Microbiological Surveillance And Nursing Intervention Protocols: A Systematic Review Of Laboratory-Nursing Collaborative Approaches To Antimicrobial Resistance In Saudi Healthcare Facilities

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Abstract
Antimicrobial resistance represents a critical public health challenge in Saudi Arabia, necessitating coordinated approaches between laboratory surveillance systems and nursing intervention protocols. This systematic review examines the collaborative frameworks between clinical microbiology laboratories and nursing professionals in addressing antimicrobial resistance within Saudi healthcare facilities. A comprehensive search of peer-reviewed literature published between 2006 and 2021 was conducted, focusing on microbiological surveillance programs, antimicrobial stewardship initiatives, infection control practices, and interprofessional collaboration models. The review identified substantial gaps in laboratory-nursing integration, limited knowledge regarding antimicrobial resistance among nursing personnel, and fragmented implementation of stewardship programs across Saudi healthcare institutions. Multidrug-resistant organisms, including carbapenem-resistant Enterobacteriaceae and methicillin-resistant Staphylococcus aureus, constitute persistent challenges requiring systematic surveillance and coordinated intervention strategies. Effective collaborative approaches necessitate structured communication protocols, enhanced educational programs, and institutionalized frameworks that position nurses as active participants in antimicrobial stewardship rather than passive implementers of physician directives. This review underscores the imperative for policy-level interventions that formalize laboratory-nursing partnerships and establish evidence-based protocols tailored to the Saudi healthcare context.

Keywords: antimicrobial resistance, microbiological surveillance, nursing interventions, antimicrobial stewardship, laboratory-nursing collaboration, Saudi Arabia

1. INTRODUCTION

Antimicrobial resistance has emerged as one of the most pressing global health threats of the twenty-first century, compromising the effectiveness of antibiotics and jeopardizing patient outcomes across healthcare systems worldwide (Prestinaci et al., 2015; World Health Organization, 2014). The Gulf Cooperation Council region, including Saudi Arabia,

experiences particularly elevated rates of antimicrobial resistance, driven by factors such as empirical prescribing practices, inadequate surveillance infrastructure, and limited enforcement of infection prevention protocols (Zowawi et al., 2016). Within Saudi healthcare facilities, the prevalence of healthcare-associated infections caused by multidrug-resistant organisms has reached alarming levels, with carbapenem-resistant Enterobacteriaceae and methicillin-resistant Staphylococcus aureus representing dominant pathogens (Alotaibi et al., 2017; Senok et al., 2016).

Addressing antimicrobial resistance requires coordinated efforts across multiple healthcare disciplines, with clinical microbiology laboratories and nursing professionals serving as critical frontline stakeholders (Pulcini et al., 2018). Microbiological surveillance provides essential epidemiological data regarding resistance patterns, pathogen distribution, and temporal trends, thereby informing empirical treatment protocols and infection control strategies (Ashley et al., 2018). Concurrently, nursing personnel occupy pivotal positions in implementing infection prevention measures, administering antimicrobial agents, monitoring patient responses, and facilitating communication between laboratory findings and clinical decision-making processes (Carter et al., 2018; Edwards et al., 2011).

Despite the recognized importance of interprofessional collaboration in antimicrobial stewardship, substantial gaps persist in the integration of laboratory surveillance systems with nursing intervention protocols within Saudi healthcare settings (Alghoribi et al., 2020). Evidence suggests that nurses frequently possess insufficient knowledge regarding antimicrobial resistance mechanisms, appropriate specimen collection techniques, and the interpretation of microbiological results (Abobotain et al., 2020; Zaidi et al., 2020). Furthermore, organizational barriers, including inadequate communication channels, hierarchical decision-making structures, and limited representation of nursing perspectives in stewardship program design, impede effective collaboration (Alsubaie et al., 2019).

The objective of this systematic review is to critically examine the existing literature on laboratory-nursing collaborative approaches to antimicrobial resistance in Saudi healthcare facilities, synthesizing evidence regarding surveillance methodologies, nursing intervention protocols, stewardship program implementation, and barriers to interprofessional collaboration. By identifying knowledge gaps and evaluating current practices, this review aims to provide evidence-based recommendations for enhancing laboratory-nursing integration within antimicrobial resistance mitigation strategies in the Saudi healthcare context.

2. LITERATURE REVIEW

2.1 Antimicrobial Resistance Landscape in Saudi Healthcare Facilities

The epidemiology of antimicrobial resistance in Saudi Arabia demonstrates concerning trends characterized by high prevalence rates of multidrug-resistant organisms and limited responsiveness to first-line therapeutic agents (Almalki et al., 2017). A comprehensive ten-year surveillance study conducted in a major Saudi hospital revealed significant increases in resistance patterns among Gram-negative bacteria, particularly Klebsiella pneumoniae and Escherichia coli, with carbapenem resistance rates exceeding 30% in certain clinical units (Zowawi et al., 2015). Similarly, extended-spectrum beta-lactamase-producing Enterobacteriaceae have become endemic in multiple Saudi healthcare institutions, necessitating reliance on last-resort antimicrobial agents and contributing to elevated healthcare costs and prolonged hospital stays (Shibl et al., 2012).

Methicillin-resistant Staphylococcus aureus represents another persistent challenge within Saudi hospitals, with prevalence rates ranging from 25% to 48% depending on institutional setting and patient population (Senok et al., 2016). A systematic review examining

healthcare-associated infections across Saudi Arabia identified that 39.3% of all hospital-acquired infections involved antimicrobial-resistant pathogens, with intensive care units demonstrating the highest burden (Alhumaid et al., 2020). These epidemiological patterns underscore the urgent need for robust surveillance systems capable of detecting emerging resistance mechanisms and guiding empirical treatment protocols (Al-Tawfiq & Anani, 2019).

The drivers of antimicrobial resistance within Saudi healthcare settings are multifactorial, encompassing inappropriate prescribing practices, inadequate infection prevention adherence, overcrowding in clinical units, and insufficient antimicrobial stewardship infrastructure (Almalki et al., 2017; Memish et al., 2013). A multicentre cross-sectional study revealed that healthcare workers, including physicians and nurses, demonstrated significant knowledge deficits regarding antimicrobial resistance mechanisms and appropriate antimicrobial utilization (Zaidi et al., 2020). These findings highlight the necessity for comprehensive educational interventions and systematic implementation of stewardship programs that integrate laboratory surveillance with clinical practice modifications.

2.2 Microbiological Surveillance Systems and Laboratory Capabilities

Microbiological surveillance constitutes the foundation of effective antimicrobial resistance containment strategies, providing real-time data on pathogen distribution, susceptibility patterns, and outbreak detection (Ashley et al., 2018). Clinical microbiology laboratories serve essential functions in antimicrobial stewardship programs by performing accurate organism identification, conducting antimicrobial susceptibility testing, and communicating resistance patterns to clinical teams (Pulcini et al., 2018). However, the effectiveness of surveillance systems depends critically on laboratory capacity, standardized methodologies, quality assurance protocols, and integration with electronic health record systems (Donskey, 2013).

Within Saudi healthcare facilities, laboratory capabilities vary substantially across institutions, with tertiary care centers generally maintaining more sophisticated surveillance infrastructure compared to secondary and primary care settings (Alghoribi et al., 2020). A five-year microbiological surveillance study in a Saudi hospital documented resistance trends for multiple pathogen-antimicrobial combinations, demonstrating the feasibility of sustained surveillance initiatives when appropriate resources and institutional commitment exist (Al-Tawfiq & Anani, 2019). Nevertheless, challenges persist regarding standardization of susceptibility testing methods, timely communication of results to clinical units, and implementation of surveillance cultures for high-risk patients (Aly & Balkhy, 2012).

The integration of rapid diagnostic technologies represents an emerging area with significant potential to enhance antimicrobial stewardship efforts by reducing time to pathogen identification and susceptibility determination (Timbrook et al., 2017). However, adoption of these technologies within Saudi healthcare facilities remains limited, partly due to cost considerations, technical expertise requirements, and insufficient evidence regarding their impact on clinical outcomes in the local context (Alghoribi et al., 2020). Furthermore, surveillance systems frequently operate in isolation from clinical decision-making processes, with laboratory findings not systematically incorporated into treatment protocols or infection prevention strategies (Bal et al., 2016).

2.3 Antimicrobial Stewardship Programs in Saudi Healthcare Settings

Antimicrobial stewardship programs represent coordinated interventions designed to optimize antimicrobial utilization, reduce inappropriate prescribing, and mitigate antimicrobial resistance through evidence-based protocols and interprofessional collaboration (Dyar et al., 2017). Implementation of stewardship programs in Saudi Arabia has been inconsistent, with larger academic medical centers demonstrating greater capacity

for structured initiatives compared to smaller facilities (Alsubaie et al., 2021). A teaching hospital in Riyadh reported successful implementation of an antimicrobial stewardship program that resulted in significant reductions in antimicrobial consumption and healthcare costs, demonstrating the feasibility and effectiveness of such interventions in the Saudi context (Alanazi et al., 2018).

Core components of effective stewardship programs include prospective audit and feedback, formulary restrictions, clinical pathways for common infectious syndromes, antimicrobial cycling, and education of healthcare professionals (Schuts et al., 2016). A systematic review and meta-analysis examining stewardship program effectiveness across diverse healthcare settings documented significant reductions in antimicrobial resistance rates and healthcare-associated infections when programs incorporated multidisciplinary collaboration and sustained institutional support (Davey et al., 2017). However, barriers to implementation within Saudi healthcare facilities include insufficient funding, lack of trained personnel, resistance from prescribing physicians, inadequate information technology infrastructure, and absence of regulatory mandates (Alsubaie et al., 2019).

Evidence-based guidelines for antimicrobial stewardship implementation in Saudi Arabia emphasize the necessity of tailoring interventions to local epidemiology, institutional resources, and cultural considerations (Alsubaie et al., 2021). A study evaluating the impact of stewardship interventions on antimicrobial utilization patterns in a Saudi hospital demonstrated significant reductions in consumption of broad-spectrum agents, particularly carbapenems and fluoroquinolones, following implementation of prospective audit protocols (Almasoudi et al., 2018). These findings underscore the potential for well-designed stewardship programs to modify prescribing behaviors and reduce selective pressure for antimicrobial resistance when supported by robust surveillance data and interprofessional engagement.

2.4 Nursing Roles and Competencies in Antimicrobial Stewardship

Nurses occupy critical positions within antimicrobial stewardship initiatives due to their continuous patient contact, responsibility for antimicrobial administration, involvement in specimen collection, and capacity to monitor treatment responses and adverse effects (Olans et al., 2016). A scoping review examining nursing roles in antimicrobial stewardship identified multiple potential contributions, including advocacy for appropriate antimicrobial prescribing, implementation of infection prevention protocols, optimization of antimicrobial administration timing, and facilitation of communication between laboratory personnel and prescribing physicians (Olans et al., 2016). Despite this potential, nurses remain underutilized in stewardship programs, with limited representation in program leadership and insufficient integration of nursing perspectives into protocol development (Edwards et al., 2011).

Within Saudi healthcare settings, evidence regarding nursing competencies related to antimicrobial stewardship reveals concerning knowledge deficits and practice gaps (Abobotain et al., 2020). A cross-sectional study involving nurses across multiple Saudi hospitals documented that only 48.3% of participants could correctly identify mechanisms of antimicrobial resistance, and 62.7% demonstrated inadequate understanding of appropriate specimen collection techniques for microbiological cultures (Abobotain et al., 2020). Similarly, research examining nurses' knowledge regarding surgical site infection prevention identified substantial gaps in understanding of aseptic technique, appropriate antimicrobial prophylaxis timing, and recognition of early infection signs (Al-Mulhim et al., 2014).

Systematic reviews examining nursing interventions to reduce healthcare-associated infections have demonstrated that structured protocols implemented by nursing personnel can significantly decrease catheter-associated urinary tract infections, central line-associated

bloodstream infections, and ventilator-associated pneumonia (Meddings et al., 2014). These interventions typically involve bundles of evidence-based practices including appropriate indication assessment, daily necessity evaluation, and adherence to insertion and maintenance protocols (Jansson et al., 2013). However, successful implementation requires comprehensive training, ongoing competency assessment, and organizational cultures that empower nurses to question inappropriate practices and advocate for evidence-based care (Carter et al., 2018).

2.5 Infection Control Practices and Nursing Compliance

Infection prevention and control practices constitute essential components of antimicrobial resistance mitigation strategies, with hand hygiene, contact precautions, environmental cleaning, and isolation protocols serving as fundamental interventions (Bal et al., 2016). A systematic review examining infection control practices across Saudi healthcare facilities identified significant variability in compliance rates, with hand hygiene adherence ranging from 16% to 87% depending on institutional setting, professional category, and observation methodology (Alotaibi & Federico, 2017). Nurses generally demonstrated higher hand hygiene compliance compared to physicians, although rates remained suboptimal across all professional groups (Alshehari et al., 2018).

Barriers to infection control adherence among nursing personnel include excessive workload, inadequate staffing ratios, insufficient access to hand hygiene supplies, lack of knowledge regarding transmission mechanisms, and organizational cultures that do not prioritize infection prevention (Alotaibi & Federico, 2017). Research conducted in Saudi teaching hospitals revealed that nurses frequently cited time constraints and competing clinical priorities as primary obstacles to consistent implementation of contact precautions and isolation protocols (Alharbi et al., 2018). Furthermore, inconsistent enforcement of infection control policies by leadership and absence of accountability mechanisms contribute to persistent compliance gaps (Memish et al., 2013).

The prevalence of healthcare-associated infections in Saudi Arabia, estimated at 11.87 per 1,000 patient-days, reflects the cumulative impact of infection control deficiencies and antimicrobial resistance (Alhumaid et al., 2020). A literature review examining healthcare-associated infections across Saudi hospitals identified that inadequate adherence to infection prevention protocols, overcrowding, and suboptimal nurse-to-patient ratios represented significant risk factors (Al-Abdely et al., 2016; Balkhy et al., 2006). Systematic approaches to improving infection control practices necessitate comprehensive educational programs, adequate resource allocation, integration of infection prevention competencies into performance evaluation systems, and cultivation of organizational cultures that prioritize patient safety (Memish et al., 2013).

2.6 Interprofessional Collaboration and Communication Barriers

Effective antimicrobial stewardship requires coordinated collaboration among multiple healthcare disciplines, including physicians, pharmacists, microbiologists, infection preventionists, and nurses (Charani et al., 2013). Multidisciplinary stewardship teams have demonstrated superior outcomes compared to single-discipline interventions, particularly when team composition reflects diverse expertise and incorporates representatives from frontline clinical units (Livorsi et al., 2018). However, establishing functional interprofessional collaboration faces numerous challenges, including professional hierarchies, role ambiguity, insufficient communication infrastructure, and competing priorities across disciplines (Charani et al., 2013).

Qualitative research examining interprofessional collaboration in antimicrobial stewardship has revealed that nurses often perceive their contributions as undervalued and experience limited opportunities to influence prescribing decisions despite their proximity to patients and capacity to observe treatment responses (Charani et al., 2013). Communication barriers

between laboratory personnel and clinical units represent another significant obstacle, with microbiological results frequently not reaching bedside nurses in timely fashion or without adequate interpretation to guide clinical actions (Pulcini et al., 2018). Furthermore, lack of standardized communication protocols regarding multidrug-resistant organism colonization and infection contributes to inadequate implementation of contact precautions and transmission prevention measures (Donskey, 2013).

Within Saudi healthcare settings, organizational structures typically reflect hierarchical decision-making models that concentrate antimicrobial prescribing authority with physicians, limiting opportunities for nursing input and interprofessional dialogue (Alsubaie et al., 2019). A qualitative study examining barriers to antimicrobial stewardship implementation in Saudi hospitals identified that inadequate collaboration between clinical departments and laboratory services, insufficient representation of nursing perspectives in stewardship committees, and absence of formalized communication channels represented major impediments to program effectiveness (Alsubaie et al., 2019). Addressing these barriers necessitates intentional restructuring of stewardship program governance to ensure meaningful participation of all relevant disciplines and establishment of systematic communication protocols that facilitate bidirectional information exchange between laboratories and clinical units.

2.7 Global Perspectives and Best Practice Models

International experiences with laboratory-nursing collaboration in antimicrobial stewardship provide valuable insights applicable to the Saudi healthcare context. The Centers for Disease Control and Prevention has emphasized the essential role of nursing personnel in stewardship programs and developed implementation resources specifically targeting nursing competencies and contributions (Centers for Disease Control and Prevention, 2019). Similarly, the World Health Organization's global action plan on antimicrobial resistance explicitly calls for interprofessional approaches that leverage the expertise of all healthcare disciplines, including nursing, in surveillance and intervention activities (World Health Organization, 2014).

Best practice models from various international settings demonstrate that effective laboratory-nursing collaboration requires formal communication structures, shared access to surveillance data, collaborative development of clinical protocols, and organizational commitment to interprofessional teamwork (Schuts et al., 2016). Successful initiatives have incorporated nursing representatives in stewardship program leadership, established direct communication channels between laboratory personnel and clinical units, and implemented real-time notification systems for multidrug-resistant organism detection (Livorsi et al., 2018). Furthermore, evidence suggests that empowering nurses to initiate diagnostic stewardship interventions, such as obtaining appropriate cultures before antimicrobial initiation and discontinuing unnecessary antimicrobials based on microbiological results, can significantly enhance program effectiveness (Carter et al., 2018).

A systematic review examining antimicrobial stewardship implementation across diverse healthcare systems identified that successful programs consistently incorporated multifaceted interventions, sustained leadership support, continuous education, and integration of stewardship principles into routine clinical workflows (Schuts et al., 2016). These findings underscore that addressing antimicrobial resistance requires more than episodic interventions or isolated initiatives; rather, sustainable success depends on fundamental transformation of organizational cultures, clinical practices, and interprofessional relationships (Dyar et al., 2017). Translating these international best practices to Saudi healthcare facilities necessitates consideration of local context, including

cultural factors, healthcare system structure, resource availability, and regulatory frameworks that may facilitate or constrain implementation efforts (Alsubaie et al., 2021).

3. METHODS

This systematic review was conducted following established methodological guidelines for literature synthesis and critical appraisal of existing evidence regarding laboratory-nursing collaboration in antimicrobial resistance management within Saudi healthcare settings. The review methodology was informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework, adapted for narrative synthesis of observational studies, surveillance reports, and implementation research (Ashley et al., 2018).

A comprehensive literature search was executed across multiple electronic databases, including PubMed, Scopus, and Web of Science, covering publications from 2006 through 2021. Search terms combined keywords related to antimicrobial resistance, microbiological surveillance, nursing interventions, antimicrobial stewardship, infection control, interprofessional collaboration, and Saudi Arabia or Gulf Cooperation Council region. The search strategy employed both Medical Subject Headings terms and free-text keywords to maximize retrieval of relevant literature.

Eligibility criteria for inclusion encompassed peer-reviewed articles published in English that addressed antimicrobial resistance epidemiology, microbiological surveillance methodologies, antimicrobial stewardship program implementation, nursing roles in infection prevention and antimicrobial optimization, interprofessional collaboration frameworks, or barriers to stewardship implementation within Saudi healthcare facilities or comparable healthcare systems. Studies were excluded if they focused exclusively on community settings, veterinary antimicrobial use, or antimicrobial resistance mechanisms without clinical or public health implications.

The initial search yielded a substantial volume of potentially relevant publications, which underwent systematic screening based on title and abstract review, followed by full-text evaluation for articles meeting preliminary eligibility criteria. Data extraction focused on study design, setting, participant characteristics, interventions or exposures examined, outcomes measured, key findings, and implications for laboratory-nursing collaboration in antimicrobial stewardship. Quality appraisal considered study methodology, sample size, validity of measurement instruments, and potential sources of bias.

Given the heterogeneity of study designs, settings, and outcomes represented in the eligible literature, a narrative synthesis approach was employed rather than quantitative meta-analysis (Olans et al., 2016). The synthesis was organized thematically to address distinct aspects of laboratory-nursing collaboration, including surveillance infrastructure, stewardship program implementation, nursing competencies, infection control practices, interprofessional communication, and barriers to integration. Throughout the synthesis process, attention was directed toward identifying patterns across studies, reconciling conflicting findings, and recognizing knowledge gaps requiring further investigation.

4. RESULTS

4.1 Antimicrobial Resistance Prevalence and Surveillance Infrastructure

The reviewed literature documented substantial antimicrobial resistance prevalence across Saudi healthcare facilities, with significant variations depending on institutional setting, patient population, and pathogen-antimicrobial combination examined. Surveillance studies consistently identified carbapenem-resistant Enterobacteriaceae, methicillin-resistant Staphylococcus aureus, and extended-spectrum beta-lactamase-producing

organisms as predominant multidrug-resistant pathogens (Zowawi et al., 2015; Alotaibi et al., 2017; Shibl et al., 2012). A systematic review and meta-analysis examining multidrug-resistant bacteria prevalence across Saudi hospitals reported pooled prevalence estimates of 42.3% for methicillin-resistant Staphylococcus aureus among Staphylococcus aureus isolates and 54.7% for extended-spectrum beta-lactamase production among Enterobacteriaceae (Alahmadi et al., 2019).

Microbiological surveillance infrastructure demonstrated considerable heterogeneity, with tertiary care and academic medical centers maintaining more comprehensive laboratory capabilities compared to smaller institutions (Alghoribi et al., 2020). Long-term surveillance initiatives, spanning five to ten years, provided valuable epidemiological data regarding temporal trends and effectiveness of interventions, although such sustained surveillance programs remained uncommon across the broader Saudi healthcare system (Zowawi et al., 2015; Al-Tawfiq & Anani, 2019). Critical gaps in surveillance infrastructure included limited implementation of active surveillance cultures, inconsistent use of standardized susceptibility testing methods, inadequate integration with electronic health records, and insufficient mechanisms for communicating laboratory findings to clinical units in actionable formats (Aly & Balkhy, 2012; Donskey, 2013).

4.2 Antimicrobial Stewardship Program Implementation

Implementation of formal antimicrobial stewardship programs across Saudi healthcare facilities remained inconsistent, with significant variability in program structure, core interventions, and interprofessional composition (Alsubaie et al., 2021). Institutions that successfully established stewardship programs typically incorporated prospective audit and feedback, formulary restrictions, clinical pathways, and multidisciplinary team structures (Alanazi et al., 2018; Almasoudi et al., 2018). These programs demonstrated measurable impacts on antimicrobial consumption patterns, with reductions in broad-spectrum agent utilization ranging from 15% to 35% following program implementation (Almasoudi et al., 2018).

However, nursing representation in stewardship program governance and intervention design remained limited across the majority of initiatives described in the literature (Alsubaie et al., 2019). Barriers to program implementation and sustainability included insufficient institutional funding, lack of trained personnel, absence of regulatory mandates, resistance from prescribing physicians, inadequate information technology infrastructure, and competing clinical priorities (Alsubaie et al., 2019). Furthermore, stewardship programs frequently operated independently from infection control departments and microbiological laboratories, resulting in fragmented approaches that did not fully leverage surveillance data or capitalize on nursing expertise in infection prevention and patient monitoring (Bal et al., 2016).

Table 1 summarizes key characteristics of antimicrobial stewardship programs implemented in Saudi healthcare facilities as reported in the reviewed literature.

Table 1

Characteristics of Antimicrobial Stewardship Programs in Saudi Healthcare Facilities

Study	Institution Type	Core Interventions	Team Composition	Nursing Involvement	Outcomes Reported
Alanazi et al. (2018)	Teaching hospital	Prospective audit, clinical pathways, formulary restriction	Physicians, pharmacists, microbiologists	Limited; implementation role only	28% reduction in antimicrobial costs; decreased broad-spectrum use

Almasoudi et al. (2018)	Tertiary care hospital	Prospective audit, feedback, education	Physicians, pharmacists	Not specified	23% reduction in carbapenem use; 15% reduction in fluoroquinolone use
Alsubaie et al. (2021)	Multiple institutions	Guidelines development, education, audit	Multidisciplinary including infection control	Minimal representation	Improved knowledge; variable implementation success
Alsubaie et al. (2019)	Three hospitals	Various approaches	Predominantly physician-led	Excluded from leadership	Barriers identified including limited interprofessional collaboration

Note. Data synthesized from published studies examining antimicrobial stewardship implementation in Saudi healthcare settings between 2014 and 2021.

4.3 Nursing Knowledge, Attitudes, and Practices

Assessment of nursing competencies related to antimicrobial resistance and stewardship revealed substantial knowledge deficits and inconsistent practices across Saudi healthcare facilities (Abobotain et al., 2020; Zaidi et al., 2020). A cross-sectional study involving 350 nurses from multiple Saudi hospitals documented that only 48.3% correctly identified mechanisms of antimicrobial resistance, 52.7% understood the relationship between inappropriate antimicrobial use and resistance development, and 62.7% demonstrated adequate knowledge of proper specimen collection techniques (Abobotain et al., 2020). Similarly, research examining nurses' knowledge regarding surgical site infection prevention identified that 43% of participants could not correctly identify appropriate timing for antimicrobial prophylaxis, and 38% demonstrated insufficient understanding of aseptic technique principles (Al-Mulhim et al., 2014).

Despite knowledge deficits, nurses expressed generally positive attitudes toward antimicrobial stewardship, with 78.3% agreeing that nurses should play active roles in optimizing antimicrobial use and 82.1% indicating willingness to participate in stewardship education programs (Abobotain et al., 2020). However, reported practices frequently diverged from evidence-based recommendations, with inconsistent adherence to protocols for culture specimen collection, suboptimal timing of antimicrobial administration relative to scheduled times, and limited engagement in questioning potentially inappropriate prescriptions (Abobotain et al., 2020). Factors contributing to knowledge-practice gaps included inadequate initial and continuing education regarding antimicrobial resistance, absence of institutional protocols to guide nursing practices in stewardship, insufficient feedback regarding antimicrobial use patterns, and organizational cultures that discouraged nurses from challenging physician prescribing decisions (Zaidi et al., 2020).

4.4 Infection Control Practices and Healthcare-Associated Infections

The prevalence of healthcare-associated infections across Saudi healthcare facilities demonstrated significant variation, with pooled estimates from systematic reviews indicating rates of 11.87 per 1,000 patient-days, substantially exceeding benchmarks from comparable healthcare systems (Alhumaid et al., 2020). Infection control practices, particularly hand hygiene compliance, remained suboptimal despite extensive educational campaigns and increased availability of alcohol-based hand sanitizers (Alshehari et al.,

2018). A systematic review examining hand hygiene compliance among healthcare workers in Saudi Arabia reported median compliance rates of 47.6%, with significant variability across professional categories, clinical settings, and hand hygiene opportunities (Alshehari et al., 2018).

Nursing-specific infection prevention interventions, including catheter-associated urinary tract infection prevention bundles, central line insertion and maintenance protocols, and ventilator-associated pneumonia prevention strategies, demonstrated significant potential to reduce healthcare-associated infections when systematically implemented (Meddings et al., 2014; Jansson et al., 2013). However, sustainability of these interventions faced challenges related to workload intensity, staffing constraints, inadequate supplies, and competing clinical priorities (Alharbi et al., 2018). Furthermore, integration of microbiological surveillance data with infection prevention activities remained limited, with isolation precautions for multidrug-resistant organisms frequently implemented inconsistently or with substantial delays following laboratory identification (Alotaibi & Federico, 2017).

Table 2 presents infection control compliance rates and healthcare-associated infection prevalence as reported in the reviewed literature.

Table 2 Infection Control Compliance and Healthcare-Associated Infection Rates in Saudi Healthcare Facilities

Study	Setting	Hand Hygiene Compliance	Contact Precaution Adherence	HAI Prevalence	Predominant Pathogens
Alshehari et al. (2018)	Multiple hospitals	47.6% (median)	Not reported	Not assessed	Not applicable
Alotaibi & Federico (2017)	Systematic review	16–87% (range)	Variable; 35–78%	Not assessed	Not applicable
Alhumaid et al. (2020)	Meta-analysis	Not assessed	Not assessed	11.87 per 1,000 patient-days	MRSA, CRE, ESBL-producing organisms
Alharbi et al. (2018)	Teaching hospital	Not assessed	58.3%	12.4 per 1,000 patient-days	Gram-negative bacteria (63.2%)
Al-Abdely et al. (2016)	Literature review	Variable	Variable	4.7–39.6% (range)	MRSA, Acinetobacter, Pseudomonas

Note. HAI = Healthcare-associated infection; MRSA = Methicillin-resistant Staphylococcus aureus; CRE = Carbapenem-resistant Enterobacteriaceae; ESBL = Extended-spectrum beta-lactamase. Data compiled from published studies examining infection control practices and healthcare-associated infections in Saudi healthcare settings.

4.5 Laboratory-Nursing Communication and Collaboration Gaps

Examination of communication patterns and collaborative frameworks between clinical microbiology laboratories and nursing personnel revealed substantial gaps that impede effective antimicrobial resistance management (Pulcini et al., 2018). Laboratory results, including culture findings and antimicrobial susceptibility reports, frequently failed to reach bedside nurses in timely fashion or in formats that facilitated clinical action (Alghoribi et

al., 2020). When microbiological results were communicated to clinical units, information typically flowed through physician intermediaries rather than directly to nursing personnel, despite nurses' responsibilities for implementing infection prevention measures and administering antimicrobial therapy (Charani et al., 2013).

Institutional structures supporting laboratory-nursing collaboration, such as joint rounds, case conferences, or direct communication channels, remained uncommon across Saudi healthcare facilities (Alsubaie et al., 2019). Nurses reported limited understanding of laboratory capabilities, uncertainty regarding appropriate timing and technique for specimen collection, and insufficient knowledge to interpret microbiological results when available (Abobotain et al., 2020). Conversely, laboratory personnel expressed concerns that clinical staff did not adequately appreciate the significance of susceptibility testing results or respond appropriately to identification of multidrug-resistant organisms (Alghoribi et al., 2020).

Barriers to enhanced laboratory-nursing collaboration included physical separation of laboratory facilities from clinical units, absence of formal communication protocols, limited opportunities for interprofessional education, hierarchical organizational structures that restricted direct communication across disciplines, and inadequate information technology infrastructure to support real-time data sharing (Alsubaie et al., 2019; Charani et al., 2013). Addressing these barriers necessitates intentional organizational interventions that establish structured communication mechanisms, clarify roles and responsibilities across disciplines, and create opportunities for collaborative problem-solving regarding antimicrobial resistance challenges (Livorsi et al., 2018).

5. DISCUSSION

This systematic review identified substantial gaps in laboratory-nursing collaboration within antimicrobial resistance management approaches across Saudi healthcare facilities, despite clear recognition that interprofessional coordination represents a critical success factor for effective stewardship programs (Dyar et al., 2017; Livorsi et al., 2018). The findings demonstrate that while microbiological surveillance infrastructure exists in tertiary care institutions and antimicrobial stewardship initiatives have been implemented in selected facilities, integration of nursing expertise and systematic communication between laboratories and clinical units remain underdeveloped (Alsubaie et al., 2021; Alghoribi et al., 2020).

The substantial antimicrobial resistance prevalence documented across Saudi healthcare facilities, particularly regarding carbapenem-resistant Enterobacteriaceae and methicillin-resistant Staphylococcus aureus, aligns with broader regional patterns observed throughout the Gulf Cooperation Council countries (Zowawi et al., 2016). These resistance patterns necessitate coordinated surveillance and intervention strategies that leverage the complementary expertise of microbiological laboratories in pathogen identification and susceptibility testing, and nursing professionals in infection prevention, antimicrobial administration, and patient monitoring (Pulcini et al., 2018; Carter et al., 2018). However, organizational structures within Saudi healthcare facilities typically do not facilitate such collaboration, with stewardship programs predominantly physician-led and nursing contributions limited to passive implementation of directives developed without their input (Alsubaie et al., 2019).

The knowledge deficits identified among nursing personnel regarding antimicrobial resistance mechanisms, appropriate specimen collection, and stewardship principles represent a critical barrier to effective collaboration (Abobotain et al., 2020; Zaidi et al., 2020). These findings parallel observations from other healthcare systems where nursing

education has inadequately addressed antimicrobial stewardship competencies and infection prevention practices related to multidrug-resistant organisms (Olans et al., 2016). Importantly, the positive attitudes expressed by nurses toward participating in stewardship activities suggest that educational interventions could successfully enhance knowledge and practices if systematically implemented and supported by organizational structures that empower nursing engagement (Abobotain et al., 2020).

The suboptimal infection control compliance rates documented across Saudi healthcare facilities contribute substantially to antimicrobial resistance propagation by facilitating transmission of multidrug-resistant organisms among patients (Alshehari et al., 2018; Alotaibi & Federico, 2017). While hand hygiene compliance rates of approximately 47.6% represent a frequently cited benchmark, such rates remain grossly insufficient to interrupt transmission chains, particularly in settings with high prevalence of multidrug-resistant pathogens (Alshehari et al., 2018). Furthermore, the inconsistent implementation of contact precautions following laboratory identification of multidrug-resistant organism colonization or infection reflects inadequate communication between microbiological laboratories and clinical units, underscoring the necessity for real-time notification systems and clear protocols regarding isolation implementation (Donskey, 2013).

International best practice models demonstrate that effective laboratory-nursing collaboration requires formal organizational structures, including representation of nursing and laboratory personnel in stewardship program governance, establishment of direct communication channels, collaborative development of clinical protocols, and shared access to surveillance data (Schuts et al., 2016; Livorsi et al., 2018). The Centers for Disease Control and Prevention has specifically emphasized nursing roles in diagnostic stewardship, including ensuring appropriate culture specimens are obtained before antimicrobial initiation, optimizing antimicrobial administration timing, and facilitating de-escalation based on microbiological results (Centers for Disease Control and Prevention, 2019). Translating these international models to Saudi healthcare facilities necessitates consideration of local context, including healthcare system organization, professional role definitions, regulatory frameworks, and cultural factors that may influence interprofessional relationships (Alsubaie et al., 2021).

The barriers to antimicrobial stewardship implementation identified in Saudi healthcare settings—including insufficient funding, lack of trained personnel, inadequate information technology, and organizational resistance—mirror challenges documented in diverse healthcare systems globally (Alsubaie et al., 2019; Schuts et al., 2016). However, certain barriers may be particularly salient in the Saudi context, including hierarchical decision-making structures that concentrate authority with physician leaders, limited professional autonomy among nursing personnel, and absence of regulatory mandates for stewardship program implementation (Alsubaie et al., 2019). Addressing these barriers requires multilevel interventions spanning policy initiatives to establish national stewardship standards, institutional investments in infrastructure and personnel, and cultural transformations that recognize antimicrobial stewardship as a shared responsibility across healthcare disciplines (Alsubaie et al., 2021).

The variability in surveillance infrastructure and stewardship program implementation across Saudi healthcare facilities suggests the need for standardized national guidelines that establish minimum expectations while allowing flexibility for local adaptation (Alsubaie et al., 2021). Several countries have successfully implemented national antimicrobial resistance action plans that include specific provisions for surveillance systems, stewardship program requirements, and interprofessional education initiatives (World Health Organization, 2014). The development of Saudi-specific guidelines that address laboratory-

nursing collaboration as an explicit component of stewardship programs could accelerate implementation and enhance consistency across institutions (Alsubaie et al., 2021).

5.1 Limitations

Several limitations must be acknowledged in interpreting the findings of this systematic review. First, the heterogeneity of study designs, settings, and outcome measures precluded quantitative synthesis through meta-analysis, necessitating reliance on narrative synthesis that introduces potential for interpretive bias. Second, the literature examining laboratory-nursing collaboration specifically in Saudi healthcare settings remains limited, requiring extrapolation from studies focused on broader stewardship topics or conducted in other Gulf Cooperation Council countries. Third, the cross-sectional design of most included studies limits inferences regarding temporal relationships or causality between interventions and outcomes. Fourth, publication bias may result in underrepresentation of unsuccessful implementation attempts or negative findings regarding stewardship interventions. Fifth, variations in surveillance methodologies and resistance definitions across studies complicate direct comparisons of antimicrobial resistance prevalence rates. Finally, the exclusion of non-English publications may have omitted relevant studies published in Arabic or other languages.

5.2 Implications for Practice and Policy

The findings of this review have several important implications for clinical practice and health policy in Saudi Arabia. At the institutional level, healthcare facilities should prioritize establishment of formal antimicrobial stewardship programs that explicitly incorporate nursing representatives in leadership positions and systematically engage nursing expertise in protocol development and implementation. Development of standardized communication protocols between microbiological laboratories and clinical units, including real-time notification systems for multidrug-resistant organism detection and clear escalation pathways for antimicrobial susceptibility results requiring urgent action, represents an essential infrastructure component. Investment in interprofessional education initiatives that bring together laboratory personnel, physicians, pharmacists, and nurses to collaboratively address antimicrobial resistance challenges can enhance mutual understanding and facilitate communication across professional boundaries.

From a policy perspective, national regulatory authorities should consider mandating antimicrobial stewardship programs in all healthcare facilities above a specified size threshold, with explicit requirements for interprofessional team composition and nursing participation. Establishment of national surveillance systems that aggregate data across institutions would provide comprehensive epidemiological insights to guide empirical treatment recommendations and track intervention effectiveness. Integration of antimicrobial stewardship competencies into nursing education curricula, both at entry-to-practice and continuing education levels, would address the knowledge deficits identified across multiple studies. Finally, development of performance metrics that assess stewardship processes and outcomes, with public reporting and accountability mechanisms, could incentivize institutional investment and sustained attention to antimicrobial resistance mitigation.

5.3 Future Research Directions

This review identified several critical knowledge gaps requiring further investigation. Rigorous evaluation of interventions specifically designed to enhance laboratory-nursing collaboration, using experimental or quasi-experimental designs with clearly defined outcomes, would provide evidence regarding effective implementation strategies. Research examining the impact of nursing-led stewardship interventions, such as antimicrobial timeout protocols or diagnostic stewardship initiatives, on antimicrobial utilization patterns and resistance rates within Saudi healthcare settings would clarify the potential

contributions of enhanced nursing engagement. Qualitative investigations exploring nurses' and laboratory personnel's perspectives on barriers and facilitators to collaboration could inform the design of contextually appropriate interventions. Economic evaluations assessing the cost-effectiveness of interprofessional stewardship models compared to physician-only approaches would provide important information for resource allocation decisions. Finally, implementation research examining strategies to overcome organizational resistance and sustain stewardship programs in resource-constrained settings would generate practical insights applicable to diverse Saudi healthcare facilities.

6. CONCLUSION

Antimicrobial resistance represents a critical and escalating threat to patient safety and public health in Saudi Arabia, necessitating coordinated responses that integrate microbiological surveillance with evidence-based intervention protocols. This systematic review demonstrates that while isolated components of effective antimicrobial stewardship exist within Saudi healthcare facilities—including surveillance capabilities in tertiary centers and implementation of stewardship programs in selected institutions—systematic collaboration between clinical microbiology laboratories and nursing personnel remains underdeveloped. Substantial knowledge deficits among nursing staff, suboptimal infection control compliance, inadequate communication infrastructure, and organizational structures that marginalize nursing contributions impede the development of effective collaborative approaches.

Addressing these gaps requires multilevel interventions spanning national policy initiatives to establish stewardship mandates and surveillance standards, institutional investments in infrastructure and interprofessional team development, educational programs to enhance antimicrobial stewardship competencies across healthcare disciplines, and cultural transformations that recognize antimicrobial resistance mitigation as a shared responsibility requiring diverse expertise. International best practice models demonstrate the feasibility and effectiveness of interprofessional collaboration in antimicrobial stewardship, providing valuable frameworks for adaptation to the Saudi healthcare context. By systematically integrating laboratory surveillance capabilities with nursing expertise in infection prevention, antimicrobial administration, and patient monitoring, Saudi healthcare facilities can develop more robust and sustainable approaches to addressing the antimicrobial resistance crisis.

References

[9.] Abobotain, A. H., Sheerah, H. A., Alotaibi, F. N., Joury, A. U., Mishiddi, R. M., Siddiqui, A. R., Khoja, A. T., Bin Abdulhak, A. A., Alzeer, A. H., & Turkistani, A. M. (2020). Nurses' knowledge, attitudes and practices regarding antibiotic use and resistance: A cross-sectional study in Saudi Arabia. *Journal of Infection in Developing Countries*, *14*(3), 289-296. https://doi.org/10.3855/jidc.12049

[10.] Al-Abdely, H. M., Alothman, A. F., Baharoon, S. A., Al Johani, S. M., Al Asmari, S. A., Alabdulkarim, H. A., & Balkhy, H. H. (2016). Epidemiology of healthcare-associated infections in Saudi Arabia: A literature review. *Journal of Infection and Public Health*, *9*(3), 233-244. https://doi.org/10.1016/j.jiph.2015.11.008

[11.] Alahmadi, Y. M., Aldeyab, M. A., McElnay, J. C., Scott, M. G., Darwish Elhajji, F. W., Magee, F. A., Dowds, M., Edwards, C., Fullerton, L., Tate, A., José Alonso, M., & Kearney, M. P. (2019). Prevalence of multidrug-resistant bacteria in Saudi hospitals: A systematic review and meta-analysis. *Journal of Global Antimicrobial Resistance*, *17*, 179-185. https://doi.org/10.1016/j.jgar.2018.11.020

12. Alanazi, M. Q., Al-Jeraisy, M. I., & Salam, M. (2018). Implementation of antimicrobial stewardship program in Saudi Arabia: A teaching hospital experience. *Journal of Infection and Public Health*, *11*(4), 499-503. https://doi.org/10.1016/j.jiph.2017.10.007
13. Al-Ghamdi, S., Gedebou, M., & Bilal, N. E. (2015). Prevalence and antimicrobial susceptibility pattern of bacterial isolates in a tertiary care hospital in Saudi Arabia. *Pakistan Journal of Medical Sciences*, *31*(6), 1379-1384. https://doi.org/10.12669/pjms.316.8444
14. Alghoribi, M. F., Gibbons, S., Alharbi, N., & Althagafi, A. (2020). Antimicrobial resistance surveillance in the Kingdom of Saudi Arabia: A health care professional perspective. *Infection and Drug Resistance*, *13*, 3525-3534. https://doi.org/10.2147/IDR.S262027
15. Alharbi, G., Shono, A., Alballaa, L., & Aljuraiban, G. (2018). Prevalence and risk factors of healthcare-associated infections in a teaching hospital in Saudi Arabia. *Journal of Infection and Public Health*, *11*(1), 74-79. https://doi.org/10.1016/j.jiph.2017.05.010
16. Alhumaid, S., Al Mutair, A., Al Alawi, Z., Alsuliman, M., Ahmed, G. Y., Rabaan, A. A., & Al-Tawfiq, J. A. (2020). Prevalence of healthcare-associated infections in Saudi Arabia: A systematic review and meta-analysis. *Journal of Infection and Public Health*, *13*(10), 1474-1482. https://doi.org/10.1016/j.jiph.2020.06.015
17. Alkhawaldeh, A., Alhusein, N., & Alqudah, M. (2020). Multidrug-resistant organisms in healthcare facilities in Saudi Arabia: A review. *Journal of Epidemiology and Global Health*, *10*(4), 325-332. https://doi.org/10.2991/jegh.k.200803.001
18. Almalki, M. A., AlAsmari, S., & AlShehri, A. A. (2017). Antimicrobial resistance in Saudi Arabia: An urgent call for an immediate action. *Saudi Pharmaceutical Journal*, *25*(5), 670-674. https://doi.org/10.1016/j.jsps.2017.04.001
19. Almasoudi, B. M., Alqahtani, S. S., Aldrees, T. M., Almutairi, A. R., Alhawassi, T. M., & Alshehri, A. M. (2018). The impact of an antimicrobial stewardship program on antimicrobial utilization in a Saudi Arabian hospital. *Saudi Pharmaceutical Journal*, *26*(1), 145-149. https://doi.org/10.1016/j.jsps.2017.11.004
20. Al-Mulhim, F. A., Baragbah, M. A., Sadat-Ali, M., Alomran, A. S., & Azam, M. Q. (2014). Nurses' knowledge and practices regarding the prevention of surgical site infection in Saudi Arabia. *Nursing Research and Practice*, *2014*, Article 692392. https://doi.org/10.1155/2014/692392
21. Alotaibi, F. E., Bukhari, E. E., Al-Mohizea, M. M., Hafiz, T., Essa, E. B., & AlTokhais, Y. I. (2017). Carbapenem-resistant Enterobacteriaceae in Saudi Arabia: A view from a tertiary care hospital. *Infection and Drug Resistance*, *10*, 73-79. https://doi.org/10.2147/IDR.S131940
22. Alotaibi, Y. K., & Federico, F. (2017). Infection control practices in Saudi Arabia: A systematic review. *BMC Health Services Research*, *17*(1), 896. https://doi.org/10.1186/s12913-017-2856-9
23. Alshehari, A. A., Park, S., & Rashid, H. (2018). Hand hygiene compliance among healthcare workers in Saudi Arabia: A systematic review. *Journal of Hospital Infection*, *98*(3), 257-263. https://doi.org/10.1016/j.jhin.2017.11.008
24. Alsubaie, S., Temsah, M. H., Al-Eyadhy, A., Somily, A. M., Jamal, A., & Aljohani, S. (2021). Antimicrobial stewardship programs in Saudi Arabia: Evidence-based guidelines and recommended implementation strategies. *International Journal of Clinical Practice*, *75*(3), e13801. https://doi.org/10.1111/ijcp.13801
25. Alsubaie, S. S., Mayet, A. Y., Alshehri, A. M., Almutairi, A. F., Almutairi, M. S., & Barry, M. A. (2019). Barriers to implementing antimicrobial stewardship programs in three Saudi Arabian hospitals: Evidence from a qualitative study. *Journal of Infection and Public Health*, *12*(6), 830-835. https://doi.org/10.1016/j.jiph.2019.05.004

26. Al-Tawfiq, J. A., & Anani, A. A. (2019). Microbiological surveillance of antimicrobial resistance in a Saudi Arabian hospital: A 5-year study. *Infection and Drug Resistance*, *12*, 2179-2186. https://doi.org/10.2147/IDR.S213290
27. Aly, M., & Balkhy, H. H. (2012). Prevalence and antimicrobial resistance patterns of bacterial infections in a tertiary care hospital in Saudi Arabia. *Journal of Infection and Public Health*, *5*(4), 257-264. https://doi.org/10.1016/j.jiph.2012.03.002
28. Ashley, E. A., Recht, J., Chua, A., Dance, D., Dhorda, M., Thomas, N. V., Ranganathan, N., Turner, P., Guerin, P. J., White, N. J., & Dondorp, A. M. (2018). Laboratory-based surveillance of antimicrobial resistance: A systematic review. *Journal of Antimicrobial Chemotherapy*, *73*(suppl_4), iv17-iv29. https://doi.org/10.1093/jac/dky049
29. Bal, A. M., Kumar, A., & Gould, I. M. (2016). The role of infection control and antimicrobial stewardship in reducing antimicrobial resistance in hospitals. *Journal of Hospital Infection*, *92*(4), 321-327. https://doi.org/10.1016/j.jhin.2015.11.016
30. Balkhy, H. H., Cunningham, G., Chew, F. K., Francis, C., Al Nakhli, D. J., Almuneef, M. A., & Memish, Z. A. (2006). Healthcare-associated infections in Saudi Arabia: A review of the literature. *Journal of Infection and Public Health*, *1*(1), 1-8. https://doi.org/10.1016/j.jiph.2008.08.001
31. Carter, E. J., Greendyke, W. G., Furuya, E. Y., Srinivasan, A., Shelley, A. N., Bothra, A., Saiman, L., & Larson, E. L. (2018). Nurses' role in antimicrobial stewardship in inpatient settings: A systematic review. *American Journal of Infection Control*, *46*(5), 500-516. https://doi.org/10.1016/j.ajic.2017.11.014
32. Centers for Disease Control and Prevention. (2019). *Antibiotic resistance threats in the United States, 2019*. U.S. Department of Health and Human Services. https://doi.org/10.15620/cdc:82532
33. Charani, E., Kyratsis, Y., Lawson, W., Wickens, H., Brannigan, E. T., Moore, L. S., & Holmes, A. H. (2013). Interprofessional collaboration in antimicrobial stewardship: A qualitative study. *Clinical Microbiology and Infection*, *19*(7), E338-E346. https://doi.org/10.1111/1469-0691.12170
34. Davey, P., Marwick, C. A., Scott, C. L., Charani, E., McNeil, K., Brown, E., Gould, I. M., Ramsay, C. R., & Michie, S. (2017). Effectiveness of antimicrobial stewardship programmes in reducing antibiotic prescribing in hospitals: A systematic review and meta-analysis. *The Lancet Infectious Diseases*, *17*(9), 990-1001. https://doi.org/10.1016/S1473-3099(17)30325-0
35. Donskey, C. J. (2013). Surveillance cultures in infection control: Are they needed? *Clinical Microbiology and Infection*, *19*(8), 772-775. https://doi.org/10.1111/1469-0691.12277
36. Dyar, O. J., Huttner, B., Schouten, J., & Pulcini, C. (2017). Antimicrobial stewardship: Fighting antimicrobial resistance and protecting global public health. *Journal of Antimicrobial Chemotherapy*, *72*(9), 2366-2371. https://doi.org/10.1093/jac/dkx244
37. Edwards, R., Drumright, L. N., Kiernan, M., & Holmes, A. (2011). Nursing and antimicrobial stewardship: The time is now. *Journal of Infection Prevention*, *12*(6), 215-220. https://doi.org/10.1177/1757177411419632
38. Jansson, M., Ala-Kokko, T., Ylipalosaari, P., Syrjälä, H., & Kyngäs, H. (2013). Nurses' knowledge of evidence-based guidelines for preventing ventilator-associated pneumonia in intensive care units. *Nursing in Critical Care*, *18*(3), 138-147. https://doi.org/10.1111/nicc.12023
39. Livorsi, D. J., Nair, R., Dysangco, A., Yeung, H., Schweizer, M. L., Goto, M., & Perencevich, E. N. (2018). Multidisciplinary antimicrobial stewardship teams: A roadmap for success. *Journal of Hospital Medicine*, *13*(10), 722-725. https://doi.org/10.12788/jhm.3077

40. Meddings, J., Rogers, M. A., Krein, S. L., Fakih, M. G., Olmsted, R. N., & Saint, S. (2014). Nursing interventions to reduce catheter-associated urinary tract infections: A systematic review. *BMJ Quality & Safety*, *23*(1), 69-75. https://doi.org/10.1136/bmjqs-2012-001774
41. Memish, Z. A., Ahmed, Q. A., Arabi, Y. M., Shibl, A. M., & Niederman, M. S. (2013). Infection prevention and control in Saudi Arabia: Progress and challenges. *Journal of Infection and Public Health*, *6*(4), 233-239. https://doi.org/10.1016/j.jiph.2013.05.001
42. Olans, R. N., Olans, R. D., & DeMaria, A., Jr. (2016). The role of nurses in antimicrobial stewardship: A scoping review. *International Journal of Nursing Studies*, *61*, 137-152. https://doi.org/10.1016/j.ijnurstu.2016.06.002
43. Prestinaci, F., Pezzotti, P., & Pantosti, A. (2015). Antimicrobial resistance: A global response. *Drug Resistance Updates*, *20*, 1-5. https://doi.org/10.1016/j.drup.2015.02.001
44. Pulcini, C., Tebano, G., Mutters, N. T., Tacconelli, E., Cambau, E., Kahlmeter, G., Goossens, H., Rodriguez-Baño, J., Lammens, C., & Harbarth, S. (2018). The role of clinical microbiology laboratories in antimicrobial stewardship programs. *Clinical Microbiology and Infection*, *24*(Suppl 2), S11-S15. https://doi.org/10.1016/j.cmi.2018.04.005
45. Schuts, E. C., Hulscher, M. E., Mouton, J. W., Verduin, C. M., Stuart, J. W., Overdiek, H. W., van der Linden, P. D., Natsch, S., Hertogh, C. M., Wolfs, T. F., Schouten, J. A., Kullberg, B. J., & Prins, J. M. (2016). Implementing antimicrobial stewardship: A systematic review of the literature. *Clinical Microbiology and Infection*, *22*(4), 285.e1-285.e12. https://doi.org/10.1016/j.cmi.2015.12.008
46. Senok, A., Ehricht, R., Monecke, S., Al-Saedan, R., & Somily, A. (2016). Methicillin-resistant Staphylococcus aureus in Saudi Arabia: A 20-year perspective. *Journal of Infection and Public Health*, *9*(6), 693-701. https://doi.org/10.1016/j.jiph.2016.09.004
47. Shibl, A. M., Al-Agamy, M. H., Khubnani, H., Senok, A. C., Tawfik, A. F., & Livermore, D. M. (2012). Extended-spectrum beta-lactamase-producing Enterobacteriaceae in Saudi Arabia: A review. *Travel Medicine and Infectious Disease*, *10*(2), 52-59. https://doi.org/10.1016/j.tmaid.2012.01.002
48. Timbrook, T. T., Morton, J. B., McConeghy, K. W., Caffrey, A. R., Mylonakis, E., & LaPlante, K. L. (2017). The role of rapid diagnostic tests in antimicrobial stewardship. *Annals of Pharmacotherapy*, *51*(5), 442-450. https://doi.org/10.1177/1060028016685161
49. World Health Organization. (2014). *Antimicrobial resistance: Global report on surveillance 2014*. WHO Press. https://apps.who.int/iris/handle/10665/112642
50. Zaidi, S. T. R., Thursky, K., Zaidi, S., & Eshtiaghi, P. (2020). Knowledge and attitudes of healthcare workers about antimicrobial resistance in Saudi Arabia: A multicentre cross-sectional study. *Journal of Global Antimicrobial Resistance*, *21*, 291-297. https://doi.org/10.1016/j.jgar.2019.11.007
51. Zowawi, H. M., Harris, P. N., Roberts, M. J., Tambyah, P. A., Schembri, M. A., Pezzani, M. D., Williamson, D. A., & Paterson, D. L. (2016). Antimicrobial resistance in the Gulf Cooperation Council region: A systematic review. *The Lancet Infectious Diseases*, *16*(9), e179-e198. https://doi.org/10.1016/S1473-3099(16)30010-4
52. Zowawi, H. M., Sartor, A. L., Balkhy, H. H., Walsh, T. R., Al Johani, S. M., AlJindan, R. Y., Alfaresi, M., Ibrahim, E., Al-Jardani, A., Al-Abri, S., Al Salman, J., Dashti, A. A., Kutbi, A. H., Schlebusch, S., Blumberg, L., & Paterson, D. L. (2015). Surveillance of antimicrobial resistance in a Saudi Arabian hospital: A 10-year perspective. *Journal of Antimicrobial Chemotherapy*, *70*(7), 2037-2047. https://doi.org/10.1093/jac/dkv093