International Research Journal of Medical Sciences and Health Care (IRJMSHC)
eISSN: 3087-405X
Volume03 Issue09 | Page No: - 17-23

Received: 16 Aug 2026, Revised: 24 August 2026, Accepted: 30 August 2026, Published: 14 September 2026

DOI: https://doi.org/10.55640/irjmshc-v03i09-03

Surface Challenge-Based Assessment Framework for the Disinfectant Efficacy of Cetrimide, Dettol, and Lizol Against Six Microbial Species in Pharmaceutical Manufacturing Environments

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ABSTRACT: Effective environmental disinfection is fundamental to contamination control in pharmaceutical manufacturing, particularly where microorganisms can persist on non-porous production surfaces. This study develops a surface challenge-based assessment framework for comparatively evaluating the disinfectant efficacy of cetrimide, Dettol, and Lizol against six microbial species on epoxy-coated pharmaceutical surfaces. The framework integrates standardized surface preparation, microbial challenge, disinfectant exposure, neutralization, recovery, enumeration, and comparative efficacy analysis. Its theoretical foundation is derived from the supplied literature concerning disinfectant validation, surface challenge testing, cleanroom disinfection, and microbial control. Particular emphasis is placed on distinguishing nominal disinfectant activity from demonstrated performance under realistic surface conditions. The proposed framework incorporates baseline microbial recovery, control verification, log-reduction assessment, contact-time effects, reproducibility, and comparative performance ranking. The literature indicates that disinfectant efficacy cannot be evaluated adequately from formulation characteristics alone because surface type, microbial characteristics, application conditions, and validation methodology influence observed outcomes. The framework therefore provides a systematic basis for comparing cetrimide, Dettol, and Lizol under controlled pharmaceutical-surface conditions. Its principal contribution is methodological: it establishes a structured approach for generating comparable evidence while minimizing interpretation errors associated with inadequate controls or inconsistent recovery procedures. The proposed model can support disinfectant selection, environmental monitoring strategies, sanitation validation, and contamination-control decision-making in pharmaceutical manufacturing environments.

KEYWORDS: Surface Challenge Test, Disinfectant Efficacy, Cetrimide, Dettol, Lizol, Pharmaceutical Surfaces, Epoxy-Coated Surfaces, Microbial Contamination, Disinfection Validation, Environmental Control.

1. Introduction

Microbial contamination control represents a critical operational requirement in pharmaceutical manufacturing because microorganisms introduced or retained on production surfaces can compromise environmental quality and potentially affect product safety. Non-porous surfaces such as epoxy-coated floors, walls, workstations, equipment exteriors, and processing-area structures are therefore important targets for validated cleaning and disinfection procedures. The effectiveness of a disinfectant, however, should not be inferred simply from its stated formulation or general antimicrobial reputation. It must be demonstrated under defined conditions using an appropriate test methodology.

Surface challenge testing provides a particularly relevant approach because it evaluates disinfectant performance directly on a defined surface following deliberate microbial contamination. This approach differs conceptually from suspension-based antimicrobial testing, where microorganisms and disinfectants interact under comparatively controlled liquid conditions. The physical characteristics of a surface can influence microbial recovery, distribution, drying, and subsequent disinfectant interaction. Consequently, validation performed on a representative pharmaceutical surface can provide more operationally meaningful evidence than an assessment conducted exclusively in suspension.

The importance of methodological control is demonstrated in the literature on disinfectant validation.

Memon et al. described disinfectant-product validation using a use-dilution approach aligned with USP 1072 principles, highlighting the need for structured validation rather than relying on generalized antimicrobial claims (Memon et al., 2024). Similarly, Joshi et al. specifically examined disinfectant efficacy on non-porous surfaces through a surface challenge test, providing a direct methodological basis for evaluating disinfectants under surface-associated conditions (Joshi et al., 2020).

Stored disinfectant systems may also demonstrate variable performance depending on their characteristics and application conditions. Ferrer et al. evaluated stored electrolyzed seawater for disinfection of Pseudomonas aeruginosa, illustrating the relevance of assessing antimicrobial performance through an applied disinfection model rather than assuming efficacy from the identity of a disinfecting agent alone (Ferrer et al., 2020).

The present study consequently proposes a comparative framework for evaluating cetrimide, Dettol, and Lizol against six microbial species on epoxy-coated pharmaceutical surfaces. The objective is not merely to identify which formulation exhibits greater antimicrobial activity, but to establish a reproducible analytical structure through which relative performance can be determined. The framework incorporates microbial challenge preparation, surface inoculation, disinfectant application, defined contact periods, neutralization, recovery, enumeration, and statistical comparison.

The research is significant because pharmaceutical sanitation programs require evidence that a selected disinfectant is effective under conditions approximating its intended application. A disinfectant that performs adequately under one set of laboratory conditions may produce different results when applied to a dried microbial population on a production surface. The framework therefore emphasizes the interaction between disinfectant, microorganism, surface, exposure condition, and recovery methodology.

The principal objectives are to establish a surface challenge-based methodology for comparative disinfectant assessment; define an analytical model for evaluating microbial reduction; compare the expected performance profiles of the three disinfectant systems across six microbial species; and identify methodological factors that should be controlled when translating laboratory findings into pharmaceutical environmental-disinfection practices.

2. Literature Review

2.1 Disinfectant efficacy as a validation problem

Disinfectant efficacy testing is fundamentally a validation problem because the objective is to establish reproducible evidence that a disinfectant can achieve an intended microbial-control outcome under specified conditions. Memon et al. (2024) demonstrated this principle through the use-dilution assessment of disinfectant products under USP 1072-based validation considerations. Their work supports the broader proposition that disinfectant selection should be connected to documented efficacy rather than informal assumptions regarding product performance.

Willison-Parry et al. further emphasized the importance of understanding expectations when designing disinfectant-efficacy studies and highlighted the value of efficient study designs capable of incorporating information across multiple sites (Willison-Parry et al., 2020). This perspective is particularly relevant to pharmaceutical environments, where sanitation programs can involve multiple rooms, surfaces, operators, and contamination scenarios.

The methodological implication is that efficacy should be expressed as an experimentally demonstrated property under defined conditions. A comparative assessment therefore requires equivalent microbial challenge levels, equivalent surface conditions, consistent disinfectant exposure, and validated recovery procedures.

2.2 Surface-associated microbial challenge

Surface challenge testing provides a closer representation of many practical disinfection scenarios than tests performed exclusively in liquid media. Joshi et al. (2020) specifically investigated disinfectant efficacy on non-porous surfaces using a surface challenge test. This study establishes a direct methodological precedent for examining antimicrobial performance where microorganisms are physically associated with a solid surface.

The distinction between surface and suspension testing is important. On a surface, microorganisms can undergo drying and may become distributed unevenly. The subsequent disinfectant interaction can therefore differ from the interaction observed in a homogeneous liquid system. Recovery after treatment can also introduce variability because the microorganism must be detached from the surface before enumeration.

Epoxy-coated surfaces are particularly appropriate for pharmaceutical environmental studies because they represent non-porous, cleanable materials commonly associated with controlled manufacturing areas. The use of a consistent epoxy-coated test substrate consequently allows disinfectants to be compared under identical physical conditions.

2.3 Relevance of microbial-specific performance

Disinfectant efficacy should not be treated as microorganism-independent. Xi et al. (2024), in their examination of chlorine-based disinfectants for controlling Legionella within premise plumbing systems, demonstrate the importance of evaluating disinfection against the specific microbial target and environmental context. The effectiveness of a disinfectant against one organism cannot automatically be extrapolated to another.

Ferrer et al. (2020) similarly focused specifically on Pseudomonas aeruginosa when evaluating stored electrolyzed seawater. This organism-specific approach supports the use of defined microbial challenges when evaluating disinfectant performance. A six-species challenge model consequently provides broader information than a single-organism assessment because it enables identification of differential susceptibility.

2.4 Cleanroom and pharmaceutical-environment considerations

Sandle (2012) provides a broader cleanroom-oriented perspective on cleaning and disinfection, emphasizing that environmental disinfection should be considered as part of an integrated contamination-control system. The implication is that disinfectant efficacy cannot be isolated from surface condition, cleaning procedures, application practices, and environmental controls.

Willison-Parry et al. (2020) likewise indicate that disinfectant studies must be designed around explicit expectations and appropriate evidence-generation strategies. This supports a framework in which the selected disinfectant is assessed not merely according to whether it produces microbial reduction, but according to whether the reduction is reproducible and sufficient for the intended application.

2.5 Research gap

The supplied literature provides important evidence concerning disinfectant validation, non-porous surface testing, cleanroom disinfection, microbial-specific efficacy, and applied environmental control. However, the references do not provide a direct comparative assessment of cetrimide, Dettol, and Lizol against six microbial species specifically on epoxy-coated pharmaceutical surfaces.

The principal research gap is therefore comparative integration. Existing evidence supports the methodological components independently, whereas the proposed framework combines these components into one structured model. The framework is positioned between conventional product validation and operational pharmaceutical environmental control by examining disinfectant performance directly on a representative non-porous surface.

3. Methodology

3.1 Research design

The study adopts a controlled comparative experimental framework based on the surface challenge methodology. Three disinfectant treatments—cetrimide, Dettol, and Lizol—constitute the principal experimental groups, while six selected microbial species represent the biological challenge panel. Epoxy-coated coupons serve as standardized non-porous test surfaces.

The methodological architecture consists of six sequential stages:

Microbial preparation → Surface inoculation → Drying/conditioning → Disinfectant application → Neutralization and recovery → Microbial enumeration and comparative analysis.

The central methodological principle is that all disinfectants should be assessed under equivalent conditions. Variation in surface size, microbial loading, contact time, environmental conditions, or recovery procedure could introduce confounding effects and weaken comparative validity.

3.2 Test-surface preparation

Epoxy-coated surface coupons should be prepared with uniform dimensions and verified for surface integrity before use. Each coupon should undergo an appropriate cleaning and sterilization procedure before microbial challenge. The purpose is to establish a consistent initial condition and eliminate background contamination.

Surface uniformity is theoretically important because differences in texture, defects, porosity, or residual contamination can influence microbial attachment and recovery. Since the study is designed to compare disinfectants, rather than different materials, the epoxy substrate should remain constant across all experimental groups.

3.3 Microbial challenge model

Six microbial species should be selected to represent a sufficiently diverse contamination panel relevant to pharmaceutical environmental monitoring. Each species should be prepared independently, standardized to a predetermined challenge concentration, and applied to separate test coupons.

The microbial inoculum should be sufficiently controlled to permit calculation of microbial reduction following treatment. Baseline recovery controls are essential because the number of microorganisms

deposited onto a surface is not necessarily equivalent to the number subsequently recovered.

A representative experimental structure can be expressed as:

Initial challenge → untreated control recovery → disinfectant treatment → neutralization → treated recovery.

The untreated control establishes the recoverable microbial population against which disinfectant-treated samples are compared.

3.4 Surface inoculation and conditioning

A measured microbial suspension should be distributed over the defined surface area of each coupon. The inoculated coupons should then undergo a standardized conditioning period that allows the microbial population to establish a surface-associated state.

This conditioning stage is particularly important because surface-associated microorganisms may respond differently to disinfectants than microorganisms maintained in suspension. Joshi et al. (2020) provide methodological support for evaluating disinfectants specifically on non-porous surfaces, making the surface challenge approach appropriate for this research design.

3.5 Disinfectant application

Cetrimide, Dettol, and Lizol should be prepared and applied according to their defined test concentrations and intended-use conditions. The same application volume, surface coverage, and contact time should be maintained for all three treatment groups.

The purpose of standardization is to ensure that observed differences can reasonably be attributed to disinfectant-related effects rather than inconsistent application. If multiple contact times are investigated, contact time should be treated as an independent experimental factor.

A factorial conceptual model can therefore be represented as:

Disinfectant × Microbial Species × Contact Time.

This structure enables the investigation of both overall disinfectant performance and disinfectant-by-microorganism interactions.

3.6 Neutralization and recovery

Following the predetermined contact period, the disinfectant must be neutralized to prevent continued antimicrobial activity from influencing microbial recovery. The recovery method should be validated to demonstrate that the neutralizer effectively stops disinfectant action without adversely affecting microbial viability.

The importance of this step follows the broader validation principles described by Memon et al. (2024). An inadequately controlled neutralization procedure could produce artificially high apparent efficacy because microorganisms may continue to be exposed to the disinfectant after the nominal contact period.

Microorganisms recovered from treated and control surfaces should subsequently be quantified using an appropriate enumeration method. Results should be expressed as recoverable microbial counts and converted into microbial-reduction measures.

3.7 Efficacy calculation

The principal quantitative measure should be logarithmic microbial reduction:

$$\text{Log Reduction} = \log_{10}(N_0) - \log_{10}(N_t)$$

where:

- N_0 = recoverable microbial count from the untreated control;
- N_t = recoverable microbial count following disinfectant treatment.

This measure provides a standardized basis for comparing disinfectants across microbial species.

Percentage reduction can additionally be calculated as:

$$\text{Percentage Reduction} = [(N_0 - N_t) / N_0] \times 100$$

Log reduction should remain the principal comparative metric because percentage reduction can become difficult to interpret when baseline counts differ substantially between organisms.

3.8 Experimental controls

The framework should include untreated positive controls, recovery controls, neutralizer controls, and sterility controls. These controls are necessary to distinguish true antimicrobial activity from methodological artifacts.

A positive control verifies that microorganisms remain recoverable in the absence of disinfectant. A neutralizer control verifies that the neutralizing system does not itself suppress microbial recovery. A sterility control establishes that the test system is free from unintended contamination.

The inclusion of these controls is consistent with the validation-oriented principles emphasized by Memon et al. (2024) and Willison-Parry et al. (2020).

3.9 Replication and statistical analysis

Each disinfectant-microorganism combination should be tested using independent replicates. Replication improves confidence in the estimated mean microbial reduction and allows experimental variability to be quantified.

The analysis should first examine descriptive statistics, including mean log reduction, standard deviation, and coefficient of variation. Where sufficient replicated observations are available, analysis of variance can be used to determine whether disinfectant type, microbial species, contact time, or their interactions significantly influence microbial reduction.

A conceptual statistical model can be expressed as:

$$Y = \mu + D + M + T + D \times M + D \times T + M \times T + \varepsilon$$

where Y represents observed log reduction, D represents disinfectant type, M represents microbial species, T represents contact time, and ε represents experimental error.

3.10 Comparative decision model

A disinfectant should not be selected solely because it produces the highest reduction against one organism. Instead, performance should be assessed across the complete microbial panel.

The proposed decision model therefore considers:

1. overall mean log reduction;
2. minimum observed log reduction;
3. consistency across microbial species;
4. variability between replicates;
5. influence of contact time;
6. reproducibility of results; and
7. suitability for the intended pharmaceutical surface.

This approach prevents a disinfectant with highly variable performance from being considered superior merely because of strong activity against one susceptible organism.

4. Results / Findings

The proposed framework generates several analytically important findings even in the absence of a supplied numerical experimental dataset. First, disinfectant efficacy should be interpreted as a multidimensional outcome rather than a single universal antimicrobial value. The experimental structure makes it possible to determine whether differences are attributable primarily to disinfectant formulation, microbial susceptibility, contact time, or interactions among these variables.

The first expected analytical output is a disinfectant-specific profile consisting of the mean log reduction achieved across the six microbial species. Such a profile would allow cetrimide, Dettol, and Lizol to be ranked according to overall performance. However, the framework deliberately avoids interpreting overall mean reduction as the sole decision criterion. A disinfectant could achieve a high average reduction while displaying inadequate activity against one particular organism. Consequently, minimum species-specific performance is also required.

The second finding concerns microbial heterogeneity. The six-organism challenge design is expected to reveal differences in susceptibility among microbial species. This is consistent with the organism-specific approach demonstrated by Ferrer et al. (2020), whose investigation focused on Pseudomonas aeruginosa, and with Xi et al. (2024), who evaluated chlorine-based disinfection specifically in relation to Legionella. These studies reinforce the methodological principle that antimicrobial performance must be interpreted in relation to the target microorganism.

The third analytical output concerns the effect of surface-associated conditions. Because the microorganisms are challenged on epoxy-coated surfaces rather than exclusively in suspension, the results would provide evidence more directly related to surface sanitation. Joshi et al. (2020) similarly positioned non-porous surface testing as an important basis for disinfectant-efficacy evaluation. The framework therefore allows the research to identify whether apparent disinfectant effectiveness remains consistent after microorganisms undergo surface conditioning.

A fourth finding concerns experimental reliability. Large variation between replicates would indicate that disinfectant performance is less reproducible and would warrant investigation of inoculum distribution, drying conditions, application consistency, recovery efficiency, or neutralization. Conversely, low variability combined with strong microbial reduction would strengthen confidence in the observed performance.

The framework also identifies the importance of contact time. If increasing exposure produces progressively greater microbial reduction, the results would support a contact-time-dependent interpretation of efficacy. If performance reaches a plateau, the data could indicate that extending contact time beyond a certain point provides limited additional benefit.

Finally, the framework produces a comparative evidence matrix rather than an unsupported product ranking. This distinction is important because no numerical experimental results were supplied for the

present manuscript. Accordingly, it would be scientifically inappropriate to claim that cetrimide, Dettol, or Lizol is empirically superior. The appropriate finding at this stage is that the proposed methodology establishes the conditions required to determine comparative superiority experimentally. Such methodological caution is consistent with the validation-oriented perspective of Memon et al. (2024) and the structured study-design emphasis of Willison-Parry et al. (2020).

5. Discussion

The proposed framework positions surface challenge testing as a bridge between laboratory antimicrobial assessment and pharmaceutical environmental-disinfection practice. Its principal theoretical contribution is the treatment of disinfectant efficacy as an interaction among chemical treatment, microorganism, surface, exposure conditions, and recovery methodology. This perspective is more appropriate than interpreting efficacy as an intrinsic and context-independent property of a disinfectant.

The use of epoxy-coated surfaces is particularly significant because it establishes a controlled non-porous environment while maintaining relevance to pharmaceutical facilities. A standardized surface minimizes material-related variation and permits the three disinfectants to be compared under equivalent physical conditions. Joshi et al. (2020) provide direct support for the methodological relevance of non-porous surface challenge testing.

The framework also addresses an important limitation of single-organism testing. A disinfectant may demonstrate substantial activity against one organism but comparatively weaker performance against another. Ferrer et al. (2020) illustrate the value of organism-specific evaluation through their focus on Pseudomonas aeruginosa. Likewise, Xi et al. (2024) demonstrate that disinfectant assessment must be interpreted within the biological and environmental context of the target organism. The six-species design consequently improves the breadth of the proposed evaluation.

From a practical perspective, the framework supports risk-based disinfectant selection. Pharmaceutical manufacturers could use species-specific log-reduction profiles to determine whether a disinfectant provides sufficiently consistent performance across their environmental contamination targets. The framework may also support rotation-program decisions, although such decisions should not be based exclusively on comparative laboratory efficacy.

Another important implication concerns validation quality. A study that does not adequately neutralize disinfectant activity can overestimate efficacy. Similarly, insufficient microbial recovery can produce apparently strong reductions that partly reflect recovery failure rather than true antimicrobial activity. The inclusion of neutralizer controls and recovery controls therefore represents a central methodological safeguard. This emphasis aligns with the broader validation principles discussed by Memon et al. (2024).

The framework is also consistent with the broader cleanroom perspective presented by Sandle (2012). Disinfection should be considered as one component of an integrated contamination-control system rather than an isolated intervention. Surface cleaning, environmental monitoring, operator practices, disinfectant preparation, contact time, and application consistency can all influence practical performance.

Willison-Parry et al. (2020) further support the need for carefully designed disinfectant studies with clearly defined expectations. Their emphasis on efficient study design has implications for the proposed framework because large pharmaceutical facilities may require evidence across multiple surfaces or locations. A standardized experimental structure could therefore facilitate comparison across sites while retaining a common methodological baseline.

Several limitations must nevertheless be recognized. First, the framework does not establish actual comparative efficacy without experimental data. Second, results obtained on epoxy-coated coupons may not automatically generalize to stainless steel, plastics, rubber, glass, or damaged surfaces. Third, laboratory challenge conditions cannot reproduce every environmental variable encountered in manufacturing facilities. Fourth, microbial reduction does not necessarily provide a complete representation of long-term environmental contamination control.

A further limitation is that the present analysis relies exclusively on the supplied references. These sources support the methodological rationale but do not provide direct comparative experimental evidence for all three named disinfectants against the six proposed microbial species on epoxy-coated pharmaceutical surfaces. Therefore, the framework should be regarded as a rigorous experimental model requiring empirical validation rather than as evidence of an already established product ranking.

Overall, the principal contribution is methodological robustness. By combining standardized surface challenge, microbial-specific evaluation, neutralization, recovery, quantitative log-reduction analysis, and reproducibility assessment, the framework provides a defensible basis for comparative disinfectant evaluation.

6. Conclusion

This study developed a surface challenge-based assessment framework for evaluating the comparative disinfectant efficacy of cetrimide, Dettol, and Lizol against six microbial species on epoxy-coated pharmaceutical surfaces. The framework integrates microbial challenge preparation, standardized surface inoculation, conditioning, disinfectant exposure, neutralization, recovery, enumeration, and statistical analysis into a unified experimental architecture.

The literature supports the methodological need for structured disinfectant validation, non-porous surface testing, organism-specific evaluation, and cleanroom-oriented contamination control. Ferrer et al. (2020), Joshi et al. (2020), Memon et al. (2024), Sandle (2012), Willison-Parry et al. (2020), and Xi et al. (2024) collectively provide the conceptual foundation for the proposed approach.

The framework's principal advantage is its ability to distinguish overall disinfectant performance from microorganism-specific performance. Rather than selecting a disinfectant based on a single antimicrobial outcome, the model evaluates mean reduction, minimum performance, reproducibility, contact-time effects, and disinfectant-microorganism interactions.

Importantly, no numerical experimental dataset was provided; therefore, definitive claims concerning the superiority of cetrimide, Dettol, or Lizol cannot scientifically be made from the supplied evidence alone. The present contribution is consequently a research-ready methodology for generating such evidence under controlled conditions.

Future empirical work should apply the framework using replicated experiments, validated neutralization and recovery procedures, defined contact times, and statistically appropriate comparisons. Additional studies could extend the model to other pharmaceutical surfaces, environmental conditions, microbial states, and operational sanitation scenarios. Such extensions would strengthen the connection between laboratory disinfectant validation and practical contamination-control programs in pharmaceutical manufacturing environments.

References

1. Ferrer MJC, Lim RKL, Cue RDA, Beltran AB, Damalerio RG, Uba MO. Performance of Stored Electrolyzed Seawater for Disinfection of Pseudomonas aeruginosa. IOP Conference Series: Materials Science and Engineering. 2020;778(1).
2. Joshi SD, Memon DI, Shaikh DT, Khan I, Kumari SSK, Dagha R. Disinfectant Efficacy Testing of Imago & Getter Disinfectant on non-porous surfaces using Surface Challenge Test. Int J Scientific Research & Engineering Trends. 2020;6(1).
3. Memon I, Memon NI, Samanta S, Mali R. Study on Disinfectant Products Validation Assessment by Use Dilution as per USP 1072 Standard Method. International Journal of Current Microbiology and Applied Sciences. 2024;13(10):206-12.
4. Sandle T. The CDC Handbook-a Guide to Cleaning and Disinfecting Clean Rooms. Grosvenor House Publishing; 2012.
5. Willison-Parry D, Yang S, Forng RY, Cirbo T, McMeel A, Kiler B, et al. Disinfectant Efficacy: Understanding the Expectations and How to Design Effective Studies That Include Leveraging Multi-Site Data to Drive an Efficient Program. PDA J Pharm Sci Technol. 2020;74(2):249-63.
6. Xi H, Ross KE, Hinds J, Molino PJ, Whiley H. Efficacy of chlorine-based disinfectants to control Legionella within premise plumbing systems. Water Res. 2024;259:121794.