Revista de Enfermagem UFJF

https://periodicos.ufjf.br/index.php/enfermagem

ORIGINAL ARTICLE

Respiratory care settings: correlation between surface cleaning and disinfection monitoring methods

Ambientes de cuidados respiratórios: correlação de métodos de monitoramento da limpeza e desinfecção

Entornos de atención respiratoria: correlación de métodos de monitoreo de limpieza y desinfección

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Information of the Article:
Received on: 09/28/2025.
Accepted on: 11/13/2025.

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ABSTRACT

Objective: To investigate the correlation between surface cleaning and disinfection methods and determine the adenosine triphosphate (ATP) cutoff for effective monitoring. **Methodology:** This correlational study was carried out in a Respiratory Syndrome Unit in Brazil's Central-West region. High-touch surfaces were systematically monitored before and after cleaning using visual inspection, bioluminescence assays, and colony-forming unit (CFU) quantification. Method agreement and diagnostic performance were evaluated using Spearman's correlation and *Receiver Operating Characteristic* (ROC) curve analyses. **Results:** A total of 384 surfaces underwent assessment. A positive association was observed between adenosine triphosphate (ATP) levels and microbial counts on mattress surfaces prior to cleaning (Spearman's *rho* = 0.786; p = 0.021). Bioluminescence showed higher sensitivity (88.9%) but lower specificity (39.1%) when compared with microbial counts. A surface was considered acceptable when adenosine triphosphate (ATP) levels were ≤ 67 relative light units (RLU). **Conclusion:** Variability in method correlations suggests that a combined approach is essential for accurately evaluating environmental cleaning in healthcare settings.

DESCRIPTORS:
Disinfection; Environmental Monitoring; Adenosine Triphosphate; Equipment Contamination; Infection Control.

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RESUMO
Objetivo: Analisar a correlação entre os métodos de limpeza e desinfecção de superfícies e determinar o valor de corte de adenosina trifosfato para o monitoramento eficaz. **Metodologia**: Estudo correlacional conduzido em uma Unidade de Síndrome Respiratória no Centro-Oeste do Brasil. Superfícies de alto contato foram monitoradas antes e após a limpeza pela inspeção visual, bioluminescência e contagens de unidades formadoras de colônias. Análises de correlação de Spearman e curva *Receiver Operating Characteristic* avaliaram a concordância e o desempenho diagnóstico. **Resultados**: Foram avaliadas 384 superfícies. Uma correlação positiva entre as contagens microbianas e adenosina trifosfato foi observada para o colchão antes da limpeza (*rho* de Spearman = 0,786; p = 0,021). A bioluminescência apresentou maior sensibilidade (88,9%) e menor especificidade (39,1%) quando comparada às contagens microbianas. O valor de corte de adenosina trifosfato para aprovação da superfície foi ≤ 67 unidades relativas de luz. **Conclusão**: Destaca-se a variabilidade na correlação entre os métodos de monitoramento, recomendando-se o uso complementar de métodos para avaliação robusta da limpeza ambiental em ambientes de saúde.

DESCRITORES:
Desinfecção; Monitoramento Ambiental; Trifosfato de Adenosina; Contaminação de Equipamentos; Controle de Infecções.

RESUMEN
Objetivo: Analizar la correlación entre los métodos de limpieza y desinfección de superficies y determinar el valor de corte del trifosfato de adenosina para un control eficaz. **Metodología:** Estudio correlacional realizado en una Unidad de Síndrome Respiratorio en la región Centro-Oeste de Brasil. Las superficies de alto contacto se monitorizaron antes y después de la limpieza mediante inspección visual, bioluminiscencia y recuentos de unidades formadoras de colonias. Los análisis de correlación de Spearman y la curva característica operativa del receptor evaluaron la concordancia y el rendimiento diagnóstico. **Resultados:** Se evaluaron 384 superficies. Se observó una correlación positiva entre los recuentos microbianos y el trifosfato de adenosina para el colchón antes de la limpieza (rho de Spearman = 0,786; p = 0,021). La bioluminiscencia presentó unmayor sensibilidad (88,9 %) y una menor especificidad (39,1 %) en comparación con los recuentos microbianos. El valor de corte del trifosfato de adenosina para la aprobación de la superficie fue ≤ 67 unidades relativas de luz. **Conclusión:** Cabe destacar la variabilidad en la correlación entre los métodos de monitorización, por lo que se recomienda el uso complementario de métodos para una evaluación sólida de la limpieza ambiental en entornos sanitarios.

DESCRIPTORES:
Desinfección; Monitoreo Ambiental; Adenosina Trifosfato; Contaminación de Equipos; Control de Infecciones.

INTRODUCTION

Contact surfaces in healthcare settings represent key poin for patient safety and quality of care, posing a continuous challenge to public health. Contaminated surfaces serve as microbiological reservoirs with epidemiological significance and often act as sources of healthcare-associated infections (HAIs)[1]. Their impacts are well documented in the literature, including high morbidity and mortality, extended hospital stays, financial costs, productivity loss, reduced quality of life for affected patients, and antimicrobial resistance emergence. These findings further highlight the need for effective interventions to reinforce prevention and control measures[2-3].

Environmental control through Surface Cleaning and Disinfection (SCD) practices has become increasingly important due to its demonstrated effectiveness in reducing pathogen transmission and cross-infection risk among patients, particularly during the COVID-19 pandemic, when contact surfaces were identified as a primary route for SARS-CoV-2 spread[3-5].

Although surfaces play an essential role in hospital infection control programs, environmental cleaning and disinfection practices are often neglected. Obstacles to successful implementation involve prioritizing hand hygiene over other measures, insufficient professional knowledge, and constraints in material, operational, financial, and human resources[6].

Visual inspection involves directly observing surfaces to detect visible debris, including dust, organic residues, and stains[7]. Although simple and inexpensive, this method shows significant limitations in detecting microbial contamination and organic matter[1]. Nevertheless, this method may help monitor adherence to cleaning and disinfection protocols, while other evaluation approaches should be considered to verify process effectiveness.

The Adenosine Triphosphate (ATP) bioluminescence monitoring method provides a rapid, straightforward, and quantitative approach to assess organic matter on contact surfaces[8]. Implementing ATP-based monitoring is challenging, as no standardized benchmarks exist, and disinfectant residues on surfaces can compromise the relationship between ATP readings and bacterial counts[9].

The Colony-Forming Unit (CFU) counting method quantifies viable microorganisms per square centimeter on contact surfaces. The technique involves incubating samples in an appropriate culture medium to support microbial growth. Although highly accurate, this method involves substantial operational costs, requires specialized laboratory equipment, and entails lengthy processing times[3], which may restrict its use in healthcare settings that demand rapid feedback.

While acknowledged as crucial for patient safety, these methods exhibit ongoing gaps regarding standardization, integration, cutoff thresholds, and metrics for accuracy, safety, and effectiveness. Consequently, performing comparative analyses to assess how well environmental monitoring and control methods align is essential, particularly in respiratory care units where patient vulnerability and the risk of healthcare-associated infections (HAIs) and cross-contamination are elevated.

Considering benefits and limitations in Surface Cleaning and Disinfection (SCD) assessment and monitoring methods, along with gaps revealed during the COVID-19 pandemic, conducting studies that correlate environmental monitoring results, establish appropriate ATP cutoff thresholds, and identify optimal combinations of methods is crucial. In this context, the present study was designed to address the following knowledge gaps: Is there a correlation between SCD monitoring methods in a Respiratory Syndrome Unit? Which ATP level indicates that Surface Cleaning and Disinfection (SCD) achieved its intended effectiveness?

OBJECTIVE

To examine the correlation between surface cleaning and disinfection monitoring methods in a respiratory syndrome care unit during the COVID-19 pandemic, and to determine the Adenosine Triphosphate (ATP) cutoff point.

METHODOLOGY

Design

This correlational, cross-sectional, analytical, and comparative study was conducted in accordance with the *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) Checklist.

Study setting and duration

The study was conducted between April and June 2022 in a Severe Acute Respiratory Syndrome (SARS) treatment unit located in the Central-West region of Brazil, structured to provide care for suspected and confirmed COVID-19 cases. The unit serves as a referral center for a population of 132,152 residents. It operates within the Brazilian Unified Health System (Portuguese acronym: SUS), offering continuous 24-hour services. Staffed by a multidisciplinary team, the unit provides five beds specifically for monitoring patients with influenza-like symptoms.

Sample

Surfaces were deliberately selected through a non-probabilistic process, considering high-touch areas and surface composition, which influence microbial adherence and ATP assessment outcomes[10-11]. The following items were chosen for analysis: countertop, mattress, patients' bathroom doorknob, and patients' chair.

Study protocol

Samples were collected by trained researchers twice a week over a two-month period, in two phases: before surface cleaning and 10 minutes after surface cleaning. Sample collection intervals were designed to allow local conditions to stabilize and to keep assessment timing consistent. A dedicated data collection form was used in this study, capturing variables such as surface type and cleaning and disinfection indicators, which were evaluated through visual inspection, Adenosine Triphosphate (ATP) bioluminescence, and Colony-Forming Unit (CFU) methods.

A total of eight daily samples were collected, four before and four after the cleaning process, totaling 16 samples per week, 64 per month, and 128 per evaluation method. This sampling method ensures representativeness and enables reliable analysis for microbial load across different assessment points.

For visual inspection, surfaces were deemed non-compliant if any of the following were present: dirt, stains, dust, scratches, deterioration, splinters, cracks, fingerprints, or moisture[12-13]. ATP quantification was performed via bioluminescence using a 3M™ *Clean-Trace ATP System* luminometer, in accordance with the manufacturer's guidelines. Light intensity readings were expressed in Relative Light Units (RLU). For sample collection, a system-specific *swab* was applied to a 100 cm² area using zigzag movements in both horizontal and diagonal directions at a 30° angle. Immediately afterward, the *swab* was placed into a cuvette containing the luciferin-luciferase enzymatic complex, allowing detection of residual organic matter on the sampled surfaces[14].

To assess total aerobic microorganisms, *Rodac Plate®* contact plates containing Tryptone Soy Agar (TSA) were used over a 24 cm² area. Culture medium was added to each plate in volumes ranging from 15 to 20 mL, with 16 mL as the preferred amount. Plates were pressed against sampled surfaces for 10 seconds and subsequently incubated at 37°C for 48 hours. Microorganism counts were expressed in CFU[12-13].

Analysis of the results and statistics

Data analysis was based on the following statistical tests: Spearman's correlation to identify potential relationships between ATP levels and microbial counts on each surface before and after cleaning and disinfection procedures. The *Receiver Operating Characteristic* (ROC) curve was used to evaluate ATP bioluminescence testing for cleaning and disinfection quality, with microbiological assessment serving as the reference and visual inspection as the gold standard. Analyses were performed using a 5% significance level ($p < 0.05$), with calculations carried out in *Minitab* 17 (*Minitab Inc*.) and *MedCalc* 16.8 (*MedCalc*®) software.

Ethical aspects

This study complied with national ethical guidelines and was approved by the Research Ethics Committee for Human Subjects at the *Universidade Federal de Mato Grosso do Sul* under approval No. 4.317.394.

RESULTS

A total of 384 assessments were carried out in this study, encompassing visual inspection, bioluminescence-based ATP quantification, and Colony-Forming Unit (CFU) counting. Table 1 presents Spearman's correlation coefficients and their associated p-values for the relationships between the applied methods.

Table 1. Spearman's correlation coefficient between Adenosine Triphosphate (ATP) levels and Colony-Forming Unit (CFU) counts for surface samples, 2022.

Stage	Surfaces	Spearman's Coefficient	p-value
I – Before	Countertop	-0.659	0.076
	Mattress	0.786	0.021[1]
	Patients' bathroom doorknob	-0.405	0.320
	Patients' chair	-0.024	0.954
II - After	Countertop	-0.286	0.493
	Mattress	0.333	0.420
	Patients' bathroom doorknob	-0.084	0.844
	Patients' chair	0.190	0.651

[1]Significant results were defined as p-values<0.05 and correlation coefficients greater than 0.700.

The results show specific, strong positive correlations between bioluminescence-based Adenosine Triphosphate quantification and microbial counts for the mattress surface during Stage I ($p = 0.021$). The results suggest a positive correlation between ATP and CFU, where higher ATP levels align with higher CFU counts. No further significant correlations were observed across the assessed surfaces.

Table 2 summarizes ROC curve results for ATP and CFU quantification methods, compared to visual inspection as the gold standard (acceptable/rejected). For ATP bioluminescence, sensitivity was 88.9%, specificity 39.1%, positive predictive value 59.6%, and negative predictive value 77.8%. CFU analysis indicated 77.8% sensitivity, 56.5% specificity, 64.1% positive predictive value, and 71.8% negative predictive value.

Specificity values suggest that CFU counting is more effective than ATP quantification at identifying soiled surfaces. When the objective is to detect clean surfaces, ATP quantification is more suitable due to its higher sensitivity. Additionally, the ATP cutoff point in this study was ≤ 67 RLU, indicating surfaces with values at or below this threshold may be considered acceptable. The cutoff point for microbial counting was set at ≤ 45 CFU/cm².

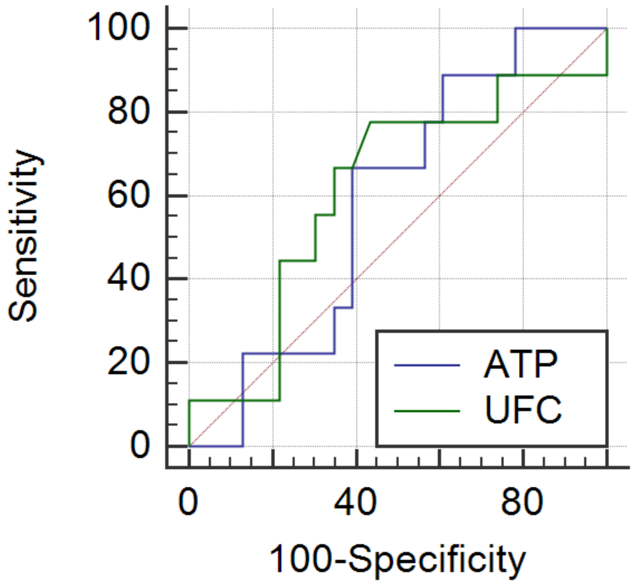
Table 2. ROC curve parameters for Adenosine Triphosphate (ATP) quantification and Colony Forming Unit (CFU) counting methods, compared with visual inspection as the gold standard, 2022.

ROC parameters	Methods	
	ATP quantification	Microbial counting
Sensitivity	88.9%	77.8%
Specificity	39.1%	56.5%
PPV	59.3	64.1
NPV	77.8	71.8
Cutoff point	<=67	<=45
p-value	0.421	0.331

ATP = Adenosine Triphosphate; PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The ROC curve also shows a better balance between positive and negative predictive values. This balance suggests a stronger correlation between the microbial counting method and the visual inspection gold standard. Figure 1 illustrates ROC curves for ATP quantification and microbial counting relative to the visual inspection as the gold standard.

Figure 1. ROC curve for Adenosine Triphosphate (ATP) quantification and Colony Forming Unit (CFU) counting methods, compared with visual inspection as the gold standard, 2022.



DISCUSSION

This study aimed to correlate different monitoring methods for Surface Cleaning and Disinfection (SCD) in a respiratory syndrome unit during the pandemic and to establish the Adenosine Triphosphate (ATP) cutoff point as an indicator of cleaning effectiveness. The evidence showed a strong positive correlation ($p = 0.021$) between ATP quantification and CFU counts only for the mattress surface prior to cleaning. This finding indicates that, although a specific association exists, it is not possible to assume that ATP reduction resulting from effective hygiene protocols consistently translates into a parallel decrease in microbial load across all evaluated surfaces. Many mattresses in the unit showed cracks, stains, and tears, likely contributing to higher organic matter and microbial buildup, influencing the correlation observed.

This finding is consistent with previous results reported in diverse healthcare settings. A study conducted with Family Health Strategy teams also found no significant correlation between ATP values and CFU counts, reinforcing that these methods do not apply uniformly to all surfaces[11]. Similarly, an investigation in an urgent care unit revealed no association between CFU and RLU, confirming that each technique captures different aspects related to environmental cleaning(13). Therefore, using complementary methods is essential to achieve a more comprehensive SCD quality assessment, rather than relying on a single technique alone(15).

There is no consensus on a single ideal method to monitor hospital cleaning and disinfection, a topic widely addressed in the literature(16). Method selection should be guided by multiple criteria, including the ability to detect resistant microorganisms, rapid feedback to personnel, available financial resources, and institutional infrastructure(17). In this context, integrating ATP, CFU, and visual inspection emerges as the most effective strategy, especially in critical environments such as urgent care units and wards for patients with severe respiratory conditions(13).

The ROC curve analysis conducted in this study offered further valuable insights. The ATP quantification method demonstrated higher sensitivity (88.9%), proving more effective for detecting surfaces considered clean, a critical factor for high-risk environments and infection prevention. In contrast, the CFU counting method showed higher specificity (56.5%), reflecting greater reliability in identifying truly contaminated surfaces. These findings suggest that, from a practical standpoint, ATP can serve as a rapid screening tool, while CFU should be applied when microbiological confirmation is required(13).

Additionally, positive and negative predictive values emphasize how the methods complement each other. The microbial counting method showed a higher positive predictive value, indicating an increased likelihood of correctly confirming contamination when it occurs. In contrast, the ATP method showed a higher negative predictive value, providing greater accuracy in identifying surfaces that are genuinely clean. Therefore, method selection should align with each institution's specific goals, whether emphasizing rapid screening and immediate feedback or microbiological confirmation, to ensure accuracy and effectiveness in the cleaning process(12–13,18).

When compared to earlier research, differences in performance parameters become evident. For instance, researchers reported 78.6% ATP sensitivity and 51.9% specificity, whereas microbial counting demonstrated 85.7% sensitivity and 37.0% specificity(12). These values differ from those observed in the present study, highlighting that method applicability depends on context, surface characteristics, and the chosen methodological design; moreover, direct comparisons should be interpreted with caution.

In this study, the Adenosine Triphosphate (ATP) cutoff point was determined as ≤ 67 RLU, differing from values reported in other healthcare settings, such as 108 RLU in pediatric units and 20 RLU in emergency departments(12–13). This variability can be attributed to multiple factors, including luminometer type and brand, service characteristics, care complexity, and institutional cleaning protocols(12). Defining ATP thresholds tailored to each context ensures effective local practice while emphasizing the need for multicenter approaches to develop widely applicable standards.

ATP's high sensitivity for detecting clean surfaces, combined with CFU's higher specificity for identifying contaminated surfaces, indicates that these methods can be used complementarily and strategically. In practice, ATP monitoring can be incorporated into routine large-scale assessments, offering rapid feedback to cleaning staff, whereas microbial counting is best suited for audits, repeated-failure investigations, or high-risk areas such as intensive care units. This approach enhances process efficiency, lowers operational costs, and maintains a high standard for patient safety.

Finally, in the post-COVID-19 context, this study's findings remain highly relevant for clinical practice and hospital management. The pandemic unmistakably highlighted surfaces as reservoirs and vectors for microorganisms, emphasizing the importance of implementing more rigorous and monitored cleaning processes. Despite the relaxation of restrictions, the study highlights that relying on one method alone cannot ensure robust evaluation, underscoring the need for complementary strategies. Defining ATP cutoff points and applying ATP, CFU, and visual inspection in a coordinated, strategic manner represent key lessons from the pandemic, as they can support long-term institutional policies, enhance infection prevention programs, and foster a patient safety culture more resilient to future health crises.

Study limitations

This study has several limitations that should be considered when interpreting the results. Primarily, since the research was carried out in one hospital, the results may not be directly applicable to other healthcare environments. Service-related structural and organizational factors, including worn or cracked surfaces, may have affected the correlation observed between monitoring methods.

Secondly, data collection occurred during the COVID-19 pandemic, a period characterized by restricted access, patient isolation, and social distancing measures. These conditions may have limited sample size and hindered close monitoring of certain processes, reducing the ability to assess other hospital wards and various critical surfaces.

Additionally, the study assessed only a limited number of surfaces over a brief follow-up period. Although high-touch surfaces were prioritized as collection sites, evaluating a wider variety of surfaces over an extended period could provide a more complete assessment regarding the tested methods' effectiveness.

Finally, not assessing specific microorganisms, including multidrug-resistant pathogens with high epidemiological significance, limits the direct use of monitoring methods in healthcare-associated infection surveillance.

Contributions to Nursing Practice, Healthcare, and Public Policy

This study offers consistent contributions to clinical practice and to the development of institutional policies aimed at patient safety. The first relevant implication concerns the need to adopt complementary methods for monitoring surface cleaning and disinfection. The uneven correlation between ATP and CFU indicates that each method assesses distinct aspects of the cleaning process. Another key aspect involves establishing specific ATP cutoff points, since this approach provides an objective and contextualized parameter for monitoring hospital environments. Results from sensitivity and specificity analyses support optimized resource management, enhance continuous professional development, and reaffirm environmental cleaning as a fundamental measure to prevent healthcare-associated infections (HAIs).

CONCLUSION

This study demonstrates that hospital surface cleaning and disinfection monitoring methods yield varying results depending on surface type and setting, indicating that they are not interchangeable. Each technique offers unique benefits, yet the results highlight that relying on a single method cannot fully assess cleaning effectiveness. Therefore, a coordinated approach using visual inspection, ATP quantification, and microbiological assessment enhances cleaning reliability, supports patient safety, and underpins effective environmental control policies.

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Acknowledgments: None.

Funding: This study was supported by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (Portuguese acronym: CAPES), *Universidade Federal de Mato Grosso do Sul* (UFMS), and the *Foundation for Supporting the Development of Education, Science, and Technology in the State of Mato Grosso do Sul* (Portuguese acronym: FUNDECT).

Authors' contributions: Research concept and design: Aline Romão dos Santos and Aires Garcia dos Santos Junior. Data collection: Aline Romão dos Santos, Luan Aparecido Alexandre Elias e Aires Garcia dos Santos Junior. Data analysis and interpretation: Aline Romão dos Santos, Luan Aparecido Alexandre Elias, Daniel de Macêdo Rocha, Alvaro Francisco Lopes de Sousa and Aires Garcia dos Santos Junior. Manuscript writing: Aline Romão dos Santos, Luan Aparecido Alexandre Elias, Patrícia Klock, Adriano Menis Ferreira, Alvaro Francisco Lopes de Sousa, Mara Cristina Ribeiro Furlan, Daniel de Macêdo Rocha and Aires Garcia dos Santos Junior. Critical review of the manuscript for the intellectual content: Patrícia Klock, Alvaro Francisco Lopes de Sousa, Adriano Menis Ferreira, Daniel de Macêdo Rocha, Mara Cristina Ribeiro Furlan and Aires Garcia dos Santos Junior.

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Editor-in-Chief: André Luiz Silva Alvim