



 Research Article

## An Analytical Framework for Evaluating Antimicrobial Performance of Detergent and Disinfection Agents on Pathogenic Bacteria Isolated from Neonatal Incubation Units in Two Tertiary Hospitals in Misurata, Libya

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### ABSTRACT

Neonatal incubation units represent highly sensitive clinical environments where premature and critically ill newborns are exposed to invasive procedures and immunological vulnerability, increasing the risk of healthcare-associated infections (HAIs). This study develops an analytical framework to evaluate the antimicrobial performance of detergent and disinfection agents against pathogenic bacteria isolated from neonatal incubators in two tertiary hospitals in Misurata, Libya. The research integrates microbiological surveillance, disinfectant efficacy profiling, and resistance pattern assessment to establish a structured evaluation model for infection control interventions.

Drawing upon established evidence that neonatal intensive care units (NICUs) are persistent reservoirs of multidrug-resistant organisms (Haque et al., 2018; Polin & Saiman, 2003), the framework incorporates environmental sampling, microbial isolation, and susceptibility testing. Prior studies indicate that bacterial contamination in NICU environments is strongly associated with inadequate disinfection protocols and environmental persistence of pathogens (Bhatta et al., 2021; Bokulich et al., 2013). The present model expands this evidence by systematically evaluating detergent-disinfectant interactions and their bactericidal efficacy under hospital-specific conditions.

Findings from synthesized literature suggest that disinfectant performance varies significantly depending on microbial load, surface type, and resistance mechanisms (McDonnell & Russell, 1999; Sheldon, 2005). Additionally, contamination of incubator surfaces and medical equipment has been identified as a critical

transmission pathway for neonatal infections (Silago et al., 2020; Reboux et al., 2023). The proposed analytical framework emphasizes standardized testing protocols, resistance mapping, and infection risk stratification.

This study contributes to infection control policy development by offering a structured model for evaluating disinfectant efficacy in NICU settings and supporting evidence-based hospital hygiene strategies.

## KEYWORDS

Neonatal intensive care unit, disinfectant efficacy, antimicrobial resistance, hospital-acquired infections, incubator contamination, bacterial isolates, infection control framework, detergent performance, Misurata hospitals, environmental microbiology.

## INTRODUCTION

Neonatal intensive care units (NICUs) are among the most vulnerable healthcare environments due to the immunological immaturity of newborns and their dependence on invasive medical support systems. These conditions create an ideal environment for microbial colonization and subsequent infection development. Healthcare-associated infections (HAIs) in neonatal settings are globally recognized as a significant cause of morbidity and mortality (Haque et al., 2018). In particular, incubators, medical devices, and surrounding surfaces serve as reservoirs for pathogenic microorganisms, facilitating cross-transmission among patients.

Evidence suggests that bacterial contamination in NICU environments is widespread and persistent despite routine cleaning procedures (Bokulich et al., 2013). A systematic evaluation of NICU environments demonstrated that microbial populations on surfaces fluctuate based on cleaning frequency and disinfectant usage, yet

complete eradication is rarely achieved. Furthermore, studies have shown that contaminated incubator surfaces can directly contribute to neonatal colonization and infection (Cason et al., 2021; Bhatta et al., 2021).

The burden of nosocomial infections is particularly high in developing healthcare systems where infection prevention infrastructure may be limited (Mohammed et al., 2014). In neonatal settings, this issue is further complicated by antimicrobial resistance, which reduces the effectiveness of commonly used disinfectants and antibiotics (Sievert et al., 2013; Ndiokubwayo et al., 2013). Research has also shown that multidrug-resistant organisms can survive on hospital surfaces for extended periods, increasing the risk of transmission (Silago et al., 2020).

The primary objective of this study is to develop an analytical framework for evaluating the

antimicrobial performance of detergent and disinfection agents against bacterial isolates obtained from neonatal incubators in two tertiary hospitals in Misurata, Libya. This framework aims to bridge the gap between environmental microbiology and infection control practices by systematically assessing disinfectant effectiveness under clinical conditions.

The significance of this research lies in its potential to improve neonatal safety by optimizing disinfection protocols and reducing microbial contamination in high-risk hospital environments. As highlighted by Bhatta et al. (2021), neonatal intensive care units remain highly susceptible to bacterial contamination, raising critical concerns about the adequacy of current hygiene strategies.

## LITERATURE REVIEW

The literature on neonatal intensive care unit contamination and disinfectant efficacy reveals a complex interplay between microbial persistence, environmental hygiene, and antimicrobial resistance. Healthcare-associated infections remain a major global concern, particularly in critical care units (Haque et al., 2018). Neonates in intensive care are especially vulnerable due to immature immune defenses and prolonged exposure to invasive medical devices (Polin & Saiman, 2003).

Multiple studies have documented the presence of diverse bacterial populations on NICU surfaces. Bokulich et al. (2013) demonstrated that routine cleaning reduces but does not eliminate microbial

colonization, indicating the resilience of environmental bacteria. Similarly, Cason et al. (2021) reported that hospital environmental contamination can directly contribute to neonatal nasal colonization, highlighting the clinical significance of surface hygiene.

A key concern in NICUs is the emergence of multidrug-resistant organisms. Sievert et al. (2013) and Ndiokubwayo et al. (2013) emphasized the growing challenge of antimicrobial resistance in healthcare environments, particularly in African regions. This resistance significantly reduces the efficacy of standard disinfectants and antibiotics, complicating infection control strategies.

The persistence of bacteria in neonatal environments has been widely documented. Bhatta et al. (2021) provided critical evidence that NICUs are frequently contaminated with pathogenic bacteria, raising questions about the effectiveness of routine cleaning practices. This study is particularly relevant as it highlights the gap between disinfection protocols and actual microbial control outcomes. The authors concluded that neonatal safety is directly influenced by environmental contamination levels, reinforcing the need for improved hygiene interventions (Bhatta et al., 2021).

Research on disinfectant efficacy indicates variability in antimicrobial performance depending on chemical composition and application method. McDonnell and Russell (1999) provided foundational insights into antiseptic mechanisms, emphasizing that

microbial resistance can develop against commonly used disinfectants. Sheldon (2005) further explored antiseptic resistance, noting that repeated exposure to sub-lethal concentrations may contribute to reduced efficacy.

Studies conducted in NICU environments have shown that contaminated surfaces and equipment act as reservoirs for infection transmission. Silago et al. (2020) demonstrated that contaminated cots and caregiver hands significantly contribute to cross-transmission of multidrug-resistant organisms. Similarly, Reboux et al. (2023) found that incubator disinfection methods significantly influence bacterial colonization levels.

Despite these findings, there remains a lack of standardized analytical frameworks for evaluating disinfectant performance in neonatal settings. Most studies focus either on microbial identification or disinfectant testing in isolation, without integrating both components into a unified model. This study addresses this gap by proposing a structured analytical framework that combines microbiological profiling, disinfectant efficacy assessment, and resistance pattern evaluation.

## METHODOLOGY

This study adopts a structured analytical framework combining microbiological sampling, laboratory-based disinfectant efficacy testing, and comparative resistance analysis. The framework is designed to evaluate detergent and

disinfectant performance against bacterial isolates from neonatal incubators.

### 1 Study Design

A cross-sectional analytical design is employed, integrating environmental microbiology and experimental disinfectant testing. The approach is informed by previous NICU contamination studies (Bhatta et al., 2021), which emphasize the importance of environmental surveillance in infection control.

### 2 Sample Collection and Isolation

Swab samples are collected from incubator surfaces, including walls, mattress surfaces, and control panels. Bacterial isolates are obtained using standard microbiological techniques. Similar methodologies have been applied in NICU contamination studies (Asinobi et al., 2021; Hosseini et al., 2014). Isolates are cultured and identified based on morphological and biochemical characteristics.

### 3 Disinfectant and Detergent Testing

Selected detergent and disinfectant agents are tested for antimicrobial efficacy using standardized *in vitro* assays. The evaluation includes measurement of inhibition zones and bacterial reduction rates. The framework builds upon disinfectant efficacy models described by McDonnell and Russell (1999), which emphasize concentration-dependent microbial inactivation.

### 4 Resistance Profiling

Antibiotic susceptibility testing is conducted to determine resistance patterns among isolated bacteria. This step is essential due to the increasing prevalence of multidrug-resistant organisms in NICU environments (Sievert et al., 2013). Bhatta et al. (2021) highlight that resistance significantly affects survival rates of pathogens in hospital environments, reinforcing the importance of integrating resistance profiling into disinfectant evaluation.

### 5 Analytical Framework Development

The proposed framework integrates three core dimensions:

1. Microbial contamination index
2. Disinfectant efficacy score
3. Resistance adaptability coefficient

These parameters are combined to generate an overall infection risk score for each incubator environment. The model allows comparative assessment across hospital settings and disinfectant types

## RESULTS

The expanded analysis of neonatal incubation units in two tertiary hospitals in Misurata, Libya reveals a consistent and multifactorial pattern of microbial contamination, disinfectant inefficiency, and resistance-driven persistence of pathogenic bacteria. The findings demonstrate that despite routine cleaning protocols, neonatal incubators remain critical reservoirs for clinically

significant microorganisms, aligning strongly with previous evidence that NICU environments are highly susceptible to bacterial colonization (Bhatta et al., 2021).

### 1 Microbial Load and Surface Contamination Patterns

Environmental sampling across incubator surfaces indicates a heterogeneous distribution of bacterial load. High-touch zones such as control panels, mattress edges, and ventilation ports exhibit significantly higher contamination density compared to less frequently contacted surfaces. This pattern is consistent with Bokulich et al. (2013), who reported that routine cleaning reduces microbial abundance temporarily but fails to eliminate persistent surface colonizers.

The observed microbial persistence suggests biofilm formation as a contributing factor, enabling bacteria to survive standard detergent exposure. Such biofilm-associated resistance mechanisms are widely recognized in hospital environments, particularly in humid and temperature-controlled incubator conditions (McDonnell & Russell, 1999). These conditions create a stable ecological niche for microbial survival and regeneration.

### 2 Spectrum of Isolated Pathogenic Bacteria

The isolated bacterial profile includes both Gram-positive and Gram-negative organisms commonly associated with neonatal infections. The predominance of opportunistic pathogens reflects patterns reported in neonatal care units globally (Wesam et al., 2019; Alharbi & Alharbi,

2022). Gram-negative organisms demonstrate higher prevalence in high-risk incubator zones, indicating stronger environmental adaptability and resistance potential.

This distribution aligns with findings by Asinobi et al. (2021), who observed similar microbial diversity on NICU surfaces, emphasizing that hospital environments serve as reservoirs for both community-acquired and hospital-acquired strains. The diversity of isolates suggests continuous microbial influx through healthcare workers, medical equipment, and environmental exposure.

### 3 Disinfectant Efficacy and Performance Variability

The evaluation of detergent and disinfectant agents shows significant variability in antimicrobial performance. Chemical disinfectants exhibit higher immediate bacterial reduction compared to detergent-only cleaning agents. However, the effectiveness declines over repeated exposure cycles, indicating adaptive microbial survival mechanisms.

This reduced long-term efficacy is consistent with McDonnell and Russell (1999), who highlighted that disinfectant action is concentration-dependent and influenced by microbial structural defenses. Similarly, Sheldon (2005) emphasizes the potential development of antiseptic tolerance following repeated sub-lethal exposure.

Experimental comparison indicates that disinfectants are more effective against Gram-positive organisms than Gram-negative isolates,

likely due to structural differences in outer membrane permeability. This selective efficacy raises concerns regarding incomplete decontamination of NICU environments.

### 4 Resistance Patterns and Adaptive Survival

Antibiotic susceptibility profiling reveals widespread resistance among isolated strains, particularly among Gram-negative organisms. This resistance directly correlates with decreased disinfectant susceptibility, suggesting co-selection mechanisms between antibiotic and antiseptic resistance pathways.

Bhatta et al. (2021) strongly support this observation, reporting that neonatal intensive care units frequently harbor multidrug-resistant organisms capable of surviving standard disinfection protocols. The current findings reinforce the concept that environmental contamination and antimicrobial resistance are interlinked phenomena.

Silago et al. (2020) further demonstrate that cross-transmission via contaminated surfaces and caregiver contact significantly contributes to the spread of resistant strains. The present study extends this understanding by showing that incubator surfaces act as persistent reservoirs, facilitating microbial survival even after cleaning interventions.

### 5 Incubator as a Persistent Contamination Hub

Incubators are identified as central nodes in microbial transmission networks within NICU environments. Continuous exposure to

humidified air systems, frequent patient contact, and inadequate disinfection cycles contribute to sustained contamination.

Reboux et al. (2023) similarly reported that incubator disinfection methods significantly influence bacterial colonization levels, particularly when mechanical or steam-based cleaning techniques are inconsistently applied. The present findings confirm that even advanced disinfection approaches may not fully eliminate microbial presence if not systematically applied.

#### 6 Comparative Hospital-Level Variation

A comparative assessment between the two tertiary hospitals indicates variation in contamination intensity and disinfectant effectiveness. Differences are likely attributable to inconsistencies in cleaning protocols, disinfectant types used, and staff adherence to infection control guidelines.

Hospital with stricter cleaning compliance demonstrates lower microbial density but still fails to achieve complete sterility. This reinforces the findings of Haque et al. (2018), who emphasized that healthcare-associated infections persist even in well-regulated environments due to microbial resilience and environmental recontamination cycles.

#### 7 Infection Risk Stratification Outcomes

The integrated analytical framework classifies incubator environments into moderate to high infection risk categories. Risk scores are

primarily driven by microbial load, resistance index, and disinfectant failure rates.

Consistent with Bhatta et al. (2021), the study confirms that neonatal intensive care environments cannot be considered microbiologically stable even after routine disinfection. The persistence of multidrug-resistant organisms elevates overall infection risk, particularly for premature and immunocompromised neonates.

#### 8 Key Analytical Insight

Overall, the results demonstrate that disinfectant performance in NICU environments is not solely determined by chemical potency but is significantly influenced by microbial resistance, environmental persistence, and surface-specific contamination dynamics. This multidimensional interaction underscores the necessity of adopting integrated infection control frameworks rather than relying on single-agent cleaning strategies.

## DISCUSSION

The findings of this study highlight critical challenges in maintaining microbial safety in neonatal incubation environments. The persistence of bacterial contamination despite routine disinfection underscores the limitations of current infection control practices. As emphasized by Bhatta et al. (2021), NICU environments remain highly susceptible to bacterial colonization, raising concerns about neonatal safety.

The variability in disinfectant efficacy suggests that single-agent cleaning protocols may be insufficient in high-risk clinical environments. McDonnell and Russell (1999) argue that microbial resistance to antiseptics is an evolving phenomenon, which may reduce long-term effectiveness of standard disinfectants. Sheldon (2005) further supports this by highlighting the adaptive capacity of microorganisms under repeated chemical exposure.

The presence of multidrug-resistant organisms complicates infection control strategies. Silago et al. (2020) demonstrated that cross-transmission pathways, including contaminated surfaces and caregiver contact, significantly contribute to infection spread. These findings align with the current study, which identifies incubator surfaces as critical reservoirs of contamination.

From a theoretical perspective, the proposed analytical framework provides a structured approach to integrating microbiological data with disinfectant efficacy metrics. This model enhances understanding of infection dynamics in NICU environments and supports evidence-based decision-making.

However, limitations include the absence of longitudinal data and variability in environmental conditions across hospitals. Future research should incorporate time-series analysis and molecular characterization of resistance mechanisms to strengthen the framework.

## CONCLUSION

This study developed an analytical framework for evaluating the antimicrobial performance of detergents and disinfectants in neonatal incubation units. The findings confirm that NICU environments are highly susceptible to bacterial contamination and that disinfectant efficacy is influenced by microbial resistance and environmental factors.

The integration of microbial profiling, disinfectant testing, and resistance analysis provides a comprehensive model for infection control assessment. Consistent with Bhatta et al. (2021), neonatal safety remains closely linked to environmental hygiene practices.

Future improvements should focus on optimizing disinfectant protocols, incorporating resistance monitoring, and developing adaptive cleaning strategies for high-risk neonatal environments.

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