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MRSA Epidemiology, Impact on Public Health, Prevention, Pathophysiology, Treatment, And Nursing Intervention-An Updated Review

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Abstract:

Background: Methicillin-resistant *Staphylococcus aureus* (MRSA) continues to be a major public health challenge due to its increasing prevalence in both healthcare and community settings. The pathogen is responsible for a wide range of infections, from skin conditions to life-threatening diseases. The global rise in MRSA infections, exacerbated by antibiotic misuse and overuse, underscores the urgent need for effective prevention and treatment strategies.

Aim: This review aims to update the current understanding of MRSA, focusing on its epidemiology, pathophysiology, impact on public health, treatment options, and nursing interventions.

Methods: A comprehensive review of recent literature on MRSA was conducted, covering its clinical manifestations, molecular mechanisms of resistance, epidemiology, transmission dynamics, and alternative therapeutic approaches. Studies on both healthcare-associated MRSA (HA-MRSA) and community-acquired MRSA (CA-MRSA) were analyzed to evaluate the evolving nature of MRSA infections and resistance patterns.

Results: MRSA remains a significant cause of morbidity and mortality, with new strains emerging globally. The pathogen's resistance to common antibiotics, including methicillin, has complicated treatment protocols, necessitating the exploration of alternative therapies. The review also highlights the zoonotic transmission of MRSA from livestock to humans and its implications for public health. Recent research suggests the potential of combination antibiotic therapies, phytochemicals, and nanoparticles in combating MRSA infections.

Conclusion: The global threat posed by MRSA demands continued vigilance, improved infection control practices, and the development of novel therapeutic strategies. Nursing interventions focusing on hygiene, surveillance, and education are critical in reducing MRSA transmission. Future research should prioritize exploring new treatment modalities, including phytochemicals and nanotechnology, to overcome the limitations of current antibiotic therapies.

Keywords: MRSA, epidemiology, pathophysiology, antibiotic resistance, zoonotic transmission, nursing interventions, alternative therapies.

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Introduction:

Staphylococcus aureus continues to be a significant pathogen in both clinical and community settings, attributable to its pronounced virulence and capacity to induce a broad spectrum of life-threatening infections [1]. S. aureus is a gram-positive, spherical bacterium (coccus) known to cause a range of infectious diseases in humans, including skin infections, infective endocarditis, osteomyelitis, septic arthritis, metastatic abscess formation, respiratory conditions, and foodborne illnesses [1]. The bacterium colonizes the skin and mucosal surfaces of the respiratory tract in both humans and animals. Although colonization is often asymptomatic, it markedly increases the risk of secondary infections such as superficial skin lesions, soft tissue infections, and sepsis [2]. Numerous studies have focused on understanding the pathogenic mechanisms of S. aureus. Despite extensive research on therapeutic strategies, including vaccine development, the incidence of S. aureus infections continues to rise [1–3].

The treatment of S. aureus infections varies depending on the type of infection; however, antibiotics such as penicillin and its derivatives, including methicillin, are commonly used [4]. Alarmingly, many strains of S. aureus have developed resistance to these antibiotics, largely due to their misuse and overuse, complicating treatment and posing a major public health challenge. Multidrug-resistant strains, commonly referred to as methicillin-resistant Staphylococcus aureus (MRSA), have emerged as a critical concern [5]. The increasing diversity and global spread of new MRSA strains underscore the necessity for a comprehensive understanding of MRSA epidemiology and transmission. Such knowledge is essential for developing effective management and prevention strategies. MRSA is a leading cause of healthcare-associated (HA-MRSA) infections and has also expanded into community settings, resulting in community-acquired MRSA (CA-MRSA). Additionally, MRSA has been identified in livestock, leading to livestock-associated MRSA (LA-MRSA) infections. This review provides an in-depth analysis of current clinical knowledge of MRSA, including its epidemiology in hospitals, community settings, and livestock, as well as sources of transmission and emerging alternative therapies.

Methicillin-Resistant Staphylococcus aureus (MRSA)

The discovery of penicillin's bactericidal properties by Alexander Fleming in 1929 revolutionized the treatment of bacterial infections, significantly reducing global mortality rates from diseases such as bacterial pneumonia and meningitis during World War II [6]. However, widespread penicillin use became a major driver of S. aureus resistance. Penicillin use in the 1940s initially improved the prognosis for patients with S. aureus infections. However, its extensive application soon led to the emergence of penicillin-resistant strains, first identified in hospitals and later in community settings, raising global concerns [7, 8]. Resistance was attributed to the production of β-lactamase (penicillinase), an enzyme that hydrolyzes the antibiotic and renders it ineffective [7].

In 1959, the introduction of methicillin, a semi-synthetic penicillinase-resistant antibiotic, represented a breakthrough in combating β-lactamase-producing bacteria. Methicillin inhibits bacterial cell wall synthesis through structural modifications in penicillin. However, methicillin-resistant strains of S. aureus were identified as early as 1961, shortly after the antibiotic's clinical introduction. The first MRSA strain was reported in a hospital in the United Kingdom, and subsequent strains emerged globally in healthcare settings. The rise of MRSA, resistant to multiple antibiotic classes, has significantly constrained treatment options and contributed to morbidity and mortality worldwide [7, 6]. Initially, MRSA infections were restricted to human hosts, but in 1972, they were isolated from bovine mastitis. Over time, MRSA has also been identified in domestic, wild, and aquatic species. Livestock, in particular, have been recognized as reservoirs of livestock-associated MRSA (LA-MRSA), facilitating zoonotic transmission to humans through food chains and animal waste [9]. The misuse and overuse of antimicrobials in human healthcare, animal husbandry, agriculture, and aquaculture have accelerated the development of antimicrobial resistance. This trend presents a global health crisis with profound social and economic consequences, including increased mortality in both humans and animals [10].

Genetics of MRSA

Molecular research indicates that methicillin resistance in S. aureus is mediated by mec genes (mecA and mecC) located on a mobile genetic element known as the staphylococcal cassette chromosome mec (SCCmec). Unlike the penicillin resistance gene, which resides on a plasmid, the mecA gene encodes penicillin-binding protein 2a (PBP2a), which is integral to bacterial cell wall synthesis [9]. PBP2a exhibits reduced binding affinity for most β-lactam antibiotics, enabling cell wall peptidoglycan synthesis to continue despite the presence of these antibiotics [11]. Methicillin resistance can also arise from the mecC gene, initially termed mecALGA251, which shares 69% nucleotide sequence homology with mecA. Although mecC encodes PBP2a and contributes to β-lactam resistance, significant differences exist in the protein properties. For instance, PBP2a mecC displays higher affinity for oxacillin than cefoxitin, whereas PBP2a mecA exhibits greater resistance to cefoxitin than oxacillin [12, 13].

Epidemiology of MRSA

MRSA typing methods have facilitated the identification of various lineages with distinct epidemiological characteristics, including human-associated, zoonotic, and host-specific strains. The first epidemic MRSA (EMRSA) strain was identified in the United Kingdom in the early 1980s, followed by global dissemination. Seventeen EMRSA strains have been described, with EMRSA-15 (ST22) and EMRSA-16 (ST36) being the most prevalent healthcare-associated MRSA strains [14]. EMRSA-15, belonging to clonal complex (CC) 22 and sequence type (ST) 22, has become a predominant hospital-associated strain in the UK and Ireland, accounting for 77% of cases. In northern Portugal, this clone constitutes 68% of diabetic foot ulcer cases, whereas 52.94% of nasal MRSA colonizations in a Tangier hospital in Morocco were attributed to ST22 [14–16]. EMRSA-16 (CC30, ST36), widespread in UK hospitals, represents 14% of cases. In specific healthcare settings, such as surgical and transplantation wards, this strain accounts for 65.4% of infections. These findings underscore the need for further investigation into the role of EMRSA-16 in healthcare settings. Clones such as CC1, CC5, and CC8 are less prevalent, ranging from 1% to 3% in England and Northern Ireland [14]. The CC398 clone, commonly associated with livestock, is a frequent colonizer of healthy animals, particularly pigs, and poses a zoonotic risk to humans through direct exposure or food chains [17].

Types of MRSA

Historically, MRSA infections were primarily associated with prolonged exposure to healthcare environments, extensive antibiotic use, and specific risk factors such as HIV, cystic fibrosis, and intensive care admissions. These infections, termed healthcare-associated MRSA (HA-MRSA), are prevalent among pediatric and geriatric patients undergoing antibiotic treatment [18, 19]. However, MRSA has also been identified in healthy individuals without prior healthcare exposure, leading to the emergence of community-associated MRSA (CA-MRSA). This shift marks MRSA as a pathogen with distinct reservoirs in healthcare and community settings [18, 19]. Advances in typing methodologies have revealed significant phenotypic and genetic differences between HA-MRSA and CA-MRSA strains [19]. Additionally, MRSA colonization has been documented in diverse animal species, establishing new reservoirs for MRSA strains, collectively referred to as livestock-associated MRSA (LA-MRSA) [20].

MRSA Transmission

Numerous studies have identical isolates of MRSA in humans and animals, including both livestock and companion animals, suggesting potential pathways for the transfer of bacterial agents or genetic material [2, 8, 22, 26]. The transmission of *Staphylococcus aureus* as a pathogen depends significantly on the expression of secreted and cell surface-associated virulence factors. These factors function across three primary mechanisms: facilitating adhesion to host extracellular matrix components, altering host cellular structure and function, and impairing the immune response [8]. The transmission of hospital-acquired MRSA (HA-MRSA) occurs via several routes, such as contact with contaminated surfaces, exposure to aerosols, lapses in hand hygiene, and interaction with healthcare personnel. Among these, adherence to strict hygiene protocols remains the most effective measure for curbing the spread of MRSA within healthcare environments. Additionally, HA-MRSA poses significant risks due to its propensity to transfer

into community-acquired MRSA (CA-MRSA), which may infiltrate hospitals, leading to the emergence of more pathogenic strains [18, 19, 22].

The complex transmission dynamics of CA-MRSA are influenced by community factors, including lifestyle, social interactions, travel, and human behavior. Given its critical role as a reservoir for resistant strains, rigorous monitoring of CA-MRSA is imperative. Approximately 60% of known infectious diseases and up to 75% of emerging infectious diseases are zoonotic in origin [28]. Zoonotic transmission of MRSA occurs through several mechanisms, including direct contact between colonized or infected animals and humans, exposure to blood or other bodily fluids during diagnostic or therapeutic procedures, indirect contact via contaminated equipment, or through vectors such as fleas and insects. Environmental contamination through air, dust, or manure may further facilitate transmission [2, 9]. The CC398 strain of MRSA is particularly associated with zoonotic transmission through direct contact. Nasal colonization of livestock-associated MRSA (LA-MRSA) CC398 has been reported in up to 86% of individuals occupationally exposed to pigs in German farming environments. The persistence and extent of colonization correlate strongly with the frequency, intensity, and duration of animal contact [29].

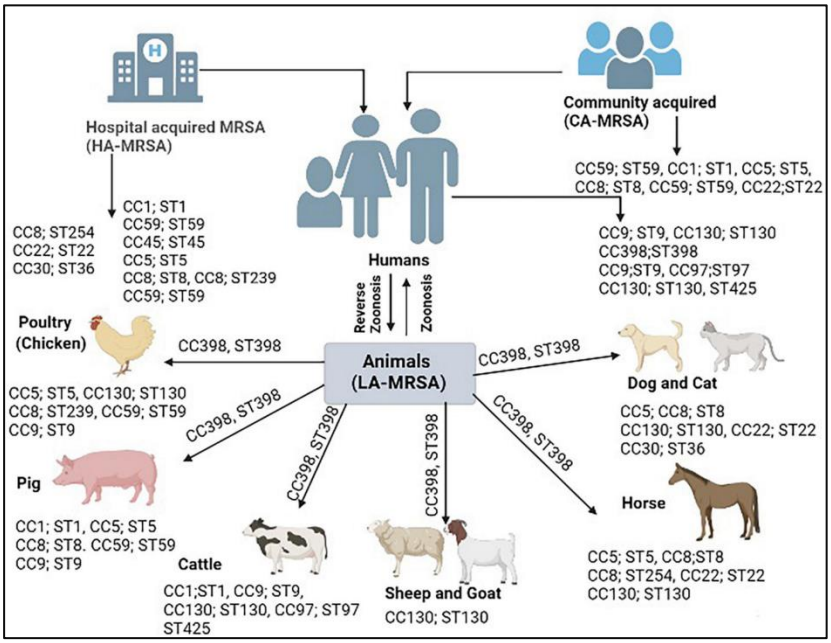

Figure 1: Bovine-Adapted MRSA infections.

Alternative MRSA Treatments

MRSA infections continue to present a significant global healthcare challenge due to the pathogen's rapid development of multidrug resistance to conventional antibiotics [5–9]. Consequently, there is an urgent need for alternative therapeutic strategies to combat resistance and achieve effective clinical outcomes. The synergistic application of two antibiotics or the combination of antibiotics with adjuvants has emerged as a promising approach. Research findings have demonstrated enhanced bactericidal activity when rifampicin and sulfamethoxazole-trimethoprim are used in conjunction with vancomycin, compared to vancomycin alone [30, 31]. Additionally, the efficacy of phytochemicals against bacterial infections has been highlighted, showing minimal adverse effects relative to chemical drugs. These phytochemicals encompass a diverse range of compounds, including polyphenols, flavonoids, terpenoids, and glycosides [30, 31]. Combination therapies involving antibiotics and phytochemicals have shown superior effectiveness compared to antibiotics alone. Notably, phytochemicals such as tannic acid and quercetin exhibited bactericidal activity against MRSA, achieving a maximum killing rate within 24 hours of incubation [32].

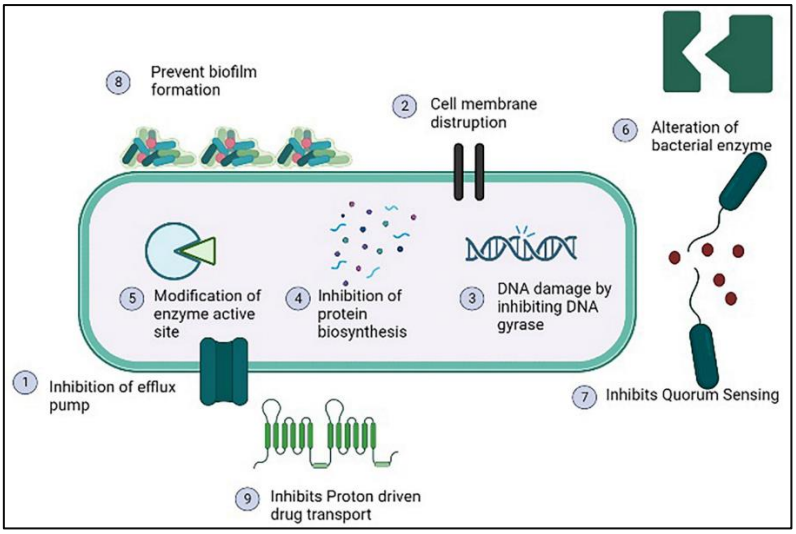

Figure 2: Tactics of MRSA Treatment.

Bioactive plant products, such as *Bauhinia kockiana* flowers, have demonstrated significant antibacterial properties. The gallic acid and methyl gallate derived from these flowers through ethyl acetate extraction have shown strong activity against MRSA, with minimum inhibitory concentrations (MIC) ranging from 250 to 500 µg/mL. Microscopic analysis has indicated that these extracts may lead to bacterial cell membrane plasmolysis [33]. Essential oils, particularly those extracted from *Oregano vulgare*, have shown substantial activity against MRSA nosocomial strains, with MIC values as low as 0.5 µg/mL. Thyme oil and trans-cinnamaldehyde have also demonstrated efficacy by reducing biofilm mass and metabolic activity significantly following 48-hour treatments [34, 35]. The compound rhodomyrtone, derived from the leaves of *Rhodomyrtus tomentosa* (*Myrtaceae*), has emerged as a potential alternative to conventional antibiotics. It has exhibited notable antibacterial activity against methicillin-resistant and other Gram-positive bacteria, with MIC values between 0.5 and 1 µg/mL. At higher concentrations, rhodomyrtone effectively inhibits macromolecular synthesis within bacteria [36]. Phytochemicals exert their antimicrobial effects through multiple mechanisms, including disruption of membrane permeability, inhibition of efflux pumps associated with multidrug resistance, and interference with β-lactam activity [37].

The integration of nanoparticles with phytochemicals has introduced an innovative avenue in MRSA treatment. Nanoparticles such as gold, silver, and copper exhibit remarkable potential due to their small size, high surface area, and ability to penetrate physiological barriers. These features enhance the stability and efficacy of bioactive molecules, making them highly effective in modern medical applications [38]. Biogenic phytochemicals, including cassinopin and isoquercetin, capped with copper nanoparticles, have shown significant antibacterial and anti-biofilm properties, achieving over 50% biofilm reduction by MRSA [38]. Similarly, phytochemical nanoparticles derived from the self-assembly of berberine and methoxycinnamic acid, based on herbal Chinese medicine, have demonstrated superior antibacterial activity compared to conventional antibiotics. These nanoparticles achieved a bacterial inhibition rate of 94.62% at a concentration of 0.1 µmol/mL and effectively removed biofilms through a dual attack mechanism [39, 40]. Silver nanoparticles combined with *Rheum ribes* extract have shown dual anticancer and antimicrobial effects. This combination displayed substantial activity against Gram-positive bacteria such as MRSA and Gram-negative strains like *Escherichia coli*, with an estimated lethal effect of 48.96% against MRSA at 200 µg/mL [41].

Prevalence of MRSA

The global emergence and dissemination of MRSA represent a critical aspect of its epidemiology. Reports indicate widespread transmission of various MRSA strains across numerous nations. This transmission occurs through two primary mechanisms: the spread of existing clones among humans and animals, including interspecies transmission, or the acquisition of the SSCmec element via horizontal gene transfer.

Presently, MRSA is predominantly endemic in healthcare environments and is classified as a significant nosocomial pathogen. It poses a severe public health threat due to its increasing prevalence in hospital, community, and animal settings, as well as its ability to transfer between humans and animals. Infections caused by MRSA lead to substantial healthcare costs, estimated at approximately $3 billion annually. Furthermore, MRSA has emerged as a primary pathogen in recent years, predominantly causing skin and soft tissue infections that often progress to bacteremia, resulting in mortality rates between 15% and 60%. The prevalence of healthcare-associated MRSA (HA-MRSA) demonstrates significant variability across countries. For instance, higher prevalence rates have been documented in Portugal (58.4% in 2013), India (46% in 2009), Pakistan (52% in 2017), China (45% between 2015 and 2017), and Norway (38.9% from 2008 to 2016). Conversely, lower prevalence rates have been observed in Germany (4.6%), Texas (25%), Mexico (19.1%), Australia (15.1%), and Italy (26%). Similarly, variations in the prevalence of community-acquired MRSA (CA-MRSA) have been noted, with higher rates reported in Japan (79%), Australia (84.9%), India (64.7%), Norway (61%), and Iran (44.3%), while lower rates have been documented in Egypt (16%), China (1.7% and 24%), Georgia (7.3%), and Switzerland (12.8%). The decline in HA-MRSA and CA-MRSA prevalence in certain regions can be attributed to the effective implementation of national prevention strategies. Increased acquisition of livestock-associated MRSA (LA-MRSA) from animal reservoirs, particularly through food and companion animals, has also been observed. The predominant LA-MRSA strain identified in human MRSA isolates is CC398. Studies have reported notable prevalence rates of LA-MRSA in various countries. For example, in Pakistan, 15.6% of goat milk, 24.5% of cow milk, 30.4% of cat samples, and 33.9% of dog samples were found to carry LA-MRSA. In Malaysia, a study detected 38.6% MRSA prevalence in cow milk. Additionally, research from Switzerland revealed prevalence rates of 1.41% in cow milk, 2.9% in pig nasal swabs, and 1.6% in calf nasal swabs [42].

MRSA Transmission Between Humans and Animals

The spread of MRSA between various hosts occurs primarily through physical contact with an infected source. The ability of MRSA lineages to transfer across host species, including humans and animals, is a defining characteristic. Healthcare-associated MRSA (HA-MRSA) is typically acquired within medical environments through contact with contaminated surfaces such as instruments, bedding, doors, and equipment, while community-associated MRSA (CA-MRSA) is often transmitted via direct contact with infected individuals or healthy carriers, as *S. aureus* commonly resides in the nasal passages of healthy people. Livestock-associated MRSA (LA-MRSA) is generally transmitted to humans following contact with animals or contaminated environments. Initially, LA-MRSA was believed to be restricted to animals until the first reported case in 1961, when throat swabs identified a Hungarian cow as the source of transmission to its caretaker. This case demonstrated the horizontal transmission potential of MRSA between animals and humans [42].

Subsequent reports worldwide have documented MRSA transmission from various animal species, including poultry, pigs, cattle, sheep, goats, equines, and companion animals. Numerous clonal complexes (CCs), such as CC5, CC8, CC9, CC59, CC1, CC30, CC45, CC22, CC130, CC97, and CC398, along with multi-locus sequence types (STs), have been identified in both human and animal MRSA isolates. Notably, strains like human clone ST1 have been implicated in bovine mastitis, while CC398, initially found in animals, has caused infections in humans resembling HA-MRSA and CA-MRSA. Additionally, the global poultry clone ST5 has been identified among poultry farm workers, and small ruminant clone CC130/ST130 has been recovered from humans. Transmission from companion animals to humans is well-documented, with studies reporting MRSA carriage rates of up to 18% among pet owners and evidence of identical strains in patients, hospital staff, and pets. In one instance, veterinary hospital staff were found colonized with a lineage of MRSA transmitted from infected dogs.

Several studies have explored the risk factors contributing to MRSA transmission. In humans, obesity, the presence of abscesses, and head-and-neck lesions have been identified as critical risk variables for cellulitis and dermatitis caused by CA-MRSA. Factors like recent skin infections, shared personal hygiene products, prior healthcare exposure, and use of antibiotics in the past year have been strongly associated with MRSA colonization and infections. Conversely, age, sex, marital status, and certain hygiene practices were not

consistently identified as significant risk factors. For livestock, risk factors for LA-MRSA mammary infections in dairy animals include parity number, age, feeding practices, body condition, and udder hygiene. Hand or machine hygiene during milking also plays a role, while milking frequency appears less significant. In companion animals, risk factors such as health status, visible infections, prolonged antibiotic use, and close interaction with humans, including bedroom access, were linked to MRSA transmission. Similarly, risk factors for MRSA transmission from poultry to humans include working on farms, handling live birds at slaughterhouses, and the type of slaughtering methods and environment, which significantly increase human carriage rates [42].

MRSA Pathophysiology

Staphylococcus aureus is a pathogenic and commensal bacterium that typically resides in the anterior nares of humans and animals. It can also colonize other regions such as the axillae, groin, and gastrointestinal tract. The pathogenesis of infection involves several key steps: colonization, virulence expression, initiation of infection, abscess formation, systemic infection, and regulation and adaptation through numerous virulence factors. Colonization significantly increases the risk of infection, especially when the host's defenses are compromised by physical disruptions or underlying diseases. Methicillin-resistant *S. aureus* (MRSA) retains numerous virulence factors, including surface proteins known as microbial surface components recognizing adhesive matrix molecules (MSCRAMMs), which bind to fibrinogen, fibronectin, and collagen fibers in host tissues, potentially leading to infections of prosthetics, bones, joints, and the endovascular system.

S. aureus exhibits the capacity to produce biofilm on both prosthetic surfaces and host tissues, enabling adherence while evading antimicrobial agents and the host immune response. It can also generate small colony variants (SCVs), which are associated with persistent and recurrent infections. Additionally, the bacterium possesses anti-phagocytic microcapsules (types 5 or 8) as a primary defense mechanism. The interaction of its zwitterionic capsule with the Fc region of immunoglobulins enables the MSCRAMM protein A to protect *S. aureus* from opsonization. Furthermore, *S. aureus* contains a variety of virulence factors, including adhesion proteins, chemotaxis inhibitory proteins, and enzymes such as proteases, lipases, hyaluronidase, staphylokinase, catalase, nucleases, coagulase, collagenases, β-lactamases, and elastases, all of which contribute to its pathogenicity. MRSA also possesses mobile genetic elements (MGEs) in various animal species, which enhance its pathogenic potential [42].

S. aureus produces numerous toxins, including exotoxins, enterotoxins, TSST-1, hemolysin toxins, and Panton-Valentine leukocidin (PVL). PVL contributes to tissue necrosis by forming a pore-forming heptamer on the membranes of polymorphonuclear leukocytes (PMNs). Low concentrations of PVL can induce apoptosis in PMNs by targeting mitochondrial membranes, while high concentrations cause PMN lysis. This process results in the release of reactive oxygen species (ROS), which contribute to tissue necrosis, as well as inflammatory responses. Certain *S. aureus* strains release superantigens, leading to conditions such as food poisoning and toxic shock syndrome (TSS). The expression of *S. aureus* virulence factors is regulated to minimize metabolic demands. Surface proteins like MSCRAMMs are expressed during the logarithmic growth phase to facilitate tissue colonization, while toxins are typically produced during the stationary phase to aid in infection dissemination. Pathogenicity is largely governed by the quorum-sensing accessory gene regulator (AGR). Although some virulence factors are clonal type-dependent, they can also function independently of genomic structure.

Hospital-acquired methicillin-sensitive *S. aureus* (MSSA) is less virulent compared to hospital-acquired MRSA (HA-MRSA), which demonstrates increased pathogenicity and mortality. HA-MRSA produces PBP2-α, a protein encoded by the mecA gene, which contributes to β-lactam antibiotic resistance and immunopathology during infection. PBP2-α results in poor peptidoglycan cross-linking, enhancing MRSA survival compared to MSSA. Community-acquired MRSA (CA-MRSA) strains exhibit increased virulence due to enhanced immune evasion and exclusive toxin production, such as PVL, which has dermonecrotic and leukocyte-lysing properties. Studies suggest a complex relationship between PVL and CA-MRSA virulence. Phenol-soluble modulins, which promote inflammation and impair neutrophil function, are more abundant

in CA-MRSA than in HA-MRSA. Livestock-associated MRSA (LA-MRSA) adds to the bacterium's pathogenicity due to genomic modifications from its diverse host range, leading to increased antibiotic resistance. LA-MRSA harbors SCCmec cassettes such as SCCmec IVa, SCCmec V, and occasionally SCCmec XI, which contains the mecC gene. The LA-MRSA CC398 lineage has reportedly lost human-associated virulence factors like exfoliative toxins but acquired antibiotic resistance genes, including mecA, tetM, and PVL. The presence of the staphylococcal protein A gene (spa) in CC398 further enhances MRSA pathogenicity [42].

Futuristic Approaches to Treat MRSA Infections

The rise of antibiotic-resistant microorganisms is among the most pressing challenges to public health, as highlighted by the World Health Organization (WHO). Each year, approximately 700,000 deaths globally are attributed to antibiotic-resistant bacteria, and this number is projected to reach 10 million by 2050. The WHO warns of a potential post-antibiotic era, where even minor infections could become fatal. Therefore, it is imperative to develop innovative, antibiotic-free strategies to combat and manage such infections effectively.

Herbal Medicine

One promising approach involves combining antibiotic stimulators with antibiotics to combat resistance and prolong the efficacy of existing treatments. For instance, the combination of β-lactam antibiotics and potassium clavulanate has shown high efficacy against MRSA. Numerous studies have demonstrated the antibacterial potential of phytochemicals, either alone or in synergy with antibiotics. These effects are largely attributed to the secondary metabolites in plants, which inhibit efflux pumps, modify active sites, increase plasma membrane permeability, and alter bacterial enzymes. For example, plant extracts such as Turnera ulmifolia combined with gentamicin or kanamycin can enhance antibacterial efficacy against MRSA strains. Similarly, grapefruit oil has been found beneficial as an efflux regulator. Traditional Korean medicine, including formulations like Sami Hyanglyum-Hwan, has also shown promise in restoring the antimicrobial activity of ciprofloxacin against MRSA strains [42].

Synergistic Effect of Antibiotics with NSAIDs

Nonsteroidal anti-inflammatory drugs (NSAIDs) have exhibited antimicrobial properties, though the precise mechanisms remain unclear. Among NSAIDs, diclofenac, aspirin, and ibuprofen demonstrate antibacterial effects against gram-positive bacteria, while aspirin is uniquely effective against certain gram-negative bacteria due to its ability to overcome the hydrophilic lipopolysaccharide barrier. In treating MRSA, NSAIDs at lower concentrations show bacteriostatic and bactericidal properties. Aspirin and ibuprofen, when combined with antibiotics such as cefuroxime and chloramphenicol, enhance antibacterial activity, producing either synergistic or additive effects. The combination of NSAIDs, antibiotics, plant extracts, and nanoparticles has also shown increased antibacterial activity against MRSA strains, as indicated by enhanced zones of inhibition (ZOIs) in in vitro studies [42].

Nanoparticles as Therapeutic Agents

Metal nanoparticles (NPs) are increasingly recognized for their potential to address antibiotic resistance. The global market for nanomaterials, including metal oxides like silver nitrate, zinc oxide, and titanium dioxide, has seen significant growth, driven by their applications in biomedical research. These nanoparticles combat bacterial infections through various mechanisms, such as inducing oxidative stress, releasing heavy metal ions, altering membrane permeability, causing DNA and protein damage, and disrupting efflux pumps. For example, green silver nitrate nanoparticles exhibit strong antibacterial activity against MRSA by inhibiting growth in vitro. Similarly, zinc oxide nanoparticles, used alone or in combination with antibiotics, show enhanced antibacterial effects. Complex formulations, such as those combining bacterial cellulose, sodium alginate nanoparticles, chitosan, and copper sulfate, have also demonstrated significant efficacy against MRSA. Numerous studies from different countries continue to explore the antibacterial properties of diverse nanoparticle forms against MRSA and other strains of *S. aureus*. This growing body of research underscores the potential of herbal medicine, NSAID-antibiotic combinations,

and nanoparticles as groundbreaking strategies in the fight against antibiotic-resistant bacterial infections like MRSA [42].

Nursing Intervention Plans:

Nursing interventions play a critical role in the management and prevention of Methicillin-Resistant *Staphylococcus aureus* (MRSA) infections. These interventions are aimed at minimizing transmission, promoting patient recovery, and mitigating complications associated with the infection. Effective nursing care plans are comprehensive, encompassing infection control measures, patient education, wound care, and pharmacological management. The cornerstone of nursing interventions for MRSA is strict adherence to infection control protocols. Nurses must implement standard and contact precautions, including the use of personal protective equipment (PPE) such as gloves, gowns, and masks, especially when handling patients with active MRSA infections. Hand hygiene remains a critical element; nurses should ensure frequent and proper handwashing using alcohol-based hand sanitizers or soap and water. Environmental hygiene is equally important; all surfaces, medical equipment, and frequently touched areas must be regularly disinfected with agents effective against MRSA. Cohorting patients with MRSA or placing them in isolation rooms can further reduce the risk of cross-contamination in healthcare settings. Nurses should also oversee visitor compliance with infection control measures, ensuring they follow proper hygiene practices and wear PPE when necessary.

Educating patients and their families about MRSA is a key component of nursing care. Nurses should provide information about the nature of the infection, transmission risks, and the importance of completing prescribed antibiotic regimens. Patients must be taught how to maintain personal hygiene, such as regular handwashing, keeping wounds covered, and avoiding sharing personal items like towels or razors. For discharged patients, nurses should emphasize the need for regular follow-ups and inform them about signs of worsening infection, such as increased redness, swelling, or fever. Additionally, nurses advocate for patients by collaborating with the healthcare team to ensure timely interventions, appropriate diagnostic tests, and adjustments to treatment plans based on patient progress. For patients with MRSA-related wounds, meticulous wound care is essential to prevent further complications and promote healing. Nurses must adhere to aseptic techniques when cleaning and dressing wounds, using appropriate antimicrobial dressings to reduce bacterial load. Monitoring the wound for signs of infection, such as purulent discharge, erythema, or delayed healing, is crucial for timely intervention. Regular assessments should be documented, and findings should be communicated to the interdisciplinary team to adjust care plans as needed. Pain management strategies, including the use of analgesics and non-pharmacological methods, should also be incorporated into the wound care regimen.

Nurses play a vital role in administering prescribed pharmacological treatments, including antibiotics such as vancomycin or linezolid, ensuring correct dosages and schedules. They must monitor patients for adverse reactions and report any signs of toxicity or allergy to the healthcare provider promptly. For patients receiving novel treatments like nanoparticles or herbal medicines, nurses need to stay informed about emerging evidence to provide safe and effective care. Supportive measures, such as ensuring adequate hydration, nutrition, and rest, are integral to enhancing the patient's immune response and overall recovery. Living with MRSA can cause anxiety and social stigma for patients and their families. Nurses should provide emotional support by actively listening to patient concerns, offering reassurance, and connecting them with support groups or counseling services if needed. Creating a non-judgmental and empathetic environment helps patients cope better with their condition, improving adherence to treatment plans. By integrating these nursing interventions into patient care, nurses contribute significantly to managing MRSA infections, preventing their spread, and improving patient outcomes.

Conclusion:

Methicillin-resistant *Staphylococcus aureus* (MRSA) remains one of the most pressing challenges in global healthcare, with substantial implications for public health. The increasing prevalence of MRSA, both in healthcare and community settings, is directly linked to its ability to develop resistance against commonly used antibiotics. The emergence of multidrug-resistant MRSA strains has resulted in severe limitations in

treatment options, complicating management and heightening the risk of morbidity and mortality. The genetic basis of MRSA resistance lies in the mec genes, which confer resistance to β-lactam antibiotics. These genetic elements have contributed to the widespread dissemination of MRSA in various environments, from hospitals to community settings and even livestock. Notably, the zoonotic transmission of MRSA from animals to humans has further expanded the potential reservoirs for the pathogen, necessitating comprehensive monitoring and control strategies in both healthcare and agricultural settings. The diversity of MRSA strains, including healthcare-associated MRSA (HA-MRSA), community-acquired MRSA (CA-MRSA), and livestock-associated MRSA (LA-MRSA), underscores the complexity of its transmission dynamics. These strains differ in their genetic makeup and epidemiological characteristics, making it crucial to tailor prevention and treatment strategies to the specific strain and setting. The review highlights the importance of strict infection control measures, including adherence to hygiene protocols and the need for continuous surveillance to mitigate MRSA spread. Despite advancements in understanding MRSA's epidemiology and pathophysiology, the ongoing development of resistance to antibiotics necessitates the exploration of alternative treatment options. The synergistic use of antibiotics, along with the incorporation of phytochemicals and nanoparticles, holds promise for enhancing treatment outcomes and addressing the growing challenge of antibiotic resistance. Bioactive plant compounds, such as tannic acid and quercetin, have shown effectiveness against MRSA, suggesting their potential as adjunctive therapies in clinical settings. Additionally, the integration of nanoparticles with these bioactive molecules enhances their stability and efficacy, presenting a novel approach to MRSA management. In conclusion, the battle against MRSA requires a multifaceted approach, including improved prevention strategies, innovative treatment modalities, and ongoing research into alternative therapies. Nurses play a crucial role in infection control through education, hygiene, and surveillance, ensuring that effective measures are in place to prevent MRSA transmission. With the continuous evolution of MRSA strains, it is essential to remain proactive in developing new strategies to combat this ever-growing threat.

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المكورات العنقودية الذهبية المقاومة للميثيسيلين-الوبائيات والتأثيرعلى الصحة العامة، الوقاية، الفسيولوجيا المرضية، العلاج، وتدخل التمريض - مراجعة محدثة

الملخص:

الخلفية :لا يزال *المكورات العنقودية الذهبية المقاومة للميثيسيلين* (MRSA)يمثل تحديًا كبيرًا للصحة العامة بسبب انتشاره المتزايد في كل من مرافق الرعاية الصحية والأوساط المجتمعية. يسبب هذا الميكروب مجموعة واسعة من العدوى، من الحالات الجلدية إلى الأمراض المهددة للحياة. يشير الارتفاع العالمي في إصاباتMRSA ، الذي تفاقم بسبب سوء استخدام الإفراط في استخدام المضادات الحيوية، إلى الحاجة الملحة لاستراتيجيات فعالة للوقاية والعلاج.

الهدف :تهدف هذه المراجعة إلى تحديث الفهم الحالي لMRSA ، مع التركيز على وبائياته، الفسيولوجيا المرضية، تأثيره على الصحة العامة، خيارات العلاج، وتدخلات التمريض.

الطرق :تم إجراء مراجعة شاملة للأدبيات الحديثة المتعلقة بMRSA ، تغطي مظاهره السريرية، الآليات الجزيئية للمقاومة، الوبائيات، ديناميكيات الانتقال، والطرق العلاجية البديلة. تم تحليل الدراسات المتعلقة بـ MRSA المرتبطة بالرعاية الصحية (HA-MRSA) و MRSAالمكتسبة من المجتمع (CA-MRSA) لتقييم تطور طبيعة العدوى وأنماط المقاومة.

النتائج :لا يزال MRSA سببًا كبيرًا للمراضة والوفيات، مع ظهور سلالات جديدة في جميع أنحاء العالم. لقد أدى مقاومته للمضادات الحيوية الشائعة، بما في ذلك الميثيسيلين، إلى تعقيد بروتوكولات العلاج، مما يستدعي استكشاف العلاجات البديلة. تبرز المراجعة أيضًا انتقال MRSA من الحيوانات إلى البشر وتبعاته على الصحة العامة. تشير الأبحاث الحديثة إلى إمكانات العلاجات المركبة من المضادات الحيوية، والمواد الكيميائية النباتية، والجسيمات النانوية في مكافحة إصابات .MRSA

الاستنتاج :التهديد العالمي الذي يشكله MRSA يتطلب اليقظة المستمرة، وتحسين ممارسات مكافحة العدوى، وتطوير استراتيجيات علاجية جديدة. تعد تدخلات التمريض التي تركز على النظافة، والمراقبة، والتعليم أمرًا بالغ الأهمية في الحد من انتقال .MRSA يجب أن تعطي الأبحاث المستقبلية الأولوية لاستكشاف أساليب علاجية جديدة، بما في ذلك المواد الكيميائية النباتية والتكنولوجيا النانوية، لتجاوز قيود العلاجات الحالية بالمضادات الحيوية.

الكلمات المفتاحيةMRSA :، الوبائيات، الفسيولوجيا المرضية، مقاومة المضادات الحيوية، الانتقال الحيواني إلى البشر، تدخلات التمريض، العلاجات البديلة.