spread from one species to another, including from people to dogs and vice versa. Treatment of a dog with MRSA is challenging. Canines are known as MRSA-colonized because they are carriers. All dogs are susceptible to MRSA. Because their immune systems are weaker, dogs that are very young or extremely old are more likely to have MRSA. MRSA can also affect dogs whose immune systems are already weakened, such as those who have been injured or suffer from other diseases. The danger of MRSA exposure is higher for therapy dogs that visit hospitals and assisted living facilities, as well as for dogs whose owners work in hospitals. The MRSA bacteria will usually be present in the nose and mouth or around the anus of a colonized dog (Petinaki and Spiliopoulou, 2015). Host-switching events occurs when pathogens are transmitted and adapted between humans and animals that pose risks to public health, animal health, and welfare, as they facilitate the spread of resistant strains such as MRSA and MRSP. Several studies have demonstrated that MRSA strains isolated from companion animals are typically of human origin, indicating reverse zoonosis, a transmission of pathogens from humans to animals (Dewulf et al., 2025). Thus the manuscript was aimed to gather research outcomes about Methicillin-resistant *Staphylococcus aureus* (MRSA) in canines and its importance in public health.

2. HISTORY

Early in the 1970s, a case of bovine mastitis in Belgium was the first account of MRSA infections in animals. MRSA has now been identified as a significant veterinary and zoonotic pathogen in a growing number of reports on its infection and colonization in companion and food-chain animals. According to molecular type, certain animal lineages are host-specific while others can colonize or infect a broad range of animals, including people. MRSA in pets was reported in the late 1990s. The clonal types that infect people in the same geographic area connect with those seen in dogs and cats. MRSA was discovered in pets in France, Germany, and in a UK. A contaminated resident cat in UK, geriatric nursing home caused the first MRSA human outbreak of feline origin in 1988, affecting both patients and staff. The transmission of MRSA is facilitated by close contact between pets and their owners. Interestingly, pet owners are more prone than the general population to become colonized with MRSA. In 2005, the Netherlands published the first report of MRSA in pigs (Aires-de-Sousa, 2017).

2.1. World scenario of occurrence of MRSA

According to Haenni et al. (2017) the rates of MRSA colonization reported by various studies are highly significant and rely on several factors such as household hygienic conditions, geographical location, the animal population studied, and many others. A study has revealed alarmingly elevated MRSA colonization rates in the most commonly seen in companion animals like dogs and cats. Additionally, considering the global population of dogs and cats as pets, the potential transmission among animals and their owners is concerning. In a study carried out in Germany, all strains of *S. aureus* obtained from pet dogs and cats are found to carry the *mecA* gene. Likewise a significant MRSA colonization rates were reported in France, where 39.3% of dogs, 26.5% of cats were tested positive for MRSA and Methicillin-susceptible *S. aureus* (MSSA) isolation rates

were 37% and 30% respectively in companion dogs and cats. The total MRSA prevalence rate was 10.8%, according to a study conducted in Greece. The prevailing lineages of MRSA of human origin are frequently reflected in the prevalence of specific clonal lineages of MRSA recovered from companion animals, which are identical throughout European nations (Drougka et al., 2016).

Clinical *S. aureus* isolates with methicillin resistance percentage were varying widely nation to nation, ranging from as low as 9% in Scandinavia to over 50% in nations like the US and China. Nosocomial MRSA infection is day by day decreasing in the Europe, US, China, and other many countries, possibly as a result of improved surveillance and sanitation practices but in developing nations MRSA still rising (Petersen et al., 2021).

In veterinary medicine, MRSA causes serious risk to the health of animals. Globally *S. aureus* is the main cause of infections linked to health care and the community and it's also becoming more and more common in veterinary environment. Human health is at risk because; the infected animals act as reservoirs. The occurrence rates of MRSA in the veterinary clinics vary significantly by species and region worldwide, more difficult to control in both developed and developing nations because it is zoonotic. It is crucial to comprehend MRSA resistance mechanisms and transmission dynamics in order to develop efficient management strategies and reduce its effects on both humans and animals health (Olanipekun et al., 2025).

The major strains of MRSA that are carried by infected dogs and cats in North America and Europe. Due to the paucity of hospital-based data and the lack of national population-based surveillance in pets, it may be difficult to determine the actual prevalence of MRSA infections in domestic pets within the community. There is a great overview of the epidemiology and genomic content of MRSA strains collected from veterinary sources (Morris et al., 2017).

Reddy et al. (2016) said that the percentage of dogs with *S. aureus* carrier infections varies from 20% to 70–80%. It has become clearer that the dog's nose acts as a carrier of infection and can be a source of spread bacterial illnesses. Dogs and cats that are identical to their owners and infected pets have been discovered to have MRSA matches in European research. Animals can spread MRSA to humans or other species by coming contact with infected humans, as evidenced by the prevalence of human MRSA strains in domestic pets. Previous research indicated that MRSA can infect dogs and that dogs can serve as MRSA reservoirs. A significant clinical sign in dogs is recurrent pyoderma caused by untreated underlying causes, improper antibiotic administration, or unsuitable antibiotic therapy duration. MRSA has been a treatment problem in veterinary dermatology in recent years due to its increased prevalence. To determine the MRSA present in dogs with recurrent pyoderma and how susceptible they are to different antimicrobials, the study was undertaken.

The World Health Organization (WHO) recognized that high-priority pathogen is MRSA. MRSA emergence and transmission worldwide is important components of its epidemiology. There are two primary ways of MRSA spreads: either by horizontal gene transfer of the staphylococcal chromosomal cassette *mec* (*SCCmec*) element or by passing on pre-existing clones from people to animals (Lee et al., 2018). Penicillin-binding protein 2a (PBP2a), which is encoded by the *SCCmec* element in MRSA strains, has a low affinity for the majority of β-lactam antibiotics. This makes antibiotics useless in preventing the enzyme activity required for the formation of cell walls, hence conferring resistance to a broad range of β-lactam antibiotics. Furthermore, certain strains of MRSA generate β-lactamase; an enzyme that degrades β-lactam antibiotics, such as methicillin (Bush and Bradford, 2020). Since the *mecA* and *mecC* genes create the PBP2a and PBP2c proteins, respectively, MRSA exhibits antibiotic resistance. The genes that cause MRSA high degree of methicillin resistance are found in the staphylococcal chromosomal cassette *mec* (*SCCmec*), where *mecA* codes for PBP2a, an alternative penicillin-binding protein. Methicillin works by preventing penicillin-binding proteins from cross-linking peptidoglycan, which is an essential step in the production of cell walls. By creating substitute penicillin-binding proteins that preserve vital functions, MRSA develops resistance, make methicillin useless (Larsen et al., 2022). Anjum et al. (2019) stated that the origin of MRSA strains determines their classification: connected to the health care sector, livestock, and community. MRSA that can conduct specialized biochemical reactions, such as target modification, efflux pumps, or enzymatic inactivation, that can be specific to several antimicrobial classes.

2.2. Study conducted in India

The *S. aureus* causes a variety of illnesses in both humans and animals, it can found all over the world from minor infections to potentially fatal bacteremia. Reports of *S. aureus* infections in domestic pets that are resistant to antibiotics appear to have increased in recent years. Antimicrobial-resistant *S. aureus* include oxacillin-resistant *S. aureus* (ORSA), MRSA, glycopeptide-resistant *S. aureus* (GRSA), vancomycin-intermediate *S. aureus* (VISA), and vancomycin-resistant *S. aureus* (VRSA), depending on the drug resistance pattern. Maximum all domestic animals in India, including cows, dogs, cats, sheep, pigs, and horses, have been found resistant to *S. aureus*. Therefore, to prevent human infections, prolonged surveillance and management

of antimicrobial-resistant *S. aureus*, especially MRSA, in domestic animals are necessary. Determining the prevalence and antibiotypes of *S. aureus* in clinical pyogenic cases of domestic animals in India was the goal of the investigation (Yadav et al., 2018).

A study conducted in Tamil Nadu, found that *Staphylococcus* is naturally found in dogs' skin, is the source of canine pyoderma is a prominent infection in dogs caused by *Staphylococcus*. The disease is characterized by pus-filled lesions due to secondary bacterial infections. It is more often reported in dogs than cats. The clinical signs include excessive itching, licking, or chewing. The skin will appear crusty or moist and the fur of the canine would be patchy with peeling. Pyoderma is caused by three major species of *Staphylococcus* namely *S. aureus, S. intermedius*, and *S. pseudintermedius*. Methicillin resistance has emerged in some species of *Staphylococcus* and poses a serious concern for animals and human beings. In pets, MDR bacteria including MRSA and *S. pseudointermedius* (MRSP) are frequently found (Raja et al., 2024).

2.3. Transmission

The skin and mucous membranes of both humans and animals naturally harbour *Staphylococci*. In addition to diseases, certain environmental conditions, close contact with infected animals and humans, can also affect the nasal carriage of coagulase-positive and coagulase-negative *Staphylococci* in dogs. Some research indicates that the close contact may increase the colonization of *S. aureus* in dogs, even though the exact mechanism of *Staphylococci* transmission between humans and dogs is still unknown (Cuny et al., 2022).

Akhtar et al. (2023) reported that health hazards, such as the spread of zoonotic diseases like *S. aureus* and MRSA, may also be linked to human and animals interactions. The spread of *S. aureus* by direct contact such as bathing, sharing a couch or bed, caressing, licking, or indirectly contact with contaminated surfaces. Pets are serving as a reservoir for *S. aureus*/MRSA; most of the time the pet owner, pets, or both were known to be colonized or infected with MRSA. Very few studies have described that zoonotic transmission within households. Cats and dogs are aiding in MRSA colonization in humans and its clinical impact. Notably, despite the potential that pets can act as "living fomites" and restart the MRSA transmission cycle inside households, there are currently no standardized recommendations for the surveillance and decontamination of pets.

S.aureus can spread from animal to animal, from person to person and from animal to human and *vice versa*. It is typically spread through the hands, with infected or colonized animals or people as well as contaminated objects and surfaces. *S. aureus* that is found in the nose and on the skin is released into the environment by infected or colonized people and animals, suggesting that airborne transmission may be a potential route of infection. Additionally, vectors such as the housefly (*Musca domestica*) have been linked to the spread of *S. aureus* (Pal et al., 2020).

Pal et al. (2024) narrated that there are multiple ways that health care-associated MRSA (HA-MRSA) can spread, including through contact with surfaces, aerosols, hand hygiene, and encounters with medical staff. In hospital settings, contaminated equipment, bedding, doors, and instruments are the main sources of HA-MRSA infections. On the other hand, since *S. aureus* can coexist peacefully in healthy people's nasal passages, community-associated MRSA (CA-MRSA) is usually spread by contact with infected or healthy people (Foster, 2017).

2.4. Pathogenicity

Even though *S. aureus* is a common bacterium found on the skin and mucous membranes, it can infect those with weakened immune systems or penetrate through any skin break. Toxin production and colonization, results in tissue invasion and destruction. These are the two potential pathways by which the disease process can be mediated (Yilmaz and Aslantas, 2017). By releasing exfoliating toxins, hemolysins that cause holes in the skin's cell membranes, and other enzymes that break down tissue, *S. aureus* compromises the skin barrier. When the physical integument breaks, the immune system is weakened, or there is localized inflammation, the invasion may be initiated. Evasion: By releasing anti-opsonizing proteins (chemotaxis inhibitory protein), which stop neutrophils from phagocytosing, *S. aureus* evades the immune system. Additionally, protein A, which is found on the surface of *S. aureus* cells, possesses antiphagocytic qualities. Additionally, *S. aureus* produces super antigens (enterotoxin and TSST1) and secretes PVL, which lyses leukocytes. These substances disrupt the normal immune response by stimulating T cells (receptor β-variable specific T cells) and causing them to proliferate. The PVL genes can be spread through bacteriophages, which have ability to transfer between organism. The formation of a biofilm is a two-stage process that includes an initial attachment phase and a following maturation phase, These phases differ physiologically and need elements unique to each phase. These phases differ physiologically and need for elements unique to each phase. A final detachment phase, which is thought to be essential for the bacteria's spread, entails the separation of individual cells or cell clusters by a variety of processes. On damaged skin or body areas, *S. aureus* quorum sensing may control gene expression to create slimy biofilms. When oxygen and nutrients are depleted, bacteria go into a dormant state where they are less vulnerable to certain antibiotics. Small-colony *S. aureus* strains in particular show nearly total resistance to

antimicrobial agents when adherent and in the stationary phase. The bacterial cells are shielded by the biofilm matrix, which prevents certain antibiotics from entering (Aung et al., 2020).

2.5. Sites for colonization

Skin infections, surgical site infections, nasal cavity infections, middle ear infections, urinary tract infections, and dog bite wounds are among the most frequent infections. Opportunistic infections, however, can also happen at different parts of the body (Afshar et al., 2023).

Asanin et al. (2019) reported that main colonization sites in cats and dogs are the nostril, mouth and perineum. Direct or indirect contact with animals and their owners may result in *S. aureus* colonization. In addition to pets, primarily dogs and cats, other investigations have shown that MRSA are present in other companion animals, such as guinea pigs, birds, turtles, and hamsters. This widespread distribution demonstrates that MRSA is well-suited to colonize a variety of animal hosts.

Dong et al. (2021) reported that *S. aureus* can invade the skin, mucosal surfaces, animal nasal passages, and other physiological sites. Humans may carry MRSA, especially those who work directly with infected animals, such as veterinarians and pet handlers. According to Traverse and Aceto (2015), MRSA can be found in feces, skin lesions, and animals' housing and veterinary clinics, which include cages, bedding, and medical equipment.

2.6. Symptoms of MRSA in dogs

In dogs, MRSA frequently affects the skin and other soft tissues, leading to skin infections or abscesses. Rarely will it impact dog's joints, eyes, ears, or urinary tract. Discharge from a wound, such as pus, lesions on the skin, skin thickness, abscess, and fever. Injuries will not heal or heal slowly. When MRSA infects burns or surgical sites, it can produce toxins that cause toxic shock syndrome, which can cause fever and, in rare cases, death. MRSA infections include bacteremia, osteomyelitis, endocarditis, pneumonia, mastitis, and skin infections (cellulitis, impetigo, and staphylococcal scalded skin syndrome). MRSA is more common in dog wounds; *S. aureus* is more commonly recovered from cat wounds. MRSA in dog kennels can cause a number of illnesses, such as pyoderma observed that animals have superficial bacterial infections that cause pus-filled skin lesions and signs like pruritus, discomfort, inflammation crusting, pustules, irritation, and even hair loss and deadly pneumonia in pups, and gangrenous mastitis in bitches (Chueahiran et al., 2021)

Significant clinical signs are pyoderma, bronchopneumonia, osteomyelitis, bacteremia and endocarditis, otitis externa, surgical site infections, urinary tract infections, ocular surface infections and most infrequently necrotizing fasciitis and toxic shock syndrome, pyothorax and peritonitis, discospondylitis, arthritis (Weese and Prescott, 2021).

Skin and wound infections, conjunctivitis, upper respiratory diseases, otitis, and post-surgical infections are the clinical signs of *S. aureus* in dogs and cats. While *S. aureus* infections are common in veterinary settings, domestic animals like dogs and cats can serve as vectors for the direct spread and colonization of *S. aureus* in both humans and animals (Qekwana et al., 2017).

3. RISK FACTORS

Several studies have shown how several "modifiable" factors affect the likelihood of MRSA infections. Some studies illustrates the correlation between MRSA infections of the skin and soft tissues and having cystic fibrosis (CF), while the majority of earlier studies included both ill and asymptomatic nasal carriers. The incidence of *S. aureus* in companion animals has been the subject of numerous clinical experiments; however, the colonization of healthy animals that have frequent contact with their owners has not been well studied. Operational challenges resulting from ignorance of MRSA's animal carriage must be resolved (Favier et al., 2025).

Various microorganisms that cause serious risk factors to human health are carried by pets. Hemeg (2021) examines companion mostly dogs and cats, as a source of MRSA and the genetic similarities between the MRSA strains collected from animals and their owners.

S. aureus particularly MRSA is a serious pathogen of animals and humans. It is still unclear how important pets are reservoirs as human infection. Bierowiec et al. (2016) methodically evaluated several anatomical sites for *S. aureus* colonization as well as the impact of several potential risk variables on the final *S. aureus* colonization rate.

In earlier research that examined the risk factors for MRSA transmission, the spread or colonization of the bacterium was found to be influenced by prior antibiotic use, prior colonization, and knowledge of prior MRSA infections. Additionally, the environment in veterinary facilities may also be a source of MRSA transmission due to widespread contamination, even though it is most likely that the primary source of MRSA infection would be the veterinary professionals interact with dogs and cats (Crespo-Piazuelo and Lawlor, 2021).

3.1. Detection and isolation: phenotypic detection of MRSA

3.1.1. Culture and isolation

Suhaili et al. (2018) cultured nasal swab samples on mannitol salt agar (MSA) and incubated for 48 h at 37°C and the resultant golden-yellow colonies suggested the presence of presumed *S. aureus*. The colonies were sub cultured onto

trypticase soy agar (TSA) and phenotypical confirmation done with colonies that consistently displayed positive findings for the Gram stain, tube coagulase, and catalase tests.

In another report by Yan et al. (2025) mentioned that Gram's staining (Gram positive cocci), catalase (positive), oxidase (negative), Vogel-Proskauer (positive), hemolysis (positive), and coagualse activity were indicative of *Staphylococcus*.

3.1.2. Antimicrobial sensitivity test

The spread of bacteria resistant to antibiotics are caused by the overuse of antibiotics in the fields of veterinary medicine and human medicine. A close genetic relationship was found between human and animal MRSA. Ten antibiotics from seven different antibiotic classes were used to test the isolated *Staphylococci*'s antibiotic susceptibility and results showed that the majority of *Staphylococci* were resistant to penicillin G (30%), ampicillin (23%), erythromycin (21%), and doxycycline (20%), respectively. The majority of the strains resistant to antibiotics were *S. aureus* (Saengsawang et al., 2025).

3.1.3. Disk diffusion method

3.1.3.1. Cefoxitin disk diffusion test

Mueller Hinton agar (MHA) with a bacterial suspension calibrated to 0.5 McFarland standards was used to test confirmed isolates of *Staphylococcus aureus* for MRSA using cefoxitin (30 µg) disks. Every agar plate was incubated for 16–18 h at a temperature between 33–35°C. The Clinical and Laboratory Standards Institute›s (CLSI) criteria were followed in the quantification and analysis of the zones of inhibition (Sharma et al., 2017).

3.1.3.2. Kirby-bauer disc diffusion method

Kirby-Bauer disc diffusion method, the susceptibility of methicillin and other antimicrobials can be determined. Following the manufacturer's instruction, isolates were plated on MHA and discs containing 30 µg of cefoxitin, 5 µg of ciprofloxacin, 15 µg of erythromycin, 25 µg of cotrimoxazole, 10 µg of gentamicin, 2 µg of clindamycin, 5 µg of rifampicin, and 30 µg of minocycline. In compliance with the CLSI guidelines, methicillin resistance was defined as an inhibitory halo for the cefoxitin disc of less than or equal to 21 mm (Humphries et al., 2021).

Faccin et al. (2023) reported that the majority of *Staphylococci* are classified as typical flora on animal skin, such as that of dogs, and they are significant opportunistic pathogens, including *S. aureus, S. pseudintermedius,* and *S. sciuri.* The disc diffusion assay was used to determine the *Staphylococcal* isolates' antibiotic susceptibility. To achieve a 0.5 McFarland standard, 3–5 colonies of each *Staphylococcal* isolate grown on TSA were adjusted in 0.85% normal saline solution (NSS). Sterile cotton swabs were then used to disseminate the suspension on MHA. Antibiotic discs were employed and the plates were then incubated at 37°C for 16–18 h. Using a vernier caliper, the inhibition zone of each antibiotic was measured and contrasted with the standard sizes suggested by the CLSI M100 30ed guideline.

MRSA isolates were found in 50 states and the District of Columbia; dogs accounted for 68.3% of these isolates. Skin and soft tissue (57.1%), urine (8.0%), and ears (79.9%) were the most frequent sources (Sobkowich et al., 2025).

Debnath et al. (2022) performed antibiotic sensitivity test using methicillin disc to identify MRSA in their research.

3.1.4. Oxacillin screen agar

MHA plates were prepared and treated with 6 µg ml^{-1} of oxacillin and 4% sodium chloride. In order to perform the oxacillin screening assay, a swab that had been previously submerged in a 0.5 McFarland suspension of the isolate was placed as a localized spot on the agar surface and was incubated for 24 h at a temperature between 33–35°C. Plates were closely examined under transmitted light for finding microbial growth. Any growth detected after 24 h of incubation period was suggestive of oxacillin resistance (Koupahi et al., 2016) (Table 1).

Table 1: Oxacillin screen assay

Anti-microbial concentration	Medium	Incubation temperature and time	Results
Oxacillin (6 µg ml^{-1})	MHA with 4% NaCl	33–35°C for 24 h	Examine carefully with transmitted light for > 1 colony (MRSA positive)

4. CROM AGAR™ MRSA

MRSA was detected using CHROM agar. Methicillin or oxacillin was added as soon as the agar reached 48 °C. Direct streaking onto the CHROM agar plate produced a fine, isolated colony of *S. aureus*. The plates were incubated for 18–24 h at 37°C in an aerobic environment. Appearance of clear Mauve-colour colonies in 18–24 h incubation period was considered as suggestive of MRSA (Xu et al., 2016).

4.1. Biofilm assay

Using the spectrophotometric microplate assay described, the biofilm assay was carried out, and the optical density (OD) values were computed. According to Bin-Hameed and Bahakim (2023), the OD cut-off value (ODc), is equal to the average OD of negative plus three times the standard deviation of negative (Table 2).

Table 2: Biofilm assay	
Biofilm producing ability of bacteria	
Formula	Biofilm intensity
OD<ODc	Non-biofilm
ODc<OD<(2×ODc)	Weak
(2×ODc)<OD<(4×ODc)	Moderate
(4×ODc)<OD	Strong

The microtiter biofilm assay was used to assess the biofilm-forming capacity of 214 *S. aureus* strains. Confocal scanning laser microscopy was used to examine the strains' structural characteristics. Both methicillin resistance and biofilm development were positively correlated with multidrug resistance (MDR). Significant variations between the isolates' clonal lineages were also found. Amikacin and tetracycline both effectively decreased the majority of the biofilm. At the highest dosage, however, none of the antimicrobials were able to completely destroy the biofilm. The findings offer crucial details regarding the ability of animal-adapted *S. aureus* isolates to form biofilms, which could potentially affect the creation of novel biofilm-targeted medications (Silva et al., 2022).

4.2. Genotypic detection

4.2.1. Polymerase chain reaction (PCR)

Suhaili et al. (2018) used *nuc* (278 bp) primers 5′-GCGATTGATGGTGATACGGTT-3′ and 5′-AGCCAAGCCTTGACGAACTAAAGC-3′; and *mecA* (533 bp) primers 5′-AAAATCGATGGTA AAG GTTGGC-3′ and 5′-AGTTCTGCAGTACCGGATTTGC-3′ for the detection of MRSA in their study.

Kar et al. (2025) used *nuc* (280 bp) primers 5'-GCGATTGATGGTGATACGGTT-3' and 5'- ACG CAAGCCTTGACGAACTAAAGC-3' and *mecA* (162 bp) primers 5'–TCCAGATTACAACTTCA CCAGG–3'and 5'–CAATTCATA TCTTGTAACG–3' for the detection of MRSA in their study of canine dermatoses at Mizoram.

In order to treat *S. aureus* infections in humans and animals, accurate MRSA diagnosis is essential. *mecA* gene identification by PCR is currently the gold standard for MRSA detection, despite the fact that other phenotypic techniques have been developed for phenotypic identification of MRSA. In another study Chanayat et al. (2021) used *mecA* (309 bp) primers 5′-TGGCTATCGTGTCACAATCG-3′; 5′-CTGGAACTTGTTGAGCAGAG-3′.

PCR was used to screen *S. aureus* and MRSA isolates for the presence of different antimicrobial resistance genes, such as those that are resistant to methicillin (*mecA*, *mecB*, and *mecC*) and *mecC*-containing *S. aureus* isolates were regarded as MRSA. The presence of virulence determinants in the *S. aureus* isolates has also been examined using PCR, including *tst*, *lukPV*, and the IEC gene cluster (*scn*, *chp*, *sak*, *sea*, and *sep*). To detect *nuc* and *mecA* genes, *S. aureus* ATCC 700699 served as the positive control (Chai et al., 2021).

4.2.2. Methicillin-resistant S. aureus (MRSA)

Methicillin is one of the antistaphylococcal penicillins to which *S. aureus* has become resistant. They are known as MRSA. MRSA has emerged as a major global cause of nosocomial infections in both human and veterinary medicine. Penicillin binding protein 2a (PBP2a), which has a very low affinity for β-lactam antibiotics, is encoded by the *mecA* gene and mediates MRSA resistance. Most MRSA infections in dogs and cats are linked to open wounds, surgical implants, and post-operative infections, and their prevalence has grown recently. Because human and canine MRSA resistance patterns and genetic screening are almost the same, cross-contamination between humans and animals (Brdova et al., 2024)

Lynch and Zhanel (2022) noted that antimicrobial drugs used to treat humans are frequently the same as those used to treat animals. β-lactams, rifamycins, macrolides, aminoglycosides, sulfonamides, fluoroquinolones, and tetracyclines are the primary drugs used to treat *Staphylococcal* infections in both humans and animals. The treatment is based on the severity of the case. Animals that test positive should be kept apart or temporarily removed from the home for three to four weeks in order to prevent ongoing exchange. Animals or humans that test positive for MRSA may not require treatment because the colonization is transient and often disappears in three weeks. The skin of animals with purulent skin infections, however, may be removed and drained. More serious infections may require antibiotic treatment, depending on the findings of culture-based antimicrobial susceptibility testing. For MRSA infections in animals, conventional antibiotics such as doxycycline, rifampin, clindamycin, trimethoprim-sulfamethoxazole, tetracyclines, and vancomycin can be administered. The use of β-lactam antibiotics, such as penicillin or methicillin, is not advised because MRSA is resistant to them. Choosing the best antimicrobial therapy is challenging for a number of reasons, including the wide range of agents available, the presence of resistant organisms, practitioners' general desire to employ the most targeted therapy (Xu et al., 2022).

Apley (2022) reported that the semi-synthetic penicillinase-resistant drug methicillin was created to get *Staphylococcal* penicillinases, which cause penicillin resistance. Penicillinases can break down the basic structure of β-lactam antibiotics, destroying the both natural penicillins (G and V) and aminopenicillins (ampicillin and amoxicillin).The *mecA*, a gene encoding particular penicillin-binding protein

(PBP2a) that has low affinity to all β-lactams, including cephalosporins, are acquired by *S. aureus* shortly after methicillin was used in human medicine, providing resistance to the antibiotic. The word methicillin resistant has endured since the discovery of cephalosporins in the 1970s to describe strains that are resistant to all β-lactam with the exception of most recent generation of cephalosporins which were used especially to treat MRSA infections (*e.g.* ceftaroline). MRSA may exhibit co-resistance to any combination of other medicine classes, such as lincosamides, aminoglycosides, rifampicin, tetracyclines, fluoroquinolones, potentiated sulfonamides, macrolides, and chloramphenicol. Extensively drug resistant (XDR) is when the strain is non-susceptible to all but two or fewer antimicrobial classes, whereas MDR is if the strain exhibits co-resistance to at least two additional antimicrobial classes. With regard to clinical MRSA isolates from dogs and cats, both MDR and XDR have emerged globally (Selvarajan et al., 2022).

A total of 14 different antimicrobial susceptibility profiles were found, 7 each for MSSA and MRSA based on phenotypic analysis. Regarding methicillin-susceptible profiles, had resistance to erythromycin and ampicillin, clindamycin, ciprofloxacin, enrofloxacin, and tetracycline. In methicillin-resistant profiles, in addition to resistance β-lactam, ciprofloxacin and erythromycin, enrofloxacin, and clindamycin are observed. All *S. aureus* isolates were sensitive to gentamicin, vancomycin, doxycycline, amikacin, trimethoprim, sulfamethoxazole, and chloramphenicol (Van Balen et al., 2017).

Algammal et al. (2020) stated that MDR-MRSA needs the collaboration among public health experts, epidemiologists, and microbiologists, veterinary and medical clinicians. Nowadays the most commercial antibiotics are resistant to MRSA infections.The investigation and screening of resistant strains are necessary for the antibiotic sensitivity test to control the antibiotic resistant issues in both humans and animals. Broad-spectrum antibiotics must not be used to treat MRSA infections; instead, an antibiotic sensitivity test can be done. To reduce the prevalence of MRSA in the community, hospitals and veterinary authorities must implement basic measures including routine infection control, general hygiene practices and environmental disinfection.

4.2.3. Treatment

The following drugs have proven effectiveness against MRSA. The dose rates given along with different drugs were taken from the work of Papich (2023).

4.2.3.1. Glycopeptides

In veterinary medicine, vancomycin is frequently the only drug that effectively combats MRSA glycopeptides (Manzillo et al., 2016). Vancomycin has been administered intravenously for 30 to 60 min. When given intramuscularly, it causes excruciating agony and cannot be absorbed orally. In order to maintain concentrations within the therapeutic range and avoid toxicity, the dosage is 15 mg kg, IV, every 6 h. Vancomycin should be used with an aminoglycoside, such as gentamicin or amikacin, for treating severe infections.

4.2.3.2. Oxazolidinone (Foti et al., 2021)

Linezolid was the first drug of the oxazolidinone class to be used in medicine. By binding to the bacterial 23S ribosomal RNA of the 50S subunit, it prevents the synthesis of a functional 70S initiation complex. Orally absorbed linezolid has been successfully utilized at NCSU to treat MRSA in cats and dogs. 10 mg kg^{-1} PO or IV every 8–12 h is the dose. Linezolid is available as 400 and 600 mg pills, an injection, and an oral solution.

4.2.3.3. Daptomycin (Ma et al., 2017)

Daptomycin is an antibiotic that works against MRSA and is a member of the peptolide class. The mechanism of action includes alteration of the cytoplasmic membrane potential and disruption of the transport of amino acids by the cell membrane. The concentration-dependent bactericidal effect of daptomycin is affected by pH and ionized calcium concentrations.

4.2.3.4. Amikacin (Tuon et al., 2023)

Clinical efficacy for treating staphylococcal skin infections has not been shown, but in vitro studies suggests that amikacin may be more effective than gentamicin against some strains. Throughout treatment, renal parameters need to be monitored due to the possibility of kidney damage. It is advised to administer 15 mg kg^{-1} once day by IV, IM, or SC.

4.2.3.5. Amoxicillin-clavulanate (Hriouech et al., 2020)

The effectiveness of amoxicillin-clavulanate against MSSA is good. According to authorized susceptibility testing guidelines, this combination is permitted for use in animals. It is advised to take 12.5 mg kg^{-1} PO twice a day.

4.2.3.6. Cefpodoxime proxetil (Pahwa et al., 2015)

It is a reliable third-generation oral cephalosporin against *Staphylococcus* species sensitive to methicillin. With approved susceptibility testing standards, it is authorized for use in animals. Dose is 5–10 mg kg^{-1} PO, once daily.

4.2.3.7. Cephalexin (Brown et al., 2021)

It is a first-generation oral cephalosporin. In some regions, cefadroxil may be available, which is equivalent. Cephalexin and cefadroxil have predictable activity against MSSA. Cephalexin is approved for use in animals, with approved susceptibility testing standards. Dose is 22–25 mg kg^{-1}, PO, twice daily.

4.2.3.8. Clindamycin (Brookshire et al., 2025)

Good activity against authorized susceptibility testing standards for wild-type strains of *Staphylococcus* species. There may be comparable lincomycin formulations for small animals available in other nations. 5.5–11 mg kg^{-1}, PO, twice day (but for a consistent response, 11 mg kg^{-1} twice daily is advised).

4.2.3.9. Enrofloxacin (Attili et al., 2016)

Enrofloxacin is authorized for the treatment of animal skin infections. In the absence of high dosages, the activity against MSSA may be erratic. Concerns about resistance make it unsuitable as a first-choice antibacterial agent. Some of the works show the effectiveness of enrofloxacin in treating *S. aureus*. The majority of organisms resistant to methicillin also have fluoroquinolone resistance. Dose is 5–20 mg kg^{-1}, once daily, PO.

4.2.3.10. Gentamicin

Although its clinical effectiveness in treating skin infections has not been proved, it is active against sensitive strains of *Staphylococcus* species. Gentamicin in combination with other compounds like *C. esculenta* aqueous extract or piperine show good antibacterial activity against MRSA (Nandhini et al., 2022). Recommended dose is 9–14 mg kg^{-1} once daily via SC, IM, or IV.

4.2.3.11. Marbofloxacin

This drug is authorized for the treatment of animal skin infections. In the absence of high dosages, the activity against MSSA may be erratic. Concerns about resistance make it unsuitable as a first-choice antibacterial agent. The majority of organisms resistant to methicillin also have fluoroquinolone resistance. Dose is 2.75 to 5.5 mg kg^{-1}, PO, once a day.

4.2.3.12. Orbifloxacin

This drug is approved for treating skin infections in animals. The activity against MSSA can be inconsistent unless high doses are used. It is discouraged as a first-choice antimicrobial agent because of resistance concerns. Most methicillin-resistant strains are resistant to fluoroquinolones. Dose is 7.5 mg kg^{-1}, PO, once daily.

4.2.3.13. Rifampin

For the treatment of infections caused by *Staphylococcus* Spp., it is not necessary to combine rifampin with another antimicrobial agent to improve clinical efficacy or reduce resistance. Rifampin is highly active against *Staphylococcus* Spp., including MRSA (Harbour et al., 2022). There is a risk of hepatic injury in dogs and monitoring of liver parameters should be performed frequently during treatment. Dose is 5 mg kg^{-1}, PO, twice daily.

4.2.3.14. Trimethoprim-sulfonamides

Approved for use in dogs in many countries but not often used because dogs are more susceptible to adverse effects than other animals. Adverse effects in dogs include keratoconjunctivitis sicca, liver injury, hypersensitivity, and skin eruptions. Paudel et al. (2023) reported about Trimethoprim sensitive *S aureus*. Dose is 15–30 mg kg^{-1}, PO, twice daily.

4.2.4. Herbal medicine

Moreover apply of different eco-friendly treatment regimens should be execute such as herbal medicine and symbiotic such as *Austroeupatorium inulaefolium* essential oil and *Leoheo domatiophorus* of leaves-extracted is the essential oil Combination of propolis, Aloe vera, tea tree oil and combination of *Myrtus communis* L, *Origanum vulgare* and tretinoin are the natural origin therapies should be apply specially in dermal infections (Mazzarello et al., 2018). Further Chandnani et al. (2023) observed that *Carica papaya* aqueous leaf extract synthesized silver nanoparticles (CPAgNP) can be used as a therapeutic agent against MRSA.

4.2.5. Public health implications

According to Sharma et al. (2024) and Ahmad et al. (2021), *S. aureus* is a systemic, multi-sectoral disease that threatens human and animal health globally, and is causing concerns within the global health community. Regardless of socioeconomic status, antimicrobial resistance (AMR) has the potential to raise global health care costs, health issues, and death rates. Humans can contract *S. aureus* from animals or animal products that are methicillin-resistant. Lienen et al. (2021) was of the opinion that due to the high degree of human-animal contact, veterinary clinicians are susceptible to MRSA outbreaks. Because of excessive antibiotic usage and overcrowding,

MRSA is a recognized emerging zoonotic infection that has serious implications for veterinary medicine and public health. It causes significant problems for both human and animal populations, exhibiting resistance to extreme environmental factors like direct sunlight and desiccation. *S. aureus* is known to colonize a number of body locations, including the nares, vagina, throat, and wounded skin surfaces. A known commensal of both humans and animals is *S. aureus*. In both humans and animals, the bacterium could cause serious infections by invading the skin, mucous membranes, and internal organs (Esemu et al., 2024).

Companion animal antimicrobial resistance (AMR), particularly in dogs and cats, is becoming a major factor in the global development of this public health issue. MRSA is commonly prevalent in veterinary settings and among companion animals; *S. aureus* can spread resistance

genes to humans and other animal species. With a focus on the transfer of resistance between animals and their owners a concerning feature given the close coexistence, shared use of antibiotics, and community access the reviewed literature substantiates the alarming incidence of MRSA. Furthermore, limiting resistance in these animal populations by means of rigorous monitoring and prudent antibiotic administration can be done. The relationship between the environmental, animal, and human domains should be monitored. In order to prevent the spread of resistant diseases and resistance genes and safeguard the health of both humans and animals, it is imperative that human health, veterinary, and environmental specialists work together in concert. Addressing this worldwide issue requires immediate action, including the implementation of efficient systems for antibiotic monitoring, education, and responsible management (Monteiro de Medeiros et al., 2025).

The *S. aureus* found on a normal flora has opportunistic pathogenic features. Due to its tendency to rise every year, *S. aureus* infection is one of the major public health concerns. Different antibiotics are used to overcome the menace of *S. aureus* infection. The growth of MRSA, a kind of *S. aureus* that is resistant to antibiotics, is a problem that arises due to the overuse of antibiotics (Decline et al., 2020).

The effects of *S. aureus* on public health and the animals are connected. Foods originating from animals that contain one or more preformed *Staphylococcal* enterotoxins (SEs), which are created by the organism, can lead to human illnesses (Hachemi et al, 2019).

4.2.6. Prevention and control measures

According to Aslam et al. (2021), improving infection control procedures like hospitals and household is a proven and effective way to reduce the spread of bacteria resistant to antibiotics and other diseases. Veterinarian clinics, do not fully execute approved infection control methods. Infection control measures, such as biosecurity and disease management programs, must be implemented to stop the spread of pathogens to humans. Measures to prevent antibiotic resistance and reduce the spread of disease include vaccination campaigns, animal and handler cleanliness, and sanitation.

Das-Mitra et al. (2023) noted that more research is being done on the creation of vaccinations to stop MRSA infections in animals in order to reduce the spread of MRSA from animals to people. Animal studies on MRSA vaccines include vaccine strategies that use immunization to produce an immune response against surface proteins involved in MRSA infection. Vaccines that use inactivated MRSA bacteria or parts of the bacteria to induce immunity without causing disease; and clinical trials of vaccines to assess the safety and efficacy of these vaccines in various animal populations and to prevent MRSA colonization in animals.

Numerous documentation on managing MRSA in humans have been released by the Centers for Disease Control and Prevention, and many of the MRSA control guidelines also apply to pets. Disease epidemiology may differ significantly between guidelines for limiting MRSA in humans and dogs. Important concerns such as prevalence, infection, the persistence of MRSA colonization in pets, the effectiveness of decolonization therapies in pets, and the MRSA transmission between humans and pets have not yet been the study of controlled investigations (Kavanagh, 2019).

Querido et al. (2019) observed that hand washing is essential in human medicine, it is also essential in preventing the transmission of MRSA from humans to animals and animals to humans. Hand should be washed after touching pets, table tops, floors, and equipment should be cleaned. Ensure that hand sanitizer is available in pet cages, at home and in rooms used for animal care. Additionally routine measures to prevent the spread of MRSA includes regular hand washing, wearing gloves when interacting with pets, particularly those exhibiting signs of infectious disease, making sure that aprons are thrown away after use, and wearing a mask at all times to protect from contaminated air or body fluids from pets. If pet splashes or aerosols are to be expected, eye protection is also advised. Another aseptic approach is sterilization of surgical instruments during pre and post-operative (Roberge, 2016). In order to implement efficient control measures in veterinary practice, human doctors and veterinarians must work closely together to identify the MRSA that may be present in both humans and pets (Yunita et al., 2020). Debbarma et al. (2025) opined that MRSA and other antibiotic resistant *S. aureus* must be continuously monitored in domestic animals in order to prevent human infections.

5. CONCLUSION

Methicillin-resistant *Staphylococcus aureus* (MRSA) was a zoonotic disease. This disease could spread from one species to another, including from people to dogs and vice versa. Treatment of a dog with MRSA was challenging. *S. aureus* infections were common in veterinary settings, domestic animals like dogs and cats served as vectors for the direct spread and colonization of *S. aureus* in both humans and animals.

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