Review Article

Journal of Advanced Veterinary Research
(2026) Volume 16, Issue 4, 662-675

Prevention and management strategies for Methicillin-Resistant *Staphylococcus aureus* (MRSA) in veterinary clinics and hospitals: A literature review

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ARTICLE INFO

Recieved: 09 April 2026

Accepted: 08 June 2026

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Keywords:

MRSA, Veterinary clinic, Biosecurity, Antimicrobial resistance, One Health, Public health.

ABSTRACT

Methicillin-Resistant *Staphylococcus aureus* (MRSA) is an infectious agent that is increasingly receiving attention as a serious threat in animal healthcare facilities. Its ability to resist various β-lactam antibiotics makes the infections it causes difficult to treat, while increasing the potential for cross-transmission in clinical settings and posing health risks to animals, veterinary health workers, and animal owners. This situation emphasizes the urgency of implementing comprehensive prevention and management strategies to reduce the impact of MRSA in veterinary practice. This review article presents a synthesis of the latest scientific evidence regarding MRSA epidemiology, transmission routes, diagnostic methods, and prevention and treatment efforts in veterinary clinics and hospitals. Discussions include biosecurity implementation, adherence to hygienic practices by medical personnel, environmental control, and the contribution of Antimicrobial Stewardship programs to reducing the rate of antimicrobial resistance. Furthermore, various challenges in managing MRSA cases in hospitalized animals, the potential for zoonotic transmission, and the importance of implementing an integrated One Health approach are reviewed. Overall, findings indicate that animal healthcare facilities have the potential to act as reservoirs for MRSA, as the high level of interaction between animals, humans, and the environment contributes to repeated contamination. Implementing strict hygiene standards, early detection, selecting evidence-based therapies, and educating pet owners have been shown to contribute to reducing infection and colonization rates. Therefore, cross-sector collaboration is key to strengthening MRSA control and preventing its further spread.

Introduction

Methicillin-Resistant *Staphylococcus aureus* (MRSA) is a resistant bacterium that is a major concern in current veterinary practice (Belhout *et al*., 2022). Its resistance to various β-lactam antibiotics is linked to the presence of the *mec*A or *mec*C genes, which encode alternative penicillin-binding proteins, thus limiting the effectiveness of standard therapy (Khairullah *et al*., 2023a). In veterinary healthcare, MRSA is of particular significance because it not only causes clinical infections but also colonizes skin and mucosal surfaces, as well as the clinical environment, ultimately increasing the risk of cross-transmission (Shoaib *et al*., 2023). High levels of antimicrobial resistance make MRSA a serious threat to patient animals, veterinary medical personnel, and animal owners who have close interactions (Khairullah *et al*., 2023b).

The epidemiological patterns of MRSA in animals show prevalence rates influenced by species differences, clinical management systems, and geographic factors (Kasela *et al*., 2023). In pets such as dogs and cats, MRSA is frequently identified in cases of dermatitis, post-surgical infections, and soft tissue infections (Petinaki and Spiliopoulou, 2015). Meanwhile, in horses, this bacterium is among the most frequently reported nosocomial pathogens, particularly in intensive care units and surgical facilities (Khairullah *et al*., 2022). In addition to causing clinical infections, some animals can act as asymptomatic carriers, contributing to the circulation of MRSA and complicating control efforts (Briki *et al*., 2025). Areas and facilities in animal healthcare facilities—such as inpatient kennels, procedure rooms, and medical equipment—have the potential to become reservoirs of MRSA due to contamination from patients and healthcare workers (Bhatta *et al*., 2022). The ability of some MRSA strains to survive for long periods on dry surfaces further increases the potential for spread, particularly in facilities with inadequate hygiene practices (Jaradat *et al*., 2020).

From a zoonotic perspective, MRSA is increasingly recognized as a critical issue within the One Health approach (Qian *et al*., 2023). Studies have reported that MRSA can be transmitted from humans to pets (reverse zoonosis), and conversely, colonized animals have the potential to transmit the same strain back to humans (zoonotic spillback) (Stein, 2009; Silva *et al*., 2022; Weese, 2010). This bidirectional transmission pattern reflects the close relationship between humans, animals, and the environment, and emphasizes that MRSA control requires cross-sector involvement (Morgan, 2008). Groups such as pet owners, veterinarians, veterinary paramedics, and workers in animal health care facilities are at higher risk of exposure during routine activities (Neradova *et al*., 2020). Furthermore, the residential environment, veterinary clinics, and animal hospitals function as part of an interconnected microbial ecosystem, potentially expanding the circulation and spread of MRSA strains within the community (Hoet *et al*., 2011).

The need for MRSA prevention and management in animal healthcare facilities is increasingly pressing, given the rise in difficult-to-treat infections, high colonization rates in hospitalized animals, and the increased use of antibiotics in veterinary practice (Barua *et al.*, 2025). Without effective biosecurity measures, these facilities have the potential to become hotspots for MRSA transmission (Sawodny *et al.*, 2025). Inappropriate practices—such as prescribing antibiotics without susceptibility testing, inconsistent environmental sanitation, poor hand hygiene compliance, and limited staff training—can increase the risk of transmission (El Roz *et al.*, 2025). Therefore, comprehensive, multidisciplinary prevention strategies need to be implemented, encompassing maintaining environmental hygiene standards, the use of appropriate personal protective equipment, the implementation of zoning systems, structured inpatient management, and the implementation of antimicrobial stewardship programs to reduce selection pressure for resistant bacteria (Khairullah *et al.*, 2023b).

This review article aims to comprehensively examine the epidemiology of MRSA, its zoonotic potential, transmission patterns, identification methods, and various prevention and management efforts in veterinary clinics and hospitals. Furthermore, this discussion emphasizes the crucial role of the One Health approach in MRSA control and presents evidence-based recommendations to support improved veterinary practice and future antimicrobial resistance control.

MRSA in animal health care facilities

MRSA is now considered a crucial problem in animal health care facilities, due to its increasing incidence in various species and the high risk of transmission triggered by intensive interactions between animals, veterinary health workers, and the clinical environment.

Prevalence of MRSA in veterinary clinics and hospitals

The incidence of MRSA in animal healthcare facilities continues to be an international concern, given its ability to spread through contact between animals, veterinary healthcare personnel, and the clinical environment (Aires-de-Sousa, 2017). MRSA has been reported in a wide variety of species, from dogs, cats, and horses to exotic animals and production animals receiving care in clinical settings (Li *et al.*, 2025). Differences in MRSA prevalence in animals are influenced by geographic location, variations in healthcare practices, antibiotic use patterns, and the success of biosecurity measures (Broens *et al.*, 2011).

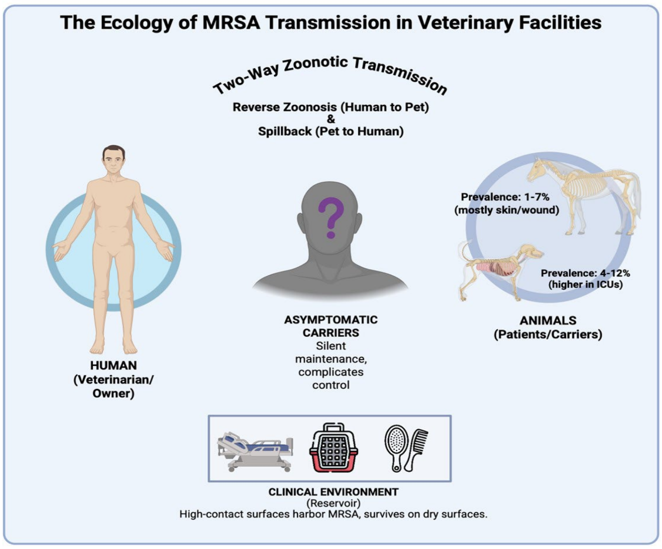


Figure 1. Ecology of MRSA transmission in veterinary facilities. Bidirectional transmission between animal patients and humans is represented, with asymptomatic carriage and contamination of the clinical environment acting as key mechanisms sustaining MRSA circulation. Reported prevalence in companion animals and horses highlights the relevance of veterinary facilities within a One Health framework.

In small animals, particularly dogs and cats, the reported prevalence of MRSA in patients visiting veterinary clinics generally ranges from 1–7%, although this percentage tends to be higher in animals with a history of hospitalization or prior antibiotic use (Petinaki and Spiliopoulou, 2012; Dewulf *et al.*, 2025; Scott *et al.*, 2022). The most common clinical manifestations in these species are skin and soft tissue infections, resulting in MRSA isolates often being obtained from cases of pyogenic dermatitis, post-surgical wounds, and otitis externa (Algammal *et al.*, 2020). Furthermore, several studies indicate that pets can be colonized with MRSA without clinical symptoms, potentially acting as reservoirs and maintaining the bacteria's presence in the veterinary healthcare environment. Figure 1 illustrates the prevalence and transmission dynamics of MRSA within veterinary healthcare facilities.

In horses, MRSA rates are generally reported to be higher than in small animals, particularly in large veterinary hospitals that handle surgical and intensive care cases (Khairullah *et al.*, 2022). Surveillance studies indicate that the prevalence of MRSA colonization in hospitalized horses ranges from 4–12%, with some facilities recording higher rates in intensive care units (Tokateloff *et al.*, 2009; Allano *et al.*, 2025; Kabir *et al.*, 2024). MRSA strains frequently isolated from horses have been reported to be genetically close to strains that infect humans, indicating the potential for cross-species transmission via healthcare personnel, medical equipment, and the hospital environment (Nwobi *et al.*, 2023).

Differences in MRSA prevalence across countries and geographic regions show significant variation (Garoy *et al.*, 2019). In Western Europe and North America, MRSA incidence rates in animal health care facilities are generally reported to be higher, which is related to more structured surveillance systems and relatively high antibiotic use intensity (Crespo-Piazuelo and Lawlor, 2021; Chastre *et al.*, 2014). In contrast, information from developing countries in Asia, Africa, and Latin America is still relatively limited, but available data indicate a high diversity of MRSA genotypes and high levels of antimicrobial resistance, which are thought to be related to less controlled antibiotic use (Turner *et al.*, 2019). Cross-country studies have shown that MRSA isolates from animals in Asia tend to exhibit a broader spectrum of resistance than isolates from Europe, reflecting differences in antimicrobial policies and biosecurity standards implemented in each region (Barua *et al.*, 2025).

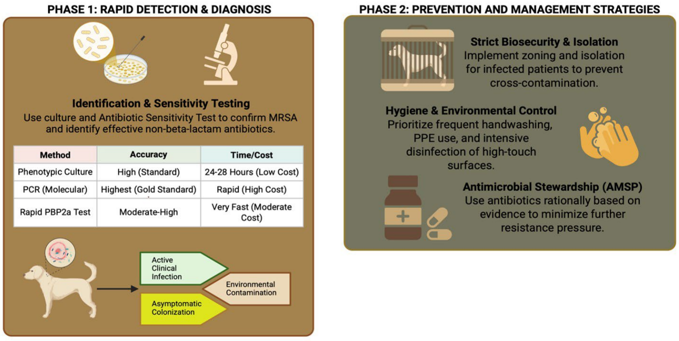
Risk factors for the spread of MRSA in animal health facilities

MRSA transmission in animal healthcare facilities is a complex phenomenon, involving interactions between patient animals, veterinary health workers, animal owners, and components of the clinical environment (Olanipekun *et al.*, 2025). Several studies have shown that the potential for MRSA transmission increases significantly when biosecurity protocols are not consistently implemented, particularly in veterinary hospitals with high levels of activity and movement (Bortolami *et al.*, 2017; Corbera *et al.*, 2025; Kassa *et al.*, 2024). These risk factors are multifactorial and interconnected, making a comprehensive understanding of the patterns and mechanisms of MRSA transmission a crucial element in infection control strategies (Santosaningsih *et al.*, 2019).

Intense interactions between patient animals, veterinary healthcare workers, and the clinical environment are key components in the transmission of MRSA (Ferreira *et al.*, 2011). Veterinary personnel—including veterinarians, nurses, and technicians—can act as mechanical carriers of MRSA through hands, work clothes, and personal protective equipment that is not properly changed or sanitized (Ishihara *et al.*, 2014). Animals undergoing examination or intensive care also have direct contact with various surfaces in the clinical facility, accelerating the transfer of bacteria (Stull and Weese, 2015). This transmission pattern aligns with the mechanisms of MRSA spread in human hospitals, where the interaction between patients, healthcare workers, and the environment is a key determinant of nosocomial infection (Hall *et al.*, 2012).

Contaminated medical equipment and surfaces in animal healthcare facilities play a significant role in maintaining the presence of MRSA (van Balen *et al*., 2014). High-contact areas—such as examination tables, inpatient kennels, stethoscopes, grooming equipment, and surgical instruments—can become persistent sources of contamination if adequate cleaning and disinfection procedures are not implemented (Bhatta *et al*., 2022). MRSA is known to persist for long periods on dry surfaces, increasing the risk of transmission between patient animals, particularly in high-traffic clinical environments (Silva *et al*., 2021).

Another contributing factor is the inappropriate use of antibiotics, which can promote the selection and persistence of MRSA strains (Abebe and Birhanu, 2023). Excessive use of broad-spectrum antibiotics or use without prior susceptibility testing increases selection pressure on the animal's normal bacterial flora, facilitating colonization by MRSA (Cocca *et al*., 2021). Furthermore, inappropriate empiric therapy for skin infections, post-operative wounds, or respiratory tract infections can accelerate the emergence of resistant strains, which then spread in the clinical environment. Figure 2 illustrates the major risk factors contributing to the spread of MRSA in veterinary clinics and hospitals, together with the sequential control framework required to reduce transmission.



PHASE 1: RAPID DETECTION & DIAGNOSIS

Identification & Sensitivity Testing
Use culture and Antibiotic Sensitivity Test to confirm MRSA and identify effective non-beta-lactam antibiotics.

Method	Accuracy	Time/Cost
Phenotypic Culture	High (Standard)	24-28 Hours (Low Cost)
PCR (Molecular)	Highest (Gold Standard)	Rapid (High Cost)
Rapid PBP2a Test	Moderate-High	Very Fast (Moderate Cost)

PHASE 2: PREVENTION AND MANAGEMENT STRATEGIES

Strict Biosecurity & Isolation
Implement zoning and isolation for infected patients to prevent cross-contamination.

Hygiene & Environmental Control
Prioritize frequent handwashing, PPE use, and intensive disinfection of high-touch surfaces.

Antimicrobial Stewardship (AMSP)
Use antibiotics rationally based on evidence to minimize further resistance pressure.

Figure 2. Two-phase framework for MRSA control in veterinary healthcare facilities. Sequential integration of diagnostic confirmation and susceptibility testing with biosecurity, hygiene, environmental control, and antimicrobial stewardship strategies to reduce MRSA transmission and antimicrobial resistance.

Animals undergoing prolonged hospitalization are at higher risk of exposure to MRSA (Kasela *et al*., 2023). Extended stays in veterinary hospitals increase contact with medical staff, equipment, and other animals that may already be colonized (Hanselman *et al*., 2006). Animals with

Table 1. Diagnostic methods, interpretation, and challenges in the identification of MRSA in veterinary clinical settings.

Diagnostic stage	Method / parameter	Description / diagnostic significance	References
Culture and phenotypic identification	Selective culture media	Isolation of suspected *Staphylococcus aureus* using Mannitol Salt Agar (MSA), Baird-Parker Agar, and CHROMagar™ MRSA to support early presumptive detection based on colony morphology and biochemical characteristics	(Wcisłek *et al*., 2025; Bashabsheh *et al*., 2024; Perry *et al*., 2004)
	Biochemical tests	Catalase, coagulase, DNase, and latex agglutination tests for confirmation of *S. aureus* identity	(Krishnakumar *et al*., 2024; Dezfulian *et al*., 2010; Crosby *et al*., 2016; Crosby *et al*., 2021)
	Phenotypic methicillin resistance	Disk diffusion (Kirby–Bauer), MIC, and automated AST using cefoxitin or oxacillin as resistance indicators	(Alghamdi *et al*., 2023; Adhikari *et al*., 2017; Swenson *et al*., 2025)
	PBP2a detection	Confirmatory detection of Penicillin-Binding Protein 2a by immunochromatography or latex agglutination	(Ramadhani *et al*., 2024; Chapin and Musgnug, 2004)
	Limitations	Longer turnaround time (24–48 h), contamination risk, and potential misclassification of heteroresistant strains	(Gajic *et al*., 2022; Lucian-Daniel *et al*., 2026)
Antibiotic susceptibility testing	Disk diffusion	Common, cost-effective method using Mueller-Hinton agar and standard antibiotic discs	(Pavani *et al*., 2025; Khan *et al*., 2019; Balouiri *et al*., 2016; Gurung *et al*., 2020; Matuschek *et al*., 2014; Skov *et al*., 2014)
	MIC determination	Broth microdilution, E-test, or automated system to determine minimum inhibitory concentration	(Kowalska-Krochmal and Dudek-Wicher, 2021; Caneschi *et al*., 2023; Stefani *et al*., 2025)
	Antibiotic panel	Includes fluoroquinolones, macrolides, lincosamides, tetracyclines, TMP-SMX, glycopeptides, and other veterinary antimicrobials	(Lade *et al*., 2022)
	D-test	Detection of inducible clindamycin resistance (iMLSB phenotype)	(Thapa *et al*., 2021; Vandana *et al*., 2009; Steward *et al*., 2005)
	Clinical interpretation	Must consider infection site, immune status, and antimicrobial pharmacokinetics	(Alikhani *et al*., 2025; Pogorzelska-Maziarz *et al*., 2013; Sheerah *et al*., 2025)
Molecular diagnostics	PCR / qPCR	Detection of *mecA* and *mecC* genes as gold standard for MRSA confirmation	(Xing *et al*., 2022; Naeim *et al*., 2023; Mohammed *et al*., 2025)
	Resistance gene target	Confirmation of PBP2a-mediated β-lactam resistance mechanism	(Fishovitz *et al*., 2014; Rosado *et al*., 2025; Roy *et al*., 2024)
	Species marker genes	Additional targets such as *nuc* and *spa* for *S. aureus* confirmation	(Sanchini, 2022; Durib, 2025; Kim *et al*., 2013)
	Diagnostic limitation	Genotypic positivity may not always correlate with phenotypic resistance	(Anjum *et al*., 2017)
	Integrated diagnosis	Combination of molecular, phenotypic, and AST approaches for accurate MRSA management	(Abebe and Birhanu, 2023; He *et al*., 2026)
Diagnostic interpretation challenges	Colonization vs infection	Difficulty distinguishing asymptomatic colonization from active infection	(Kumar *et al*., 2025; Touaitia *et al*., 2025)
	Limited laboratory access	Restricted availability of PCR and advanced diagnostic tools in veterinary clinics	(Aldea *et al*., 2025; Sakoulas *et al*., 2001)
	Host and environmental factors	Influence of immune status, chronic wounds, and cross-contamination	(Scott *et al*., 2022; O'Mahony *et al*., 2005)
	Screening challenges	Cost, time, and uncertainty in optimal sampling sites	(Rasmussen *et al*., 2011; Ayebare *et al*., 2019; Kosnik *et al*., 2016)
	Standard interpretation differences	Variation between CLSI and EUCAST susceptibility criteria	(Gajic *et al*., 2022; Rodloff *et al*., 2008)

weakened immune systems or open wounds are also more susceptible to secondary MRSA infections (Algammal *et al*., 2020). Furthermore, intensive care procedures such as catheter placement, intravenous therapy, and other invasive procedures increase the risk of infection (Mehta *et al*., 2020).

The movement of animals and their owners contribute to the spread of MRSA in various environments (Li *et al*., 2025). Pets moving from home to clinic, referred to veterinary facilities, or visited at grooming parlors can potentially carry MRSA to other locations (Ferreira *et al*., 2011). Pet owners can also act as passive carriers, especially if they interact closely with colonized animals. This makes veterinary facilities a crucial link in the MRSA transmission chain connecting animal and human populations (Scott *et al*., 2022).

Identification and diagnosis of MRSA

Detection and diagnosis of MRSA in veterinary clinics require precise and standardized methods, because the phenotypic and genotypic diversity of this bacterium often makes it difficult to determine whether an animal is infected or simply colonized. Table 1 summarizes the principal diagnostic approaches used for the identification and confirmation of MRSA in veterinary clinical settings.

Culture techniques and phenotype identification

The culture and phenotypic characterization approach for identifying MRSA is a crucial step in diagnosing MRSA infections and colonization in animal healthcare facilities (Wcisłek *et al*., 2025). This method is still considered the gold standard in clinical microbiology because it provides comprehensive information on bacterial growth, antibiotic resistance, and phenotypic patterns relevant for determining therapy (Lakhundi and Zhang, 2018). Despite the advancement of molecular techniques, culture and phenotypic identification remain the primary methods, especially in resource-constrained veterinary laboratories (Mairi *et al*., 2025).

The MRSA identification process begins with bacterial isolation using selective culture. Clinical samples, such as swabs from wounds, skin, nasal passages, respiratory tracts, or clinical environmental samples, are grown on media that support the growth of *S. aureus* while suppressing the growth of other bacteria (Bashabsheh *et al*., 2024). Commonly used media include Mannitol Salt Agar (MSA), Baird-Parker Agar, or specialized selective media such as CHROMagar™ MRSA, which utilizes chromogenic dyes to display colonies with characteristic colors (Perry *et al*., 2004). These media allow for early detection of MRSA through differences in colony morphology, mannitol fermentation ability, or specific biochemical reactions. Figure 3 illustrates the sequential workflow for the identification and confirmation of MRSA in veterinary healthcare facilities.

Once a suspect colony has been successfully isolated, the next step is phenotypic identification through a series of biochemical tests (Krishnakumar *et al*., 2024). This process typically includes catalase and coagulase tests, two classic methods for distinguishing *S. aureus* from coagulase-negative *Staphylococcus* species (Dezfulian *et al*., 2010). *S. aureus* typically exhibits a positive coagulase result, which is indicated by the formation of clumps in the plasma (Crosby *et al*., 2016). Some laboratories also employ additional tests, such as the DNase test or the latex agglutination test, to detect protein A or clumping factor, which are characteristic of *S. aureus* (Crosby *et al*., 2021).

MRSA phenotype determination is performed through resistance testing to beta-lactam antibiotics, particularly methicillin or oxacillin (Alghamdi *et al*., 2023). This testing can be performed using the disk diffusion method (Kirby–Bauer), the minimum inhibitory concentration (MIC) test, or automated antimicrobial susceptibility testing (Adhikari *et al*., 2017). Oxacillin and cefoxitin are often used as resistance indicators because they provide more consistent and sensitive results than methicillin (Swenson *et al*., 2025). Isolates showing inhibition zone diameters below the clinical threshold or high MIC values are categorized as MRSA.

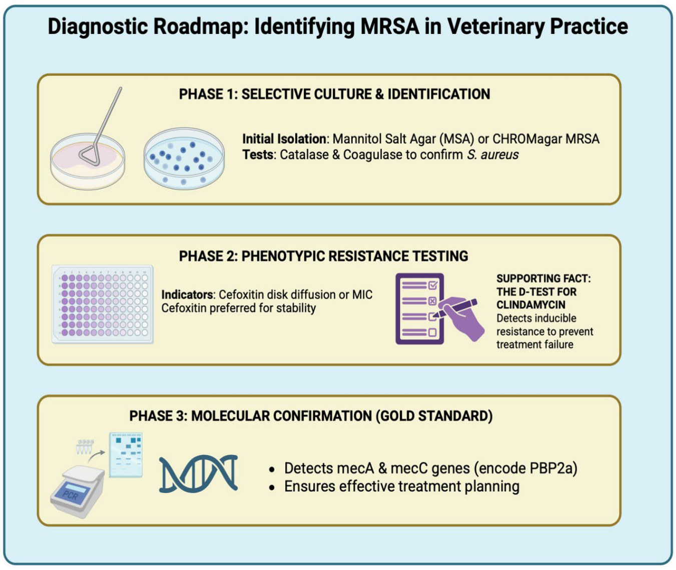


Figure 3. Diagnostic roadmap for MRSA identification in veterinary settings. Sequential integration of culture-based screening, phenotypic resistance assessment, and molecular confirmation enables accurate differentiation of MRSA from susceptible strains.

Some veterinary laboratories also perform additional confirmatory testing by detecting Penicillin-Binding Protein 2a (PBP2a), a penicillin-binding protein encoded by the *mec*A gene (Ramadhani *et al*., 2024). Phenotypic detection of PBP2a using immunochromatography or latex agglutination kits can improve diagnostic accuracy, especially in isolates with borderline resistance that may give ambiguous results on disk diffusion tests (Chapin and Musgnug, 2004).

Although culture and phenotypic identification techniques provide reliable data, these methods have limitations, such as relatively long testing times (24–48 hours), the risk of contamination, and the potential for errors in heteroresistant strains (Gajic *et al*., 2022). Nevertheless, culture remains an important component in MRSA management because it provides the basis for antibiotic susceptibility testing that guides therapy, while also enabling epidemiological analysis and monitoring of antimicrobial resistance in animal health facilities (Lucian-Daniel *et al*., 2026).

Antibiotic sensitivity test

Antibiotic susceptibility testing plays a crucial role in the clinical management of MRSA infections, particularly in animal healthcare settings, as the results form the basis for selecting effective antimicrobial therapy (Pavani *et al*., 2025). Given that MRSA is intrinsically resistant to beta-lactam antibiotics due to the presence of the *mec*A or *mec*C genes, assessing susceptibility to other antibiotic groups is crucial to minimize the risk of treatment failure and prevent further resistance development (Abebe and Birhanu, 2023).

The most commonly used methods for determining antibiotic sensitivity profiles include disk diffusion (Kirby–Bauer method) and Minimum Inhibitory Concentration (MIC) measurements (Khan *et al*., 2019). Disk diffusion is widely preferred by veterinary laboratories due to its simplicity, cost-effectiveness, and ease of interpretation (Balouiri *et al*., 2016). In this method, MRSA isolates are inoculated onto Mueller-Hinton agar surfaces and treated with antibiotic discs at standard concentrations (Gurung *et al*., 2020). The zone of inhibition formed around the disc is then measured and compared with threshold values established by the Clinical and Laboratory Standards Institute (CLSI) or EUCAST (Matuschek *et al*., 2014). Cefoxitin is often used as a surrogate agent for detecting methicillin resistance because it provides more consistent results than oxacillin, especially in isolates with a heteroresistant phenotype (Skov *et al*., 2014).

MIC measurements provide more accurate results because they assess the minimum antibiotic concentration capable of inhibiting bacterial growth (Kowalska-Krochmal and Dudek-Wicher, 2021). This method can be performed using broth microdilution techniques, E-tests, or automated systems (Gajic *et al*., 2022). MICs are crucial for assessing resistance levels and determining whether antibiotics are still effective, especially in severe or systemic infections requiring intensive therapy in animals (Caneschi *et al*., 2023). MICs are also recommended for isolates with unusual resistance patterns or when disk diffusion results indicate a borderline zone of inhibition (Stefani *et al*., 2025).

Antibiotic susceptibility testing for MRSA typically includes a range of non-beta-lactam antimicrobial classes, including fluoroquinolones, macrolides, lincosamides, tetracyclines, trimethoprim-sulfamethoxazole, glycopeptides (such as vancomycin), and other antibiotics recommended for veterinary use (Lade *et al*., 2022). MRSA resistance patterns in animals tend to vary across regions and reflect antibiotic practices in specific species (Kasela *et al*., 2023). For example, resistance to fluoroquinolones and macrolides tends to be higher in veterinary facilities that routinely use these two classes of antibiotics as first-line therapy (Caneschi *et al*., 2023).

Some MRSA isolates may exhibit inducible clindamycin resistance (iMLSB), which is only detectable by the D-test (Thapa *et al*., 2021). Identification of this phenomenon is important because isolates that appear phenotypically sensitive to clindamycin may become resistant during therapy, potentially leading to treatment failure (Vandana *et al*., 2009). Therefore, the D-test is recommended as an additional procedure when isolates exhibit resistance to erythromycin but appear sensitive to clindamycin (Steward *et al*., 2005).

Interpretation of antibiotic susceptibility test results must take into account the clinical context, site of infection, the animal's immune status, and the antibiotic's pharmacokinetics in the species concerned (Alikhani *et al*., 2025). Inappropriate antibiotic selection not only increases the risk of treatment failure but also encourages the selection of multiresistant MRSA strains (Pogorzelska-Maziarz *et al*., 2013). Therefore, susceptibility testing is a crucial step in implementing antimicrobial stewardship in animal healthcare facilities, ensuring the rational, effective, and sustainable use of antibiotics (Sheerah *et al*., 2025).

Molecular diagnostic techniques

Molecular identification is considered the most accurate method for detecting MRSA because it can confirm the presence of genetic determinants that directly cause methicillin resistance (Xing *et al*., 2022). This approach is particularly useful when phenotypic identification results are unclear, for example in heteroresistant strains or isolates with borderline inhibition zones in oxacillin or cefoxitin tests (Naeim *et al*., 2023). Therefore, detection of the *mec*A and *mec*C genes via polymerase chain reaction (PCR) has become the gold standard in MRSA diagnosis, including in veterinary laboratories (Mohammed *et al*., 2025).

The *mec*A gene encodes the penicillin-binding protein 2a (PBP2a), a transpeptidase enzyme with low affinity for all beta-lactam antibiotics, including penicillins, cephalosporins, and carbapenems (Fishovitz *et al*., 2014). The presence of PBP2a allows the bacteria to continue cell wall synthesis even when exposed to antibiotics, resulting in the characteristic resistance phenotype of MRSA. In addition to *mec*A, there is a homologous gene, *mec*C, that has lower sequence identity but confers a similar resistance pattern (Rosado *et al*., 2025). The *mec*C gene is commonly found in animal and environmental reservoirs, making it relevant in the context of veterinary health and the One Health approach (Roy *et al*., 2024).

Both conventional PCR and real-time PCR (qPCR) methods are used to amplify specific fragments of the *mec*A or *mec*C genes. This process typically begins with DNA extraction from bacterial colonies cultured on selective media (Aldea *et al*., 2025). Specific primers are then used to target genetic segments unique to MRSA (Liu *et al*., 2016). Amplification results can be analyzed by agarose gel electrophoresis in conventional PCR or by fluorescence signal in qPCR. The qPCR technique offers advantages of higher sensitivity and specificity, shorter analysis time, and relative quantification capabilities (Wittmeier and Hummel, 2022).

In addition to amplifying resistance genes, some PCR protocols also include detection of species marker genes, such as nuc or spa, to confirm that the isolate is indeed *S. aureus* (Sanchini, 2022). This multiplexing approach improves the accuracy and efficiency of testing, especially in laboratories processing large numbers of samples (Durib, 2025). Multiplexing PCR is also particularly useful in MRSA surveillance programs in animal health facilities, as it allows for rapid identification of resistant strains while simultaneously monitoring genetic changes in the bacterial population (Kim *et al*., 2013).

Although molecular detection methods demonstrate high sensitivity, they cannot completely replace phenotypic testing. The presence of the *mec*A or *mec*C genes does not always translate into phenotypic resistance, so results need to be analyzed in conjunction with clinical findings and data from culture and antibiotic susceptibility testing (Anjum *et al*., 2017). Conversely, some isolates exhibiting a resistance phenotype may be found without the presence of either gene, although this is rare and is generally caused by alternative resistance mechanisms, such as modification of penicillin-binding proteins (PBPs) or excessive beta-lactamase production (Alghamdi *et al*., 2023).

In animal healthcare facilities, the use of molecular diagnostics plays a crucial role in determining the source of MRSA infection, differentiating between primary infection and colonization, and aiding decision-making regarding therapy and preventive measures (Abebe and Birhanu, 2023). An approach combining molecular identification, phenotypic culture, and antibiotic susceptibility testing provides a comprehensive diagnostic strategy, which is essential for effective, accurate, and sustainable MRSA management (He *et al*., 2026).

Interpretation and diagnostic challenges in the veterinary clinic

The diagnosis of MRSA in animals is complex due to species variation, differences in clinical symptoms, and limited laboratory facilities in many veterinary clinics (Weese, 2010). The process of identifying MRSA requires a combination of clinical examination, bacterial culture, and confirmation of antibiotic resistance through valid laboratory tests (Kumar *et al*., 2025). However, interpretation of results is often challenging because *S. aureus* can colonize without causing an active infection (Touaitia *et al*., 2025). Therefore, a proper understanding is needed to differentiate between colonization, sample contamination, and infections that require therapy.

Limited veterinary laboratory facilities, particularly in developing countries, are a major obstacle to ensuring diagnostic accuracy. Not all clinics have access to molecular-based resistance confirmation methods such as PCR to detect the *mec*A or *mec*C genes, so most diagnoses still rely on phenotypic tests, such as disk diffusion or MIC (Aldea *et al*., 2025). Differences in the sensitivity and specificity of these methods can produce variable results, particularly for borderline oxacillin-resistant *S. aureus* (BORSA) or *mec*A-negative MRSA isolates, necessitating a more rigorous diagnostic approach (Sakoulas *et al*., 2001).

Furthermore, host factors also play a role in interpreting diagnostic results. Animals with compromised immune systems or chronic wounds are more susceptible to MRSA colonization, making it difficult to assess whether a recovered isolate is truly related to the patient's clinical condition (Scott *et al*., 2022). This situation is further complicated by the possibility of cross-contamination from the veterinary hospital environment, staff, or other animals, which can produce MRSA isolates that are not clinically relevant to the animal being examined (O'Mahony *et al*., 2005).

An additional challenge arises from the need to screen hospitalized animals for MRSA as part of infection control strategies (Rasmussen *et al*., 2011). However, routine screening is often hampered by cost, time, and limited laboratory facilities (Ayebare *et al*., 2019). Furthermore, selecting the most appropriate sample type—such as nasal, skin, or perineal swabs—remains a matter of debate, as colonization rates can vary across species and anatomical sites (Kosnik *et al*., 2016).

On the other hand, antibiotic susceptibility test results require careful interpretation because different standards, such as CLSI and EUCAST, can assign different sensitivity categories to certain antibiotics (Gajic *et al*., 2022). This requires clinicians to be able to accurately interpret laboratory reports and relate them to the patient's clinical condition, history, and potential zoonotic risk (Rodloff *et al*., 2008).

MRSA prevention strategies in veterinary clinics and hospitals

MRSA prevention efforts in animal health facilities require a comprehensive strategy, including biosecurity, hygienic practices by medical personnel, environmental control, and rational and controlled use of antibiotics. Table 2 summarizes the major prevention strategies used to control MRSA transmission in veterinary clinics and hospitals.

Biosecurity protocols

Biosecurity protocols play a crucial role in preventing the spread of MRSA in animal healthcare facilities (Sawodny *et al*., 2025). In veterinary clinics and hospitals, this pathogen can persist for long periods on various surfaces and is easily transmitted through direct contact, medical equipment, and the movement of staff and patients (Jaradat *et al*., 2020). Therefore, the integrated and consistent implementation of biosecurity is a key foundation for achieving effective infection control (Hanselman *et al*., 2006).

Cleanliness of cages, practice rooms, and inpatient rooms must be standardized, using disinfectants effective against Gram-positive bacteria, including resistant strains (Doll *et al*., 2018). Routine cleaning should be complemented by periodic deep cleaning, especially in areas with high levels of contamination, such as operating rooms or rooms occupied by animals with infected wounds or a history of MRSA colonization (Lei *et al*., 2017). Reusable medical equipment must undergo standard decontamination and sterilization procedures, as cross-contamination due to improperly sterilized instruments is a major cause of MRSA spread in veterinary facilities (Dancer, 2014). Furthermore, clean work clothes and the use of personal protective equipment by staff also play a crucial role in breaking the chain of environmental contamination (Lena *et al*., 2021).

In addition to maintaining environmental cleanliness, implementing a zoning system and managing patient flow are essential components for strengthening biosecurity (Salge *et al*., 2017). Dividing work areas based on risk levels such as clean zones, transition zones, and contaminated zone, which aims to limit the movement of animals, staff, and equipment to minimize the risk of pathogen spread (EFSA BIOHAZ Panel, 2022). Animals suspected or confirmed to have MRSA should be placed in isolation zones with special supervision to prevent transmission through direct contact or droplets (Stein, 2009). Patient flow should also be structured according to risk level, so that healthy and infected animals are handled separately (Fenta *et al*., 2025). Staff movement between zones needs to be strictly limited and regulated to prevent the transfer of contaminants from high-risk areas to clean areas (Coia *et al*., 2006). The use of person-

Table 2. MRSA prevention strategies in veterinary clinics and hospitals.

Prevention component	Strategy / measure	Description and practical significance	References
Biosecurity protocols	Environmental cleaning and disinfection	Standardized routine cleaning and periodic deep cleaning of cages, consultation rooms, inpatient units, and operating rooms using disinfectants effective against Gram-positive resistant bacteria	(Sawodny *et al*., 2025; Doll *et al*., 2018; Lei *et al*., 2017)
	Equipment decontamination	Sterilization and decontamination of reusable medical instruments to prevent cross-contamination	(Dancer, 2014)
	PPE and work clothing	Use of clean uniforms, gloves, masks, and gowns to reduce environmental contamination and direct pathogen transfer	(Lena *et al*., 2021; Hughes *et al*., 2013)
	Zoning system	Separation into clean, transition, and contaminated zones to restrict movement of staff, animals, and equipment	(Salge *et al*., 2017; EFSA BIOHAZ Panel, 2022)
	Isolation and patient flow	Isolation of suspected/confirmed MRSA animals and structured patient flow according to infection risk	(Stein, 2009; Fenta *et al*., 2025; Coia *et al*., 2006)
Habits-based prevention of medical personnel	Hand hygiene	Handwashing with antiseptic soap or alcohol-based sanitizer before and after patient contact and other critical moments	(Pineles *et al*., 2017; Creech *et al*., 2015; Mathur, 2011)
	PPE compliance	Appropriate use and removal of gloves, masks, and gowns according to procedural risk	(López-Alcalde *et al*., 2015; Roghmann *et al*., 2016; Gund *et al*., 2024)
	Staff training	Regular training on MRSA epidemiology, hand hygiene, PPE use, and management of high-risk patients	(Popovich *et al*., 2023; Byrne and Wilcox, 2011; Braun *et al*., 2020)
Environmental control	Surface and equipment disinfection	Routine disinfection of high-touch surfaces, treatment tables, doorknobs, and reusable medical equipment	(Akwuobu *et al*., 2021; Commission for Hospital Hygiene and Infection Prevention (KRINKO), 2024; Callahan *et al*., 2010; Commission for Hospital Hygiene and Infection Prevention at the Robert Koch-Institute, 2009)
	Sanitation monitoring	Hygiene audits, inspections, and microbiological testing of high-risk areas	(Rutala and Weber, 2016; Makovska *et al*., 2025)
	Medical waste management	Proper segregation, transport, storage, and disposal of infectious waste such as swabs, bandages, and syringes	(Cimolai, 2008; Cirstea *et al*., 2025; Yang *et al*., 2024; Kurashige *et al*., 2016)
Antimicrobial Stewardship Program (AMSP)	Antibiotic use guidelines	Rational antibiotic prescribing based on clinical condition, dosage, route, and treatment duration	(Rajendran *et al*., 2025; Endale *et al*., 2023; Sousa *et al*., 2025; De Waele *et al*., 2020)
	De-escalation therapy	Switching from empirical broad-spectrum therapy to narrow-spectrum agents after AST results	(De Waele *et al*., 2020)
	Resistance surveillance	Monitoring local MRSA resistance trends from clinical and environmental isolates	(Alghamdi *et al*., 2023; Boswihi *et al*., 2026; Oliveira *et al*., 2024)
	Clinician–laboratory collaboration	Integration of culture, AST, and molecular diagnostic results into clinical decision-making	(Gajic *et al*., 2022; Mohammed *et al*., 2025; Muteeb *et al*., 2023; Morency-Potvin *et al*., 2016)

al protective equipment, clothing change procedures, and room entry and exit procedures in accordance with biosecurity principles are integral parts of this system (Hughes *et al.*, 2013).

Habits-based prevention of medical personnel

Behavioral prevention of medical personnel is a crucial aspect in reducing the spread of MRSA in veterinary clinics and hospitals (Subba and Tsering, 2025). Proper professional behavior directly impacts the risk of pathogen transmission, as medical personnel frequently interact with multiple patients, equipment, and potentially contaminated environments (Nadimpalli *et al.*, 2020). Proper handwashing practices, the use of personal protective equipment (PPE) appropriate to the risk level, and regular staff training are key steps to strengthening infection prevention systems in veterinary healthcare facilities (Weese, 2010).

Hand hygiene is a key factor in preventing the spread of MRSA, as healthcare workers' hands often serve as the primary route of transmission between patients (Pineles *et al.*, 2017). The use of antiseptic soap or alcohol-based hand sanitizer has been shown to reduce the number of pathogens on the skin (Creech *et al.*, 2015). Implementing handwashing protocols that follow critical moments—before and after patient contact, before performing aseptic procedures, after contact with bodily fluids, and after touching the patient's environment—should become routine practice (Mathur, 2011). Failure to adhere to these procedures has been shown to increase the risk of nosocomial infections, including those caused by MRSA (Abebe and Birhanu, 2023).

The use of PPE, such as gloves, masks, and gowns, plays a crucial role in preventing direct and indirect contact with MRSA (López-Alcalde *et al.*, 2015). PPE serves as a physical barrier that reduces the risk of contamination of healthcare workers' skin, clothing, and mucous membranes (Roghmann *et al.*, 2016). The selection and use of PPE should be tailored to the risk level of each procedure, for example, gloves for all contact procedures, masks for wound care or aerosol-generating procedures, and gowns when caring for patients with active infections (López-Alcalde *et al.*, 2015). Furthermore, proper removal of PPE must be performed to avoid contamination of oneself or the environment (Gund *et al.*, 2024).

Regular staff training is key to ensuring consistent and sustainable implementation of infection prevention measures (Popovich *et al.*, 2023). These training programs encompass not only theoretical understanding of MRSA epidemiology and biosecurity principles, but also practical skills, such as proper handwashing techniques, donning and doffing procedures for PPE, and handling high-risk patients (Byrne and Wilcox, 2011). Furthermore, regular monitoring and evaluation, including compliance audits, feedback, and case simulations—can increase staff awareness and foster a culture of safety within the clinical environment (Braun *et al.*, 2020).

Environmental control

Environmental control is a crucial aspect in preventing the spread of MRSA in veterinary clinics and hospitals (Hoet *et al.*, 2011). Veterinary healthcare facilities can serve as reservoirs for resistant pathogens, particularly on frequently touched surfaces, medical equipment, and animal care areas (Akwuobu *et al.*, 2021). Therefore, implementing systematic, evidence-based environmental control strategies is essential to minimize the risk of infection transmission, both between animals and from animals to humans (Barua *et al.*, 2025).

Disinfecting medical surfaces and equipment is a crucial step in MRSA control. This bacterium can survive for long periods on dry surfaces, such as examination tables, doorknobs, treatment rooms, and non-disposable equipment, making mechanical cleaning alone inadequate (Commission for Hospital Hygiene and Infection Prevention (KRINKO), 2024). The use of disinfectants effective against Gram-positive bacteria—such as chlorine-based solutions, stabilized hydrogen peroxide, or quaternary ammonium compounds—must be performed routinely and according to a schedule outlined in standard operating procedures (Callahan *et al.*, 2010). Repeatedly used medical equipment should undergo sterilization or high-level disinfection, depending on the risk of contact with patient tissues (Commission for Hospital Hygiene and Infection Prevention at the Robert Koch-Institute, 2009). Failure to adhere to sterilization protocols can lead to cross-contamination, a leading cause of nosocomial infections (Coia *et al.*, 2006).

Environmental sanitation monitoring plays a critical role in ensuring the effectiveness of cleaning and disinfection (Rutala and Weber, 2016). Evaluation can be conducted through routine inspections, hygiene audits, and microbiological testing of high-risk areas. This approach helps identify vulnerable points, such as hard-to-reach surfaces or equipment frequently overlooked during cleaning (Makovska *et al.*, 2025). A good monitoring system not only assesses staff compliance with hygiene procedures but also provides objective data for continuous improvement. Thus, sanitation monitoring serves as an indicator of facility quality and safety (El Roz *et al.*, 2025).

Medical waste management is also a critical component of environmental control (Cimolai, 2008). Infectious waste, such as used bandages, swabs, syringes, and surgical waste, can become a source of MRSA transmission if not handled properly (Cirstea *et al.*, 2025). Waste segregation based on risk level, the use of closed, puncture-resistant containers, and safe transport and storage procedures are essential before further processing through incineration or other regulatory methods (Yang *et al.*, 2024). Failure to adhere to waste management protocols increases the risk of exposure to healthcare personnel, cleaning staff, and the surrounding environment (Kurashige *et al.*, 2016).

Antimicrobial Stewardship Program (AMSP)

The Antimicrobial Stewardship Program (AMSP) is a strategic component in controlling the spread of MRSA in veterinary clinics and hospitals. This program aims to ensure the rational, measured, and evidence-based use of antibiotics, thereby maintaining therapeutic effectiveness while reducing selection pressures that trigger antimicrobial resistance (Rajendran *et al.*, 2025). In the context of animal health, AMSP is crucial because inappropriate antibiotic use remains a major factor in the emergence of MRSA as a pathogen both in clinics and in the environment (Endale *et al.*, 2023).

Implementing antibiotic use guidelines is a fundamental aspect of AMSP. Veterinarians are encouraged to follow proven therapy protocols, including antibiotic selection, dosage, route of administration, and duration of treatment, based on the patient's clinical condition (Sousa *et al.*, 2025). Empirical use of broad-spectrum antibiotics should be limited and considered only in urgent clinical situations or when culture results are not yet available. The principle of de-escalation therapy should be implemented after susceptibility testing results are available, by switching the initial antibiotic to a narrower spectrum but equally effective agent. This strategy aims to reduce the risk of selection of MRSA and other resistant pathogens (De Waele *et al.*, 2020).

Monitoring resistance patterns is a crucial component that enables the assessment of MRSA dynamics in veterinary facilities (Alghamdi *et al.*, 2023). By collecting and analyzing bacterial isolates from patients and the environment, clinics can determine which antibiotics remain effective and observe changes in resistance over time (Boswihi *et al.*, 2026). This information is crucial for developing local therapeutic guidelines, assessing the potential for internal outbreaks, and prioritizing biosecurity measures. Furthermore, routine reporting of resistance patterns can support regional and national surveillance systems, strengthening broader antimicrobial resistance control efforts (Oliveira *et al.*, 2024).

Close collaboration between veterinarians and diagnostic laboratories is crucial to the success of AMSP (Muteeb *et al.*, 2023). The laboratory provides rapid and accurate culture and antimicrobial susceptibility test results, which serve as the basis for clinical decision-making (Gajic *et al.*, 2022). Effective communication between clinicians and laboratory analysts ensures that submitted samples are relevant, collection techniques are appropriate, and interpretation of test results follows standards such as CLSI or EUCAST (Morency-Potvin *et al.*, 2016). Furthermore, this collaboration allows for discussion of rare isolates, emerging resistance patterns, or the need for additional testing, such as *mec*A and *mec*C gene detection using molecular methods (Mohammed *et al.*, 2025).

Clinical management of MRSA in animals

Clinical management of MRSA in animals requires appropriate therapeutic strategies, careful monitoring during the treatment process, and follow-up measures after treatment to prevent recurrence and reduce the risk of spreading. Table 3 summarizes the principal strategies for the clinical management of MRSA infections in animals, including therapeutic interventions, inpatient management, and post-treatment follow-up.

Therapeutic approach

Management of MRSA infections in animals requires a careful, evidence-based strategy, given the bacterium's ability to resist multiple antibiotic classes (Kumar *et al.*, 2025). Antibiotic selection should be based on culture and susceptibility testing results, as empiric treatment carries a higher risk of triggering additional resistance (Thacharodi *et al.*, 2025). In clinical practice, several antibiotics remain effective against MRSA, including lincosamides, tetracyclines such as doxycycline, trimethoprim-sulfamethoxazole, and chloramphenicol (An *et al.*, 2024). However, the effectiveness of these antibiotics is not uniform and depends heavily on the local resistance profile and the type of animal being treated (Li *et al.*, 2025). The use of fluoroquinolone or beta-lactam antibiotics should be avoided, as MRSA naturally possesses a resistance mechanism via the *mec*A gene, which produces PBP2a with low affinity for beta-lactams (Lade and Kim, 2023).

Treatment for MRSA infections generally requires longer duration than for infections caused by susceptible bacteria, particularly in cases of skin infections, chronic wounds, or abscesses that require deep tissue penetration and intensive infection control (Dryden *et al.*, 2010). According to various reports, the duration of treatment typically ranges from 3 to 6 weeks, depending on the clinical response and the effectiveness of infection source control (Olanipekun *et al.*, 2025; Fetsch *et al.*, 2021). Therapy is monitored through regular clinical evaluations, repeat cultures when necessary, and assessment of local symptomatic improvement, such as decreased inflammation, wound healing, and reduced exudate (Tomo *et al.*, 2021). Dose reduction or discontinuation of therapy should not be undertaken before objective signs of improvement are observed, as premature discontinuation can increase the risk of relapse and prolong the potential for transmission (Lucian-Daniel *et al.*, 2026).

In addition to antibiotics, several alternative therapies have been reported as complementary approaches, although their use should be done with careful consideration (Kasela *et al.*, 2023). Therapies such as topical antiseptics (e.g., chlorhexidine or povidone-iodine), honey-based wound care, or ozone therapy have been shown to have the potential to reduce bacterial counts on wound surfaces and accelerate the healing process (Astuti *et al.*, 2023). These approaches are commonly used as adjuncts to antibiotic therapy, especially in cases of persistent skin infections or colonization (Song *et al.*, 2018). However, scientific evidence regarding the effectiveness of these alternative therapies is still mixed and insufficient

Table 3. Clinical management strategies for MRSA in animals.

Management component	Clinical strategy / measure	Description and clinical significance	References
Therapeutic approach	Culture- and AST-guided antibiotic therapy	Antibiotic selection based on culture and susceptibility results to avoid empiric misuse and reduce additional resistance development	(Kumar *et al*., 2025; Thacharodi *et al*., 2025)
	Recommended antibiotics	Use of lincosamides, doxycycline, trimethoprim-sulfamethoxazole, and chloramphenicol depending on species and local resistance profile	(An *et al*., 2024; Li *et al*., 2025)
	Avoided antibiotics	Avoidance of β-lactams and fluoroquinolones due to intrinsic MRSA resistance mediated by *mecA* / PBP2a	(Lade and Kim, 2023)
	Treatment duration	Prolonged treatment period (generally 3–6 weeks), especially in chronic wounds, abscesses, or deep skin infections	(Olanipekun *et al*., 2025; Dryden *et al*., 2010; Fetsch *et al*., 2021)
	Therapy monitoring	Regular clinical evaluation, repeat culture when needed, wound healing assessment, and exudate reduction	(Tomo *et al*., 2021; Lucian-Daniel *et al*., 2026)
	Adjunctive therapies	Use of chlorhexidine, povidone-iodine, honey-based wound care, and ozone therapy as complementary treatments	(Kasela *et al*., 2023; Astuti *et al*., 2023; Song *et al*., 2018; Mdarhri *et al*., 2022)
Inpatient animal care	Isolation room	Placement of suspected or confirmed MRSA animals in isolation rooms with adequate ventilation and restricted access	(Khairullah *et al*., 2023b), (Ferreira *et al*., 2011)
	Contact precautions	Mandatory use of PPE (gloves, gowns, masks) and strict replacement after each patient contact	(Khairullah *et al*., 2023b; López-Alcalde *et al*., 2015)
	Dedicated equipment	Use of patient-specific equipment such as thermometers and wound care tools to prevent cross-contamination	(Liang *et al*., 2018; Bergström *et al*., 2012)
	Continuous risk assessment	Ongoing assessment based on wounds, exudate, behavior, and room conditions to adjust infection control measures	(Shoaib *et al*., 2023), (Ferreira *et al*., 2011; Ishihara *et al*., 2014; Vincze *et al*., 2014)
Post-treatment animal management	Owner education	Education regarding wound care, treatment adherence, and prevention of home transmission	(Khairullah *et al*., 2023b; Sawodny *et al*., 2025; Kumar *et al*., 2025)
	Personal hygiene	Handwashing with antiseptic soap after contact with animals, bedding, or feeding equipment	(Sawodny *et al*., 2025; Silva *et al*., 2023)
	Restriction of close contact	Avoiding kissing animals or allowing them to sleep in human beds during recovery	(Cotter *et al*., 2023)
	Equipment sanitation	Regular cleaning of bedding, food bowls, combs, and grooming tools	(Hogan *et al*., 2019)
	Household prevention	Limiting interaction with high-risk family members and routine disinfection of frequently touched surfaces	(Stein, 2009; Li *et al*., 2025; Kurashige *et al*., 2016; Knox *et al*., 2015)
	Veterinary follow-up	Continued monitoring until transmission risk is confirmed to be significantly reduced	(Hanselman *et al*., 2006)

to replace conventional antimicrobial treatment (Mdarhri *et al*., 2022).

Inpatient animal care

Handling inpatient animals at risk of or already infected with MRSA requires strict biosecurity measures to prevent transmission, both between animals and from animals to humans (Khairullah *et al*., 2023b). Animals infected or suspected of carrying MRSA should be placed in an isolation room with adequate ventilation and limited staff access. This isolation aims to separate high-risk animals from other patients, thereby reducing the possibility of transmission through direct contact, droplets, or environmental contamination (Ferreira *et al*., 2011). Furthermore, the isolation room facilitates more intensive clinical monitoring and facilitates the implementation of more specific cleaning protocols (Sawodny *et al*., 2025).

Contact precautions are a crucial aspect of managing hospitalized animals infected with MRSA (Khairullah *et al*., 2023b). Staff handling these animals are required to wear PPE, such as gloves, gowns, and masks, as clinically necessary (López-Alcalde *et al*., 2015). Protocols for changing PPE after each contact are crucial to prevent cross-contamination within the facility (Khairullah *et al*., 2023b). Additionally, the use of patient-specific medical equipment in isolation rooms, such as thermometers, stethoscopes, or wound care devices, helps minimize the transfer of microorganisms through objects (Liang *et al*., 2018). Non-separate equipment should be thoroughly sterilized or disinfected before use on another patient (Bergström *et al*., 2012).

Transmission risk assessments are conducted continuously throughout the animal's care (Ferreira *et al*., 2011). These assessments consider factors that can increase the spread of MRSA, such as the presence of open wounds, exudate levels, aggressive or unruly animal behavior, and the environmental conditions of the isolation room (Shoaib *et al*., 2023). This data helps veterinarians and clinic staff determine additional preventative measures, such as increasing cleaning frequency, limiting the number of staff members handling patients, or adjusting ventilation and sanitation protocols (Ishihara *et al*., 2014). Accurate risk assessments enable swift and focused action, while reducing the likelihood of an outbreak within the facility (Vincze *et al*., 2014).

Post-treatment animal management

Post-treatment animal management is a crucial step in reducing the risk of MRSA transmission after the animal leaves the healthcare facility (Kumar *et al*., 2025). Even if the clinical condition improves, the possibility of bacterial colonization on the skin, fur, or home environment remains (Silva *et al*., 2023). Therefore, comprehensive education for pet owners is crucial to prevent further transmission (Khairullah *et al*., 2023b). Veterinary guidance should include wound care, adherence to treatment, and home hygiene measures that can be implemented to minimize the risk of transmission (Sawodny *et al*., 2025).

Pet owners should be educated on the importance of personal hygiene after handling animals recovering from MRSA infections (AVMA Group Health and Life Insurance Trust, 2009). Highly effective basic steps include washing hands with antiseptic soap after contact with animals, feeding equipment, or bedding (Sawodny *et al*., 2025). Owners should also avoid close contact, such as kissing animals or allowing them to sleep in human beds during recovery, as this can increase the risk of bacterial transfer (Cotter *et al*., 2023). Additionally, pet equipment, including bedding, food bowls, and grooming tools like combs or nail clippers—should be cleaned or sanitized regularly to minimize environmental contamination (Hogan *et al*., 2019).

Furthermore, household education is a crucial component in preventing MRSA transmission between family members (Knox *et al*., 2015). The public needs to understand that MRSA is an opportunistic zoonosis that can be transmitted from animals to humans, primarily through direct contact or contaminated objects (Stein, 2009). Therefore, animal interaction with high-risk family members, such as children, the elderly, or individuals with weakened immune systems, should be limited during the recovery period (Li *et al*., 2025). Households are also advised to maintain environmental hygiene by lightly disinfecting surfaces frequently touched by animals, such as floors, sofas, or cages (Kurashige *et al*., 2016). This practice should be carried out routinely until a veterinarian confirms that the risk of transmission has significantly decreased (Hanselman *et al*., 2006).

Outbreak management in animal health facilities

Managing MRSA outbreaks in animal health facilities requires rapid identification and tracing of the source of infection, and the implementation of coordinated control measures to stop the spread and prevent similar cases from occurring in the future.

Identification and investigation of outbreaks

Outbreak identification and investigation are crucial aspects of epidemiology to understand disease patterns and prevent further spread in animal and human populations (Briki *et al*., 2025). This process begins with early detection through surveillance systems that monitor changes in disease incidence over time (Thacharodi *et al*., 2025). When an unusual increase in cases occurs, the first step is to verify reports and ensure the data obtained is accurate and reflects the situation on the ground (Turner *et al*., 2019). This validation is crucial to ensure the response is appropriate to the threat level and to avoid epidemiological misinterpretations (Arieno *et al*., 2022).

Following initial indications of a possible outbreak, field investigations are conducted to determine the source, transmission routes, and affected populations (Belhout *et al*., 2022). Data are systematically collected through interviews, observations, and clinical records to obtain a picture of the distribution of cases by time, location, and host characteristics (Haapia *et al*., 2026). Biological samples taken from infected animals, the environment, or vectors are then used for laboratory analysis, which helps establish a diagnosis and identify the causative agent (Attia *et al*., 2024). The use of molecular techniques, such as PCR and sequencing, further improves the accuracy of pathogen identification and the understanding of epidemiological relationships between cases (Bai *et al*., 2021).

During an investigation, a risk factor analysis is conducted to understand conditions that facilitate an outbreak, such as animal population density, biosecurity weaknesses, or environmental changes that influence disease spread (Algammal *et al*., 2020). This information is essential for designing effective control strategies. Interventions may include isolating sick animals, improving sanitation, strengthening biosecurity, vaccination, or restricting animal movement to break the chain of transmission (Butucel *et al*., 2022). All actions must be aligned with scientific evidence, while considering animal welfare and the economic impact on the owner or the relevant industry (Kasela *et al*., 2023).

In the final stage, a post-outbreak evaluation is conducted to assess the effectiveness of control measures and identify weaknesses in the response system (Dickmann *et al*., 2017). Structured documentation is crucial for improving epidemiological understanding, refining investigation guidelines, and enhancing early detection capabilities for similar future outbreaks (Briki *et al*., 2025). With a comprehensive, evidence-based approach, outbreak identification and investigation not only serve as disease mitigation but also make a vital contribution to strengthening animal health and public health resilience in accordance with the One Health principle (Fitranda *et al*., 2024).

Surveillance and screening of staff / patients

Surveillance and screening of staff and patients are essential components of infection control in veterinary clinics and hospitals, particularly to prevent the spread of MRSA (Shoaib *et al*., 2023). Implementing both approaches allows for early detection of colonization and infection, allowing interventions to be initiated before the pathogen spreads to other animals, the facility environment, or humans (Lucian-Daniel *et al*., 2026). Continuous surveillance provides a dynamic understanding of MRSA incidence patterns over time, while focused screening of high-risk individuals improves healthcare facilities' ability to identify potential sources of infection (Briki *et al*., 2025).

Staff screening focuses on individuals who have extensive contact with animals or potentially contaminated medical equipment (Leszczyński *et al*., 2024). Screening typically involves sampling from the nasal cavity, hands, or other skin areas frequently colonized by MRSA (Lee *et al*., 2015). In veterinary patients, screening is primarily performed in cases with a history of recurrent infections, chronic wounds, or prior to invasive medical procedures (Struelens *et al*., 2009). The results of this screening are used to determine whether the individual is a carrier, allowing specific protocols—such as isolated handling, increased hygiene, and the use of personal protective equipment—to be implemented (Ojeh *et al*., 2025).

Environmental surveillance also plays a crucial role because surfaces such as cages, examination tables, medical equipment, and even work clothing can potentially become reservoirs of MRSA (Yu *et al*., 2022). By combining data from staff, patients, and the environment, animal healthcare facilities can more accurately map transmission chains (Turner *et al*., 2019). Trend analysis from this surveillance provides a scientific basis for evaluating the effectiveness of implemented infection control policies and identifying critical points requiring additional intervention (Lucian-Daniel *et al*., 2026).

Systematic implementation of surveillance and screening not only serves as a detection tool but also strengthens a culture of safety and vigilance in clinical settings (Touaitia *et al*., 2025). Supported by staff training, adherence to hygiene protocols, and effective risk communication, these efforts can significantly reduce the burden of MRSA (Humphreys *et al*., 2009). Furthermore, this approach aligns with the One Health principle, as preventing the spread of MRSA in animal healthcare facilities also protects public health, given the potential for zoonosis and the exchange of strains between animals and humans (Ramirez-Plascencia *et al*., 2025). With a data-driven strategy focused on prevention, surveillance and screening are essential pillars of sustainable and scientific infection risk management (Lucian-Daniel *et al*., 2026).

Area closure, intensive disinfection, and reopening policy

Area closures, thorough disinfection, and implementation of reopening policies are key strategies for controlling the spread of MRSA in veterinary clinics and hospitals (Dancer, 2014). When cases increase or a significant source of contamination is identified, closing specific areas is the first step to temporarily halt activities and break the chain of transmission (Santosaningsih *et al*., 2019). This step allows the infection control team time to conduct risk assessments, identify critical points of transmission, and plan appropriate corrective actions before the facility is reopened (Hughes *et al*., 2013).

During the closure period, thorough disinfection of all surfaces, medical equipment, treatment rooms, and high-contact areas is performed (Commission for Hospital Hygiene and Infection Prevention at the Robert Koch-Institute, 2009). MRSA can persist for long periods in the environment, making the selection of an effective disinfectant, the use of the correct concentration, and the appropriate contact time crucial (Abebe and Birhanu, 2023). Disinfection procedures include initial mechanical cleaning, application of a chlorine-based disinfectant, quaternary ammonium compounds, or other approved agent, and post-disinfection verification through culture or rapid testing to ensure the environment is free of contamination (Callahan *et al*., 2010). Additionally, non-disposable equipment must undergo additional sterilization to eliminate the risk of microbial residues that could lead to recontamination (Dancer, 2014).

Once disinfection is complete and the area is declared safe, the reopening of the facility should be done in a phased manner, taking into account biosecurity evaluations, staff adherence to hygiene protocols, and the facility's readiness to prevent a recurrence (Minary-Dohen *et al*., 2003). Reopening policies include stricter staff and patient movement controls, initial patient restrictions, and increased monitoring for MRSA colonization and infection through regular surveillance (Samuel *et al*., 2023). Furthermore, re-education of animal health workers regarding handwashing practices, the use of personal protective equipment, and the handling of high-risk patients is a crucial part of this phase (Gould *et al*., 2017).

Implementing area closures, thorough disinfection, and evidence-based reopening policies not only improve the safety of clinical environments but also strengthens pet owners' confidence in the quality of healthcare services (Khairullah *et al*., 2023b). By ensuring each step is systematic, measured, and adheres to epidemiological standards, animal healthcare facilities can minimize the risk of MRSA transmission while increasing preparedness for future outbreaks (Li *et al*., 2025). This strategy reflects a commitment to the One Health principle, where animal infection control contributes to protecting human health and the environment (Shoaib *et al*., 2023).

Case study of MRSA outbreak in a veterinary clinic

Case studies of MRSA outbreaks in veterinary clinics provide important insights into how antibiotic-resistant pathogens spread and persist in veterinary healthcare settings (Petinaki and Spiliopoulou, 2015). Several reports have shown that MRSA outbreaks in veterinary facilities often begin with one or more asymptomatically colonized animals or with skin infections that do not respond to standard therapy (Sawodny *et al*., 2025). These animals then become a major source of environmental contamination and a source of transmission to other patients and clinic staff (Khairullah *et al*., 2023b). This highlights the role of asymptomatic colonization in triggering outbreaks, particularly in facilities with high case densities and shared equipment (Lakhundi and Zhang, 2018).

Epidemiological investigations into these cases generally reveal weaknesses in biosecurity practices, such as improperly sterilized equipment, inconsistent hand hygiene, or inadequate ventilation (El Roz *et al*., 2025). Molecular analysis, using methods such as pulsed-field gel electrophoresis (PFGE) or whole-genome sequencing (WGS), is often used to identify genetic similarities between isolates, thus confirming that circulating strains originate from a common source (Naorem *et al*., 2021). These findings confirm that MRSA transmission in veterinary clinics can occur through direct contact between animals and staff, as well as indirectly through contaminated environmental surfaces (Szabó, 2014).

Outbreak management in reported case studies generally included temporary closure of treatment areas, isolation of confirmed animals, and thorough disinfection of all rooms and equipment (Agha, 2012). Staff identified as carriers underwent decolonization using topical antiseptics or antibiotics as recommended by medical professionals (Westgeest *et al*., 2021). These measures have proven effective in stopping transmission, but their success depends heavily on adherence to procedures and post-outbreak monitoring to ensure MRSA strains do not re-emerge (Coia *et al*., 2006). Post-intervention evaluations have shown that implementing stricter handwashing protocols, using personal protective equipment, and updating sterilization policies are crucial steps to prevent future outbreaks (Gould *et al*., 2017).

Documentation of MRSA outbreaks in veterinary clinics provides clear evidence of the importance of implementing a comprehensive preventive approach in the management of veterinary healthcare facilities (Barton *et al*., 2006). These studies emphasize that resistant pathogens are not only a threat to animal health but also pose a potential zoonotic risk relevant to the One Health principle (Li *et al*., 2025). By understanding the factors driving outbreaks and the effectiveness of response measures, veterinary clinics and hospitals can improve preparedness, strengthen infection control programs, and mitigate the long-term impact of antimicrobial resistance in the veterinary healthcare context (Sheerah *et al*., 2025).

The role of the one health approach

The One Health approach plays a key role in understanding and controlling the spread of MRSA, as this bacterium can move between species and persist in various environmental compartments (Al-Khalaifah *et al*., 2025). The close relationship between animals, humans, and the environment makes MRSA a health threat that cannot be addressed in isolation (Li *et al*., 2025). Domestic animals, production animals, and wildlife can act as reservoirs facilitating cross-transmission to humans, while clinical environments, farms, and public spaces act as intermediaries, perpetuating the infection cycle (Barua *et al*., 2025). The complexity of these dynamics demands management that integrates epidemiological data, resistance patterns, and interactions between living organisms, so that interventions can be designed holistically and based on evidence (Briki *et al*., 2025).

Intersectoral collaboration between animal health and human health institutions is a crucial aspect of the One Health framework to reduce the burden of MRSA (Roy *et al*., 2024). Sharing information on circulating strains, antibiotic resistance patterns, and colonization or infection events across both health systems allows for early detection of epidemiological changes that could have far-reaching impacts (Santosaningsih *et al*., 2019). Collaborative programs, such as integrated surveillance, cross-facility outbreak investigations, and comparative studies of animal and human isolates, provide a more comprehensive understanding of transmission pathways (Lucian-Daniel *et al*., 2026). Through this collaboration, antibiotic use policies can be aligned, particularly to reduce inappropriate antimicrobial use in animals that contributes to the emergence of resistant strains (Mehndiratta and Bhalla, 2014).

Policy implications at the national and global levels further emphasize the importance of a One Health approach in MRSA control (Algammal *et al*., 2020). Many countries are now integrating antimicrobial resistance issues into national action plans that simultaneously encompass human health, animal health, and environmental health (Nazir *et al*., 2025). These strategies include strict regulations on antibiotic use in animals, enhanced cross-species surveillance systems, strengthened veterinary laboratory infrastructure, and harmonized biosafety and biosecurity standards (Sawodny *et al*., 2025). Globally, organizations such as the WHO, OIE, and FAO are promoting international cooperation in MRSA monitoring and mitigation, as human and animal mobility can accelerate the spread of resistant strains between countries (Salam *et al*., 2023). Therefore, a One Health approach is not only relevant for MRSA control in veterinary clinics but also serves as a foundation for overall public health stability in the face of the growing threat of antimicrobial resistance (Khan *et al*., 2026).

Challenges and future research directions

Although understanding of MRSA in the context of animal health has advanced rapidly, several scientific challenges remain that limit the effectiveness of prevention and management strategies in veterinary clinics and hospitals (Sharma *et al*., 2024). One major obstacle is the limited number of studies specifically assessing the epidemiology of MRSA in animal health facilities, particularly in developing countries (Azzam *et al*., 2026). Data on colonization rates, environmental risk factors, and interspecies transmission dynamics are scarce and often not standardized. This hampers the ability to build accurate predictive models and limits the applicability of research results across regions or types of facilities (Callejón Fernández *et al*., 2023). Furthermore, the lack of integration between veterinary and human health data creates gaps in understanding the movement of MRSA strains along the animal-human-environment chain of transmission (Lakhundi and Zhang, 2018).

The next challenge is the need to develop and implement an AMSP specifically designed for veterinary clinics (Abebe and Birhanu, 2023). Currently, most AMSPs focus on human healthcare facilities, while guidelines for antibiotic use in animals are often inconsistent across practices, influenced by clinician preferences, and sometimes driven by owner demand (Li *et al*., 2025). Implementing AMSP in the veterinary field requires adequate training, audit mechanisms, monitoring of antimicrobial use, and clear regulations regarding critical antibiotics whose use should be restricted (Oliveira *et al*., 2024). Without a robust stewardship system, overuse or inappropriate antibiotic use will continue to be a major factor in the emergence of new MRSA strains in veterinary settings (Salam *et al*., 2023).

Advances in diagnostic technology offer significant opportunities for future research, particularly through the use of antigen-based rapid tests, point-of-care PCR, and high-speed molecular diagnostic platforms (Tenover and Tickler, 2022). These technologies enable faster identification of MRSA in animals and clinical settings, enabling more rapid and targeted interventions (Aldea *et al*., 2025). Furthermore, genomic surveillance using WGS allows for understanding the phylogenetic relationships between strains, tracing transmission routes, and detecting potential new variants (Tiwari *et al*., 2025). However, the application of these technologies is still limited by cost, laboratory availability, and limited expertise in bioinformatics analysis. Further research is needed to optimize their use in veterinary facilities with varying resource levels (Yamin *et al*., 2023).

Furthermore, several knowledge gaps remain that require further research. One such gap concerns understanding the persistence of MRSA in veterinary clinical settings, including the complex interactions between environmental surfaces, biofilms, and the effectiveness of disinfectants against various strains (Khan *et al*., 2021). Knowledge of animal colonization mechanisms, carrier duration, and host factors influencing susceptibility is also limited (Abebe and Birhanu, 2023). Furthermore, studies on the ecological impact of veterinary antibiotic use on environmental resistance and gene transfer between bacterial species are still limited (Caneschi *et al*., 2023). Filling these knowledge gaps is crucial for designing more comprehensive, evidence-based control strategies that are adaptable to changing antimicrobial resistance epidemiology (Li *et al*., 2025).

Conclusion

MRSA remains a significant threat to animal health and the clinical environment, with the risk of cross-transmission to humans through direct contact and environmental contamination. Numerous studies have shown that successful MRSA prevention and management rely heavily on rigorous biosecurity, ongoing surveillance, rational antibiotic use, and intersectoral collaboration. This integrated approach not only reduces the risk of infection in animals but also strengthens health systems within the One Health framework, where protecting animal health directly supports human safety and the overall balance of the ecosystem.

Acknowledgement

The authors would like to express their sincere gratitude to Prof. Dr. Mustofa Helmi Effendi, DTAPH for his generous financial support and valuable contribution to the completion of this research.

Conflict of interest

The authors declare that there is no conflict of interest.

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