Rev Rene. 2025;26:e96009.
DOI: 10.36517/2175-6783.20252696009
www.periodicos.ufc.br/rene

Original Article

Methods for evaluating surface cleaning and disinfection in a pediatric intensive care unit

Métodos de avaliação da limpeza e desinfecção de superfícies em unidade de terapia intensiva pediátrica

How to cite this article:
Moreira FS, Mota MA, Elias LAA, Gonçalves VP, Rocha DM, Sousa AFL, et al. Methods for evaluating surface cleaning and disinfection in a pediatric intensive care unit. Rev Rene. 2025;26:e96009. DOI: https://doi.org/10.36517/2175-6783.20252696009

Flávia Silva Moreira[1]
Mariana Anjos Mota[1]
Luan Aparecido Alexandre Elias[1]
Viviane Perbeline Gonçalves[1]
Daniel de Macedo Rocha[2]
Alvaro Francisco Lopes de Sousa[1,3]
Aires Garcia dos Santos Junior[1]

[1]Universidade Federal do Mato Grosso do Sul, Campus Três Lagoas. Três Lagoas, MS, Brazil.
[2]Universidade Federal do Mato Grosso do Sul, Campus Coxim. Coxim, MS, Brazil.
[3]Instituto de Ensino e Pesquisa, Hospital Sírio-Libânes. São Paulo, SP, Brazil.

Corresponding author:
Alvaro Francisco Lopes de Sousa
Av. Cap. Olinto Mancini, 1662 - Jardim Primaveril.
CEP: 79600-080. Três Lagoas, MS, Brazil.
E-mail: sousa.alvaromd@gmail.com

Conflict of interest: the authors have declared that there is no conflict of interest.

ABSTRACT

Objective: to analyze the correlation between methods for evaluating the cleaning and disinfection of surfaces in a pediatric intensive care unit. **Methods**: a single-group, three-phase, quasi-experimental study conducted in a public unit. The effectiveness of cleaning 120 surfaces was assessed by performing 960 measurements before and after the process, using adenosine triphosphate quantification, visual inspection, and aerobic bacterial colony counts. **Results**: there was a significant positive correlation between adenosine triphosphate and colony-forming units only in phase three for the caregiver chair (Spearman's rho = 0.74; p-value = 0.038). For the other surfaces, across the three phases, no significant correlations were observed between the two methods before or after cleaning and disinfection, indicating a lack of consistent association in most situations. **Conclusion**: the methods have distinct sensitivity and specificity profiles, are not interchangeable, and are influenced by the nature of the unit, the type of surface, and the equipment and supplies used. **Contributions to practice**: combining bioluminescence and fluorescence with visual inspection may strengthen infection prevention protocols, support managerial decisions, improve audit quality, and enhance nursing performance for patient safety in critical areas.
Descriptors: Pediatric Nursing; Biological Contamination; Infection Control; Intensive Care Units, Pediatric.

RESUMO

Objetivo: analisar a correlação entre métodos de avaliação da limpeza e desinfecção de superfícies em unidade de terapia intensiva pediátrica. **Métodos:** estudo quase-experimental de grupo único, trifásico, realizado em unidade pública. Avaliaram-se a eficácia da higienização de 120 superfícies, realizando 960 medições antes e depois do processo, utilizando a quantificação de trifosfato de adenosina, inspeção visual e contagem de colônias de bactérias aeróbias. **Resultados:** houve correlação positiva e significativa entre trifosfato de adenosina e unidades formadoras de colônias apenas na fase três, para a poltrona do acompanhante (coeficiente de Spearman = 0,74; valor de probabilidade = 0,038). Nas demais superfícies, nas três fases, não se observaram correlações significativas entre os dois métodos, antes ou depois da limpeza e desinfecção, indicando ausência de associação consistente na maior parte das situações. **Conclusão:** os métodos apresentam características próprias de sensibilidade e especificidade, não se substituem e são influenciados pela natureza da unidade, pelo tipo de superfície e pelos equipamentos e insumos empregados. **Contribuições para a prática:** combinar bioluminescência e fluorescência com inspeção visual pode fortalecer protocolos de prevenção de infecções, apoiar decisões gerenciais, qualificar auditorias e aprimorar a atuação de enfermagem na segurança do paciente em áreas críticas.
Descritores: Enfermagem Pediátrica; Contaminação Biológica; Controle de Infecções; Unidades de Terapia Intensiva Pediátrica.

Received: Aug. 22nd 2025; Accepted: Oct. 8th 2025.

Introduction

Environmental contamination in pediatric intensive care units is recognized as a determinant of healthcare-associated infections (HAIs), and contact surfaces—especially when neglected or inadequately cleaned—represent a recurrent source of this risk. These surfaces act as reservoirs for microorganisms and vehicles for cross-transmission, as well as facilitating the spread of pathogens and multidrug resistance. Direct impacts are evidenced by increases in morbidity and mortality indicators, hospital length of stay, and hospital costs[1]. Moreover, failures in environmental control processes affect the service's credibility with regulatory and accrediting bodies, undermining quality indicators and patient safety[2-3].

Surface Cleaning and Disinfection (SCD) has gained emphasis as an essential measure for infection prevention and the sustainability of healthcare services. Epidemiological projections estimate that up to 60% of surfaces around infected or colonized patients may be contaminated by microorganisms such as methicillin-resistant Staphylococcus aureus[4-6]. Despite being fundamental, cleaning procedures alone do not ensure effectiveness, making systematic monitoring indispensable[6-8].

Although SCD is recognized as essential, its effectiveness is not guaranteed by the procedure itself but by systematic monitoring that ensures proper execution, coverage of critical areas, and consistent performance over time. Three bedside operational methods are widely used for this purpose, each capturing distinct dimensions of the phenomenon and presenting complementary advantages and limitations.

Visual inspection stands out for its practicality, speed, and low cost, making it useful for screening and routine audits; however, it does not detect microscopic soiling, biofilms, or non-perceptible residues, is subject to interrater variability, and can induce a false sense of security by classifying as "clean" surfaces that remain contaminated[1,6-8]. The fluorescent marker allows objective verification of the reach and quality of friction during cleaning, providing immediate feedback and supporting educational and corrective actions in real time; nonetheless, it depends on standardized prior application, requires curing time, and evaluates process rather than microbiological outcomes, and is therefore not a substitute for assessing microbial load[9]. Bioluminescence via adenosine triphosphate (ATP) provides a rapid, quantitative measure of total organic residue, with potential for short improvement cycles and immediate team feedback; its limitations include low microbiological specificity, heterogeneity across devices/protocols, and uncertainty regarding universally accepted cutoffs, which hinders interinstitutional comparability[8-12].

Culture for colony-forming units (CFU) remains the microbiological reference for detecting viable microorganisms; however, it requires laboratory infrastructure, incurs higher costs, and yields delayed results, limiting its use as a real-time routine monitor, although it is valuable for surveillance and process validation[13].

Although these methods are widely described and recognized as fundamental for HAI prevention, gaps persist in settings other than adult and geriatric care. First, there is a lack of standardized protocols and consensus ATP cutoffs applicable to pediatrics/neonatology, where environmental organic load, surface profiles, touch density, and the surrounding microbiome may differ substantially from those in adult settings[8-11]. Second, there is a scarcity of comparative investigations conducted within the same care environment that simultaneously assess correlation and agreement among visual inspection, fluorescent marker, and ATP, using CFU culture as the reference, in order to clarify the extent to which each approach informs operational decisions and which combination offers the best balance among cost, timeliness, and accuracy[9-13]. Finally, few studies explicitly integrate process indicators (coverage and cleaning technique) and outcome indicators (organic residue and viable microbial load) to guide monitoring policies with immediate applicability in the routine of pediatric and neonatal intensive care units[6-9,12-13].

Given this problem, the study setting was de-

fined as a pediatric intensive care unit of a high-complexity public hospital—an environment with high circulation of professionals and family members and multiple contact interfaces—representative of Brazilian contexts in which effectiveness, feasibility, and sustainability of environmental control interventions must be reconciled. The choice of a pediatric Intensive Care Unit (ICU), with explicit relevance to neonatal care, is justified by the high susceptibility of developing patients, the increased risks of contamination stemming from family-centered care, and the need for actionable evidence to guide combinations of monitoring methods in highly vulnerable environments[2,4-6].

Within this framework, we formulated the following research question: is there a correlation among different methods of evaluating SCD in a pediatric intensive care unit? Our hypothesis is that correlations exist but vary in magnitude according to the surface and the time of measurement (before/after and across phases). The objective of this study was to analyze the correlation between methods for evaluating the cleaning and disinfection of surfaces in a pediatric intensive care unit.

Methods

Study type

Single-group, three-phase, quasi-experimental study aligned with the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) checklist. Samples were obtained between November and December 2023 in a pediatric intensive care unit with 10 beds, serving a reference population of 132,152 inhabitants in the city of Três Lagoas, in Brazil's Central-West region.

Population and sample

The selection of surfaces was intentional and nonprobability-based, grounded in systematic observation with an emphasis on high-touch frequency and relevance to cross-transmission. The following items were prioritized for analysis: medication table, meal table, caregiver chair, bed elevation control, and patient bed[1,7,9]. The choice also considered material composition, given its potential to significantly influence microbial adherence and evaluation results.

Study protocol

Samples were collected twice per week, before and after the SCD process, to ensure consistent analysis of microbial load at different time points. The monitoring methods used in this study included: 1) ATP as an indicator of residual organic matter, enabling detection of residues after terminal cleaning using portable luminometers; 2) CFU using plates containing culture medium, with samples incubated for 48 hours and subsequently analyzed; 3) fluorescent marker applied in advance to high-touch surfaces. After SCD was performed by the teams, marker removal was assessed and categorized as total, partial, or absent, and visual inspection was conducted using criteria for stains, soiling, structural defects, and the presence of blood and dust. These methods were selected due to their wide use in national[1,9,14] and international[15-17] studies.

The system used to monitor the presence of organic matter by ATP bioluminescence consisted of a portable luminometer (NGi 3M™ Clean-Trace™, St. Paul, MN) and swabs (3M™ Clean-Trace™ ATP Surface). To monitor total aerobic microorganisms, 24 cm^2 contact plates (Rodac Plate®, Biocen do Brasil) containing tryptic soy agar and neutralizers were used. After pressing the plates onto the surfaces for 10 seconds, they were incubated at 37°C for 24 to 48 hours. Plate readings were performed with a digital colony counter (Logen LS6000; Texas Instruments Inc., Dallas, TX).

The following parameters were used as cutoffs: for ATP bioluminescence, results equal to or less than 250 relative light units were considered acceptable, with values above this limit interpreted as unacceptable. For visual inspection, any evidence of dirt, dust, grease, stains, fingerprints, moisture, or structural defects was classified as unacceptable. The fluorescent

marker was deemed acceptable when fully removed after cleaning. For total aerobic colony counts, values below 2.5 CFU per square centimeter (CFU/cm^2) or up to 60 CFU per plate were considered acceptable[14-18].

It is noteworthy that the study institution had an operational protocol, carried out by nursing and environmental services professionals, that recommended concurrent cleaning once daily and terminal cleaning once weekly or when a patient was discharged, transferred, or died.

Data collection and organization

Data collection was conducted in three phases comprising baseline, intervention, and medium-term follow-up. Samples were collected by the researcher in all phases, immediately before and 5 minutes after completion of SCD.

Phase I – Baseline

This phase involved a situational assessment of the SCD process. Samples were collected twice weekly, before and immediately after SCD with Perox4D, during morning, afternoon, and night shifts over 30 days. Given the study's real-world monitoring design, it is important to note that the research team was trained in advance and that participants were not informed of the study objectives to minimize changes in professional behavior due to observation and to avoid the Hawthorne effect in the sample.

Phase II – Intervention

The educational intervention was carried out immediately after the baseline phase and consisted of a lecture with open discussion, presentation of initial results, demonstrations of techniques, and standardization of SCD practices. Activities were conducted during working hours and lasted an average of 40 minutes. Content addressed included the methods used for environmental monitoring and control, the surfaces analyzed, the supplies used, and the standardization of these products according to surface type. The educational intervention also covered aspects related to HAIs, the importance of SCD, the most common microorganisms in critical environments, their persistence on surfaces, and the main mechanisms of transmission.

Phase III – Medium-term follow-up

To assess the sustainability of the intervention's results, this phase monitored SCD practices in the medium term using ATP, CFU, fluorescent marker, and visual inspection. This follow-up lasted 30 days and began 60 days after the educational intervention. No training or feedback was provided to the team during this period; only process monitoring was performed. In each phase, 320 assessments were conducted, distributed equally among the four monitoring methods. Thus, 240 evaluations were recorded in each method, for an overall total of 960 analyses. This study did not include screening for specific multidrug-resistant microorganisms.

Data analysis

Collected data were organized in duplicate spreadsheets in Microsoft Excel and subjected to descriptive and inferential analysis using Epi Info™ 7.2.4 (Centers for Disease Control and Prevention, Atlanta, Georgia, United States) and BioEstat 5.3 (Sociedade Mamirauá, Belém, Pará, Brazil). Spearman's correlation test (ρ) was used to estimate the association between monitoring indicators (ATP in relative light units, fluorescent marker, and visual inspection) and the microbiological reference (CFU), with p-values reported, and Pearson's Chi-square test was used to compare the proportions of surfaces classified as "acceptable" before and after SCD, as well as across collection phases. To estimate the applicability (performance relative to the microbiological reference) of the SCD monitoring methods against CFU culture (gold standard), sensitivity, specificity, and accuracy were calculated; for the ATP method (continuous variable), the area under the ROC curve (AUC) was additionally estimated.

For regression analysis, we evaluated statistical assumptions: (i) normality of residuals by Shapiro–Wilk; (ii) homogeneity of variances by Levene (and Brown–Forsythe in sensitivity analyses); (iii) linearity between continuous predictors and outcomes by inspecting residuals versus fitted values; and (iv) multicollinearity by variance inflation factor (VIF). When these conditions were met, log10-transformed ATP was modeled as a continuous outcome using linear regression, including study phase, time of measurement (before/after), and surface as covariates, with coefficients and 95% confidence intervals (CI) reported. Given the repeated measurements by surface/bed, robust (sandwich) standard errors were used, when appropriate, to mitigate residual heteroskedasticity. All analyses were conducted at a 5% significance level ($\alpha = 0.05$, two-tailed tests).

Ethical aspects

The study followed all ethical guidelines and received approval from the Research Ethics Committee for Human Subjects at the Federal University of Mato Grosso do Sul (Certificate of Presentation for Ethical Appraisal: 66976522.3.0000.0021), under opinion no. 6,172,781/2023.

Results

A total of 120 surfaces were analyzed, and 960 assessments were conducted before and after SCD across the three study phases; monitoring employed visual inspection, ATP quantification by bioluminescence, CFU counts, and a fluorescent marker.

Baseline results identified the initial approval rates in phase I. For visual inspection, the proportion classified as acceptable increased from 65.0% before SCD to 75.0% after the procedure, a significant difference ($p = 0.024$). Improvements were also observed for ATP (52.5% to 67.5%) and CFU (47.5% to 67.5%) when comparing results before and after cleaning and disinfection. The fluorescent marker showed a low approval rate (22.5%). Considering all methods combined, approval increased from 55.0% to 58.1%, indicating that although SCD yields meaningful results in environmental control, the process remains limited and requires interventions to support best practices.

Table 1 presents ATP values for the evaluated surfaces across the three study phases. Marked reductions were observed on the patient bed (221.4 relative light units to 65.1) and bed elevation control (992.4 to 460.0) in phase I; on the medication preparation table (101.0 to 55.8) and bed elevation control (182.1 to 69.0) in phase II; and on the patient bed (259.8 to 124.5) and medication preparation table (62.0 to 38.5) in phase III. These results suggest a positive effect of SCD on high-contact surfaces with direct patient interface, while also demonstrating inconsistency in process effectiveness at specific points, such as chairs and tables, underscoring the need for greater standardization and rigor in procedures.

Table 1 – Mean and standard deviation of adenosine triphosphate values, in relative light units, across phases, before and after surface cleaning and disinfection. Três Lagoas, MS, Brazil, 2023

Phases and surfaces evaluated	Surface cleaning and disinfection			
	Before		After	
	Mean	Standard deviation	Mean	Standard deviation
Phase I				
Patient bed	221.4	167.8	65.1	44.2
Meal table	615.5	491.0	328.1	308.2
Medication preparation table	243.6	268.1	170.9	241.1
Caregiver chair	304.0	237.9	383.1	228.6
Bed elevation control	992.4	2309.1	460.0	654.2
Phase II				
Patient bed	247.0	297.3	133.8	186.9
Meal table	319.0	369.1	295.3	360.0
Medication preparation table	101.0	83.3	55.8	57.1
Caregiver chair	373.6	222.2	480.0	543.7
Bed elevation control	182.1	183.9	69.0	59.3
Phase III				
Patient bed	259.8	353.2	124.5	128.1
Meal table	1813.4	2356.5	1310.9	1998.1
Medication preparation table	62.0	78.4	38.5	32.6
Caregiver chair	416.6	324.1	357.8	278.7
Bed elevation control	216.8	268.2	681.8	1388.3

It was found that ATP values obtained after cleaning and disinfection were explained primarily by the ATP values recorded before the procedure, whereas study phases and surface types showed no statistically significant association. In contrast, for CFU values after cleaning and disinfection, both the pre-procedure CFU values and surface type were significant predictors, while study phases did not exert a relevant influence. These findings indicate that, regardless of the phase in which data were collected, final ATP and CFU results depended chiefly on initial measurements, and, in the case of microbiological cultures, surface type also played a determining role (Table 2).

A positive, statistically significant correlation was observed between ATP and CFU values in Phase III, specifically for the caregiver chair (rs = 0.74; p = 0.038). For the other surfaces evaluated, both in Phase III and in Phases I and II, no significant correlations were identified between ATP and CFU values before or after cleaning and disinfection, indicating a lack of consistent association between the two evaluation methods in most of the situations analyzed (Table 3).

Table 2 – Multiple linear regression of adenosine triphosphate and colony-forming unit values after cleaning and disinfection (dependent variables) in relation to independent variables. Três Lagoas, MS, Brazil, 2023

Independent variables	Assessment after cleaning and disinfection			
	ATP		CFU	
	b*	p-value†	b	p-value
Study phases	90.57	0.124	0.81	0.505
Surface types	43.89	0.204	5.03	0.020†
ATP before cleaning and disinfection	0.51	<0.001†	–	–
CFU before cleaning and disinfection	–	–	0.47	<0.001†

*b: Partial regression coefficient; †Statistical significance level (Type I error probability); p≤0.05 was considered statistically significant; ATP: Adenosine triphosphate; CFU: Colony-forming units

Table 3 – Spearman correlation of adenosine triphosphate and colony-forming unit values before and after cleaning and disinfection according to study phases and surface type. Três Lagoas, MS, Brazil, 2023

Phases	Before		After	
	rs*	p-value†	rs	p-value
Phase I				
Patient bed	0.33	0.420	0.41	0.320
Meal table	0.06	0.888	0.01	0.978
Medication preparation table	0.10	0.823	0.17	0.693
Caregiver chair	0.43	0.283	0.40	0.332
Bed elevation control	-0.24	0.570	0.02	0.955
Phase II				
Patient bed	-0.48	0.233	-0.49	0.213
Meal table	0.36	0.385	0.28	0.509
Medication preparation table	0.14	0.734	0.09	0.839
Caregiver chair	0.08	0.844	0.41	0.320
Bed elevation control	0.16	0.713	-0.04	0.933
Phase III				
Patient bed	-0.32	0.444	0.19	0.651
Meal table	-0.11	0.800	-0.67	0.071
Medication preparation table	0.26	0.528	0.22	0.608
Caregiver chair	0.74	0.038†	0.30	0.479
Bed elevation control	0.34	0.417	0.14	0.736

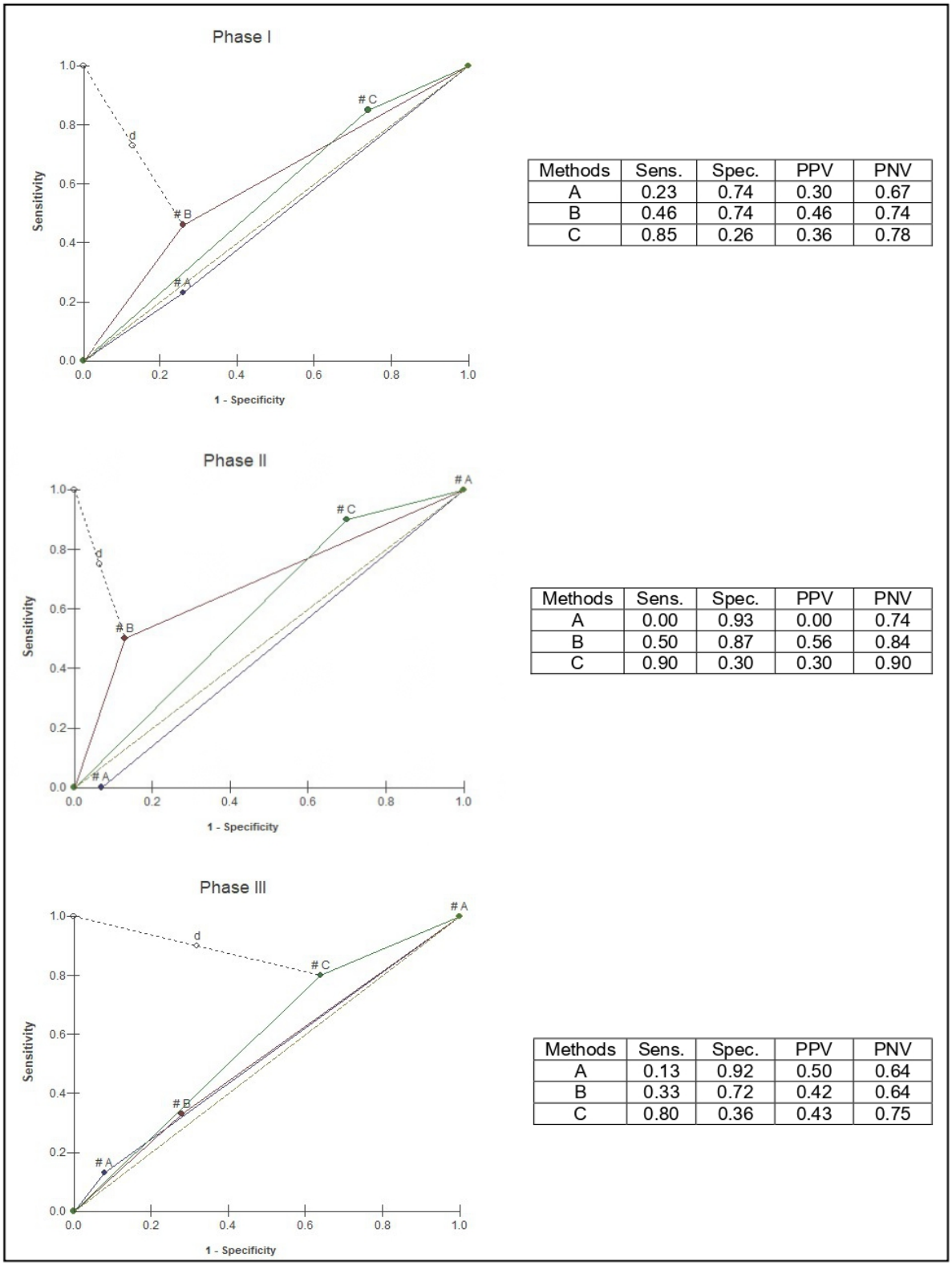
*rs: Spearman's coefficient; †Statistical significance level; p≤0.05 was considered indicative of a non-null (statistically significant) correlation

When comparing the microbiological culture (gold standard) with the other monitoring methods (visual inspection, ATP, and fluorescent marker) after cleaning and disinfection, ATP and visual inspection were found to be highly specific (ability to identify clean surfaces), whereas the fluorescent marker was highly sensitive (ability to identify dirty surfaces).

ATP showed the highest accuracy—that is, the best probability of correctly classifying surfaces (test correctness)—in both the first and second phases of the study. In phase III, the fluorescent marker demonstrated the highest accuracy.

In evaluating the diagnostic performance of the methods, the positive predictive value (PPV) and negative predictive value (NPV) for visual inspection and ATP detection were close to the corresponding sensitivity and specificity values, indicating consistency between the ability to correctly identify clean surfaces and the probability of test correctness.

In contrast, for the fluorescent marker, high sensitivity was associated with a low PPV, and low specificity was coupled with a high NPV (Figure 1). This relationship indicates that, although the marker was effective in identifying dirty surfaces, it also generated a high proportion of false positives—that is, marked surfaces that were not contaminated. Conversely, although it had low effectiveness in identifying clean surfaces (low specificity), when it did identify them, the probability of correctness was high (high NPV).



Methods	Sens.	Spec.	PPV	PNV
A	0.23	0.74	0.30	0.67
B	0.46	0.74	0.46	0.74
C	0.85	0.26	0.36	0.78

Methods	Sens.	Spec.	PPV	PNV
A	0.00	0.93	0.00	0.74
B	0.50	0.87	0.56	0.84
C	0.90	0.30	0.30	0.90

Methods	Sens.	Spec.	PPV	PNV
A	0.13	0.92	0.50	0.64
B	0.33	0.72	0.42	0.64
C	0.80	0.36	0.43	0.75

Note: Methods: A = visual inspection; B = adenosine triphosphate; and C = fluorescent marker; Sens. = sensitivity; Spec. = specificity; PPV = positive predictive value; NPV = negative predictive value. The method with the smallest distance (d) from the gold standard (microbiological culture) has the highest accuracy

Figure 1 – Receiver Operating Characteristic (ROC) curve for phases I, II, and III. Três Lagoas, MS, Brazil, 2023

Discussion

Based on the results, the comparative analysis across methods revealed significant discrepancies: visual inspection showed notable limitations, whereas instrumental methods—especially ATP and the fluorescent marker—demonstrated greater sensitivity in identifying failures, even in environments that appeared visually clean.

These results were expected, given that the visual method often overestimates the quality of cleaning, as it does not capture microscopic organic residues that can sustain pathogenic microorganisms[19-20]. Likewise, the ATP method, when adjusted to the sampled area, provides more precise results, reinforcing the need for standardized techniques and contextualized interpretation of data[21].

Comparative analyses of ATP values across the different phases of the study revealed variations that warrant consideration. On certain critical surfaces, such as the patient bed and the medication preparation table, pronounced and consistent reductions were observed after SCD, demonstrating the positive effect of the procedure. However, on chairs and meal tables, results remained at unacceptable levels or showed only modest improvements.

These inconsistencies may be associated with the complexity of cleaning specific materials and designs, as well as contextual and environmental factors, reflected by the higher frequency of contact and constant handling of these surfaces. In addition, differences in the execution of, and adherence to, protocols by the cleaning team, as well as the equipment used to quantify ATP, may also influence these results[22-23]. Such conditions—often difficult to control in real-world care settings—can affect SCD performance and help explain divergent results across study phases.

Overall, agreement between visual and instrumental methods is low, supporting the use of combined approaches to increase assessment accuracy[1,14]. The present findings reinforce this recommendation, showing that methods such as ATP and fluorescent markers are more effective at detecting inadequately cleaned surfaces, even when formal cleaning protocols are in place.

It is also noteworthy that the performance of these methods can vary according to surface type, the cleaning product used, the time elapsed since disinfection, and other environmental variables. There is consensus on the need for local contextualization of data to avoid misinterpretation of ATP-derived relative light unit values[1,16,22]. The use of simplified algorithms for result interpretation has also been proposed, which may be a useful alternative for services with limited analytical capacity[15,19,22].

A critical aspect of this study concerns the specific context of pediatric intensive care units, where data collection was conducted. The results showed that instrumental methods, particularly the fluorescent marker and ATP, detected failures in surface cleaning that were classified as satisfactory by visual inspection. This disparity is particularly concerning in this setting, since newborns and children hospitalized in these units have immature immune systems, greater dependence on invasive devices, and frequent contact with critical surfaces such as incubators, monitors, and infusion pumps[7,23-25]. Surfaces that appear clean may therefore conceal invisible organic loads that facilitate the transmission of pathogenic microorganisms. In this regard, a multicenter evaluation in hospitals showed low agreement between visual and instrumental methods such as ATP, indicating the persistence of organic residues on surfaces classified as clean[26]. Similarly, analyses conducted in hospital units found that visual tests often overestimate cleaning effectiveness, whereas objective methods such as ATP and fluorescence have greater capacity to detect failures[27-28].

In neonatal and pediatric ICUs, adopting multimodal intervention bundles that integrate objective monitoring with immediate feedback can significantly improve the quality of surface cleaning, underscoring the need for complementary, systematic strategies in critical environments[7].

Accordingly, the results of this study indicate that objective monitoring methods have greater sensitivity for detecting cleaning failures, demonstrating that visual assessment alone is insufficient to ensure patient safety in intensive care and pediatric units. In this context, the need for a multimodal approach is evident—one that combines precise tracking technologies with structured audit protocols[7-9]. Research conducted in adult intensive care units has confirmed the effectiveness of the systematic use of fluorescent markers in high-complexity scenarios, such as during the COVID-19 pandemic[9]. In addition, ATP bioluminescence has proven to be an agile and efficient tool for tracking cleaning failures, enabling immediate interventions and reducing risks related to environmental contamination[1].

The implications of this study span clinical, managerial, educational, and institutional dimensions, providing support to strengthen programs for auditing, patient safety, surveillance, and infection prevention. From a clinical perspective, the results show that ATP can be incorporated into monitoring in pediatric and neonatal ICUs, as it enables rapid interventions, immediate correction of nonconformities, and a reduced risk of exposing patients to potentially contaminated surfaces. From managerial and institutional perspectives, the evidence indicates that the use of ATP can support hospital accreditation processes, contribute to cost control, and create opportunities for educational interventions based on quality indicators and professional performance in cleaning processes.

Study limitations

This study has limitations. The investigation was conducted in a single pediatric intensive care unit at one hospital, which may restrict the generalizability of the results to other care settings. The absence of direct microbiological evaluation limited the possibility of complementing the analysis of organic matter with the identification of specific pathogens, reducing the scope of the conclusions. It is also important to acknowledge that uncontrolled environmental and contextual variables—such as staff flow, the presence of family caregivers, and the unit's structural characteristics—may have influenced the persistence of residues and microorganisms after SCD.

Although the team was trained and participants were not informed of the study objectives as a strategy to mitigate reactivity, behavioral changes resulting from the implementation of best practices cannot be ruled out.

Methodological limitations related to measurement, selection, and observation—reflected in the limited precision of the techniques used, the subjectivity of visual inspection, and the definition of surfaces and periods evaluated—should be addressed in future studies. Recognizing these gaps enables the development of future plans aimed at expanding the geographic representativeness of the sample and designing robust study frameworks capable of conferring greater internal and external validity to the results.

Contributions to practice

Nursing plays a central role in coordinating strategies for unit cleaning and disinfection. As a key actor in care delivery and environmental management, nursing is responsible not only for supervising hygiene processes but also for leading the implementation of monitoring technologies, critically interpreting results, and promoting continuous improvement actions to ensure patient safety. Training and continuing education should incorporate content related to interpreting data generated by methods such as adenosine triphosphate and fluorescence, thereby strengthening teams' technical–scientific capacity.

In addition, the findings of this study have implications for institutional policy development. The adoption of cleaning and disinfection protocols should be accompanied by systematic mechanisms for evaluating their effectiveness. Nursing, working across multiple stages of care, is strategically positioned to foster an evidence-based safety culture in which environmental monitoring data are integrated with care quality indicators.

Conclusion

In the pediatric intensive care unit evaluated, correlations among visual inspection, fluorescent marker, adenosine triphosphate, and colony-forming unit culture were heterogeneous and dependent on surface type and timing of measurement. Overall, no consistent, stable correlation among methods was observed that would support their equivalence. Thus, the hypothesis that the existence and magnitude of correlations vary within the context studied is confirmed.

Acknowledgments

This study was carried out with support from the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES), the Federal University of Mato Grosso do Sul, and the Foundation to Support the Development of Education, Science and Technology of the State of Mato Grosso do Sul.

Authors' contributions

Conception and design or data analysis and interpretation; drafting of the manuscript or critical revision of the manuscript for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the manuscript in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Moreira FS, Mota MA, Elias LAA, Gonçalves VP, Rocha DM, Sousa AFL, Santos Junior AG.

References

1. Li T, Zhang H, Luo H, Li K, Huang N, Yang S, You J. Development and optimization of disinfection protocol for negative pressure wards: a Delphi study. BMC Infect Dis. 20257;25(1):1242. doi: https://doi.org/10.1186/s12879-025-11659-y
2. Nadi ZB, Raisali F, Jafari N, Bayramzadeh S. The influence of physical environment on health care–associated infections: a literature review. Am J Infect Control. 2024;52(2):229-42. doi: https://doi.org/10.1016/j.ajic.2023.06.010
3. Verhougstraete M, Cooksey E, Walker JP, Wilson AM, Lewis MS, Yoder A, et al. Impact of terminal cleaning in rooms previously occupied by patients with healthcare-associated infections. PLoS One. 2024;19(7):e0305083. doi: https://dx.doi.org/10.1371/journal.pone.0305083
4. Boyce JM. Hand and environmental hygiene: respective roles for MRSA, multi-resistant Gram negatives, Clostridioides difficile, and Candida spp. Antimicrob Resist Infect Control. 2024;13(1):110. doi:https://dx.doi.org/10.1186/s13756-024-01461-x
5. Alqurashi MS, Sawan AA, Berekaa MM, Hunasemarada BC, Al Shubbar MD, Al Qunais AA, et al. Hospital hygiene paradox: MRSA and Enterobacteriaceae colonization among cleaning staff in a tertiary hospital in Saudi Arabia. Medicina (Kaunas). 2025;61(3):384. doi: http://dx.doi.org/10.3390/medicina61030384
6. Hong W, Nyaruaba R, Li X, Liu H, Yang H, Wei H. In-situ and real-time monitoring of the interaction between lysins and staphylococcus aureus biofilm by surface plasmon resonance. Front Microbiol. 2021;12:783472. doi: https://doi.org/10.3389/fmicb.2021.783472
7. Silva MHN, Ciofi-Silva CL, Souza VS, Rocha DM, Sousa AFL, Felix AMS, et al. Comparative effectiveness of a multimodal intervention package on surface cleaning and disinfection in Brazilian neonatal intensive care units. Front Public Health. 2025;13:1557538. doi: https://doi.org/10.3389/fpubh.2025.1557538
8. Leistner R, Kohlmorgen B, Brodzinski A, Schwab F, Lemke E, Zakonsky G, et al. Environmental cleaning to prevent hospital-acquired infections on non-intensive care units: a pragmatic cluster randomized trial. EClinicalMedicine. 2023;59:101958. doi: https://dx.doi.org/10.1016/j.eclinm.2023.101958
9. Rigonato EM, Lima HP, Sousa AFL, Santos JLG, Jorge BM, Klock P, et al. Cleaning and disinfection of surfaces in a COVID-19 respiratory syndrome unit: a quasi-experimental study. Coronaviruses. 2024;5(2):88-96. doi: https://doi.org/10.2174/0126667975333048241025050846
10. Artasensi A, Mazzotta S, Fumagalli L. Back to basics: choosing the appropriate surface disinfectant. Antibiotics (Basel). 2021;10(6):613. doi: https://doi.org/10.3390/antibiotics10060613
11. Tseng WC, Wang YC, Chen WC, Lin KP. Utilizing an adenosine triphosphate bioluminescence assay as an indicator of instrument and environmental

cleanliness in the radiology department: a pilot study. Infect Prev Pract. 2025;7(2):100449. doi: https://doi.org/10.1016/j.infpip.2025.100449

12. Niephaus V, Parohl N, Heiligtag S, Reuter H, Hackler R, Popp W. Can the ATP bioluminescence assay be used as an indicator for hospital cleaning? GMS Hyg Infect Control. 2024;19:Doc07. doi: https://doi.org/10.3205/dgkh000462

13. Frota OP, Santos EA, Oliveira SM, Silva LR, Sousa AFL. Efficiency of surface cleaning and disinfection: correlation between evaluation methods. Rev Bras Enferm. 2017;70(6):1176-83. doi: https://doi.org/10.1590/0034-7167-2016-0608

14. Frota OP, Ferreira AM, Rigotti MA, Andrade D, Borges NMA, Ferreira Júnior MA. Effectiveness of clinical surface cleaning and disinfection: evaluation methods. Rev Bras Enferm. 2020;73(1):e20180623. doi: https://dx.doi.org/10.1590/0034-7167-2018-0623

15. Xiong J, Jiang W, Wan W, Zuo L, Tu P, Rao DX. Improving precision instrument cleaning with a quality control module: implementation and outcomes. Front Public Health. 2025;13:1553113. doi: https://doi.org/10.3389/fpubh.2025.1553113

16. Fieldhouse S, Bastaki BB, Ledgerton A, Clarke P, Lewis T. Assessing Hospital Cleaning Effectiveness Using Fluorescence: A Proof-of-Concept Study and Comparison to ATP Testing. J Hosp Infect. 2025;9:S0195-6701(25)00267-1. doi: http://doi.org/10.1016/j.jhin.2025.08.008

17. Chan ASF, Chan HLY, Yan BKL, Lai MKC. Effectiveness of adenosine triphosphate to monitor manual cleaning and disinfection efficacy of flexible endoscopes in Hong Kong. JGH Open. 2023;7(2):141-7. doi: https://doi.org/10.1002/jgh3.12863

18. Boyce JM, Havill NL, Dumigan DG, Golebiewski M, Balogun O, Rizvani R. Monitoring the effectiveness of hospital cleaning practices by use of an ATP bioluminescence assay. Infect Control Hosp Epidemiol. 2009;30(7):678-84. doi: https://doi.org/10.1086/598243

19. Wu Y, Li L. An investigation into cleaning quality of suction-type metal lumen instruments: a cross-sectional study. Sci Rep. 2025;15(1):2492. doi: https://doi.org/10.1038/s41598-024-83215-8

20. Chen YC, Huang HM, Lin PY, Shi ZY. Comparing visual inspection and performance observation for evaluation of hospital cleanliness. Am J Infect Control. 2021;49(12):1511-14. doi: https://doi.org/10.1016/j.ajic.2021.07.011

21. Weber DJ, Rutala WA, Anderson DJ, Sickbert-Bennett EE. Biofilms on medical instruments and surfaces: do they interfere with instrument reprocessing and surface disinfection? Am J Infect Control. 2023;51(11):114-9. doi: https://doi.org/10.1016/j.ajic.2023.04.158

22. Whiteley GS, Glasbey TO, Fahey PP. Using a simplified ATP algorithm to improve data reliability and improve cleanliness standards for surface and medical device hygiene. Infect Dis Health. 2022;27(1):3-9. doi: http://dx.doi.org/10.1016/j.idh.2021.07.001

23. Komamizu S, Yamamoto Y, Morikane K, Kuwabara Y, Kondo M, Tatebayashi K, et al. Clinical and microbiological effectiveness of pulsed-xenon ultraviolet light disinfection in a neonatal intensive care unit in Japan. J Hosp Infect. 2025;156:13-6. doi: https://doi.org/10.1016/j.jhin.2024.11.015

24. Ishikawa K, Tsuchida T, Ichiki K, Ueda T, Yamada K, Iijima K, et al. Efficacy of enhanced environmental cleaning/disinfection using pulsed xenon ultraviolet light in preventing MRSA outbreaks in neonatal intensive care units. Epidemiologia. 2025;6(1):12. doi: https://doi.org/10.3390/epidemiologia6010012

25. Dramowski A, Aucamp M, Bekker A, Pillay S, Moloto K, Whitelaw AC, Cotton MF, Coffin S. NeoCLEAN: a multimodal strategy to enhance environmental cleaning in a resource-limited neonatal unit. Antimicrob Resist Infect Control. 2021;10(1):35. doi: https://doi.org/10.1186/s13756-021-00905-y

26. van Arkel A, Willemsen I, Kluytmans J. The correlation between ATP measurement and microbial contamination of inanimate surfaces. Antimicrob Resist Infect Control. 2021;10(1):116. doi: https://doi.org/10.1186/s13756-021-00981-0

27. Salih AN, Allo RR. Evaluation of nursing intervention measures in infection control at dialysis units in Mosul city hospitals. Med J Babylon. 2024;21(2):245-50. doi: http://doi.org/10.4103/MJBL.MJBL_360_22

28. Gastaldi S, Accorgi D, D'Ancona F. Tools and strategies for monitoring hospital environmental hygiene services. J Hosp Infect. 2025;159:52-61. doi: https://doi.org/10.1016/j.jhin.2025.01.011