Research Article

Assessment of Antimicrobial Performance of Two Detergents on Predefined Surface Categories in Veterinary Clinical Environments

Camilo Romero-Núñez[1], Laura Reyes-Climaco[1], Laura Miranda-Contreras[1], Ariadna Flores-Ortega[2*], Rafael Heredia-Cárdenas[3]

[1]Dermavet Hospital Veterinario, José de la Luz Blanco, Mz. 187, Lt. 33, Col. Santa Martha Acatitla, Ciudad de México; [2]Postdoctoral Fellowship Program. Secretariat of Science, Humanities, Technology and Innovation (Secihti). UAEM Amecameca University Center. Autonomous University of the State of Mexico (UAEM); [3]Centro Integral Veterinario, CIVET, Estado de México, México.

Abstract | Effective disinfection is essential for minimizing microbial contamination in veterinary clinical environments, yet there is limited evidence regarding the antimicrobial performance of detergents on clearly defined clinical surface types. This study evaluated the efficacy of SoluVet® and EsteriClean® in reducing aerobic mesophiles and total coliforms recovered from six standardized surface categories in two veterinary clinics. A 1 m^2 sampling area was delimited for each surface, and samples were processed in a microbiology laboratory using conventional quantification methods. In phase one, coliforms were absent except in pre-cleaning samples on day 15, prior to cleaning on the scale in Clinic B (1600 CFU) and on the sink in Clinic A (15 CFU). Between post-cleaning samples collected on day 1 and day 5, microbial counts decreased significantly by 85.46% (P = 0.02), indicating superior effectiveness of SoluVet®/EsteriClean®. In phase two, both disinfectants significantly reduced CFU levels (quaternary: 96.43%, P = 0.03; SoluVet®/EsteriClean®: 96.45%, P = 0.01), with SoluVet®/EsteriClean® producing a highly significant 92.72% reduction in mesophilic counts from day 19 to day 26 (P = 0.005), consistent with the values reported in Table 1. These findings demonstrate that SoluVet®/EsteriClean® provides greater antimicrobial efficacy across defined veterinary clinical surfaces compared with the quaternary ammonium disinfectant. The study offers novel, surface-specific evidence to inform disinfectant selection and strengthen biosecurity protocols in veterinary practice.

Keywords | Antimicrobial detergents, Surface disinfection, Veterinary clinics, Coliform bacteria, Aerobic mesophilic bacteria

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***Correspondence** | Ariadna Flores Ortega, Postdoctoral Fellowship Program. Secretariat of Science, Humanities, Technology and Innovation (Secihti). UAEM Amecameca University Center. Autonomous University of the State of Mexico (UAEM); **Email:** ariadnafloresortega@gmail.com
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INTRODUCTION

Healthcare-associated infections caused by antimicrobial-resistant bacteria are an increasing concern in both human and veterinary medicine. Patients may acquire infections during hospitalization and may even be discharged carrying antimicrobial-resistant organisms (Hamilton *et al*., 2012). Although nosocomial infections are well documented in human hospitals, their prevalence and characteristics in veterinary facilities remain less understood. Surveillance data indicate that 16.3% of hospitalized dogs and 12% of cats develop healthcare-associated infections, and 82% of university veterinary hospitals have reported outbreaks within a five-year period, with 50% also reporting zoonotic infections among staff (Wood *et al*., 2014; Churak *et al*., 2021).

A broad spectrum of bacterial pathogens has been implicated in veterinary hospital–acquired infections, including *Enterococcus* spp., *Escherichia coli*, *Staphylococcus* spp., *Enterobacter* spp., *Klebsiella* spp., *Acinetobacter* spp., and *Pseudomonas* spp. Importantly, fecal-associated bacteria such as Enterococci and E. coli can persist for long periods on dry, inanimate surfaces, contributing to continuous environmental contamination. These microorganisms have been detected on frequently handled surfaces and equipment in veterinary clinical environments and are associated with increased morbidity and mortality among hospitalized animals (Churak *et al*., 2021; Singaravelu *et al*., 2023; Geraldes *et al*., 2021).

Environmental surfaces and medical equipment can act as reservoirs of pathogens if cleaning and disinfection procedures are inadequate. Furniture, instruments, and other clinical tools may harbor microbes capable of transferring to the hands of veterinary personnel, facilitating indirect transmission to patients (Wood *et al*., 2014; Verdial *et al*., 2021). The structural dynamics of hospital contact networks further contribute to pathogen dissemination, highlighting the importance of environmental hygiene in preventing nosocomial events (Ueno and Masuda, 2008). Beyond the clinical impact, outbreaks of hospital-associated infections also impose financial and operational burdens on veterinary centers (Geraldes *et al*., 2021).

A wide variety of disinfectants is currently used in veterinary practice. However, some conventional formulations can cause adverse reactions such as skin irritation, nasal discomfort in animals, and environmental toxicity. These limitations have prompted growing interest in alternative disinfectants with safer toxicological properties, such as SoluVet® and EsteriClean® (ESTERIPHARMA, Mexico City, Mexico). These neutral-pH electrolyzed superoxidized solutions contain active oxygen and chlorine species at 0.006%, offering antiseptic, disinfectant, and sterilizing effects while reducing potential risks to animal health and the environment (Rojas-Briones *et al*., 2013). Previous studies indicate their antimicrobial activity against a wide range of microorganisms, including biofilms, bacteria, viruses, spores, and fungi (Yan *et al*., 2021).

Despite their increasing use, there is limited empirical evidence assessing the antimicrobial performance of these electrolyzed solutions on clearly defined veterinary clinical surfaces under real-world conditions. Existing literature does not provide surface-specific or controlled evaluations comparing their efficacy against mesophilic and coliform microorganisms. Recent evidence maps also highlight substantial variability in disinfectant efficacy across healthcare surfaces, underscoring the need for standardized, surface-specific evaluations (Christenson *et al*., 2021). This lack of standardized, surface-oriented data represents a significant research gap in veterinary infection control. These concerns have led to increasing interest in safer and more effective disinfectant strategies in small-animal practice, particularly those supported by evidence-based guidelines such as the ABCD (European Advisory Board on Cat Diseases) recommendations for feline environments (Addie *et al*., 2015).

Therefore, the objective of this study was to evaluate the antimicrobial effectiveness of SoluVet® and EsteriClean® on mesophilic and coliform microorganisms isolated from standardized clinical surface types in two veterinary clinics. The study was conducted in two 12-day phases, during which each clinic alternated between a control quaternary ammonium disinfectant and the SoluVet®/EsteriClean® protocol. Surface samples were collected 30 seconds after cleaning using SRK® Swab Rinse Kits (Coapan, Italy), following the manufacturer's recommended sampling procedures, a standardized interval commonly used in surface-disinfection studies to allow disinfectant contact time while avoiding recontamination or drying artifacts (Akwuobu *et al*., 2021).

MATERIALS AND METHODS

Study design and site

The study was conducted in two companion animal veterinary clinics located in Mexico City: CVM Dermatología Especializada (Clinic A) and Hospital Veterinario DERMAVET (Clinic B). Sampling and disinfection procedures were performed from September 18 to October 13, 2024. Following a quasi-experimental applied research design (Akwuobu *et al*., 2021), the study was divided into two consecutive 12-day phases in which clinics alternated between the control disinfectant and the electrolyzed superoxidation solutions (Figure 1).

Six predefined surface categories were selected based on their high contact frequency in veterinary practice: Tile floors, marble laminate surfaces, stainless-steel sinks, Formica countertops, ribbed rubber mats (positioned on a scale), and stainless-steel grate preparation tables. A standardized 1 m^2 sampling area was delimited on each surface.

Disinfectant characteristics

Two disinfectant formulations based on electrolyzed superoxidation with neutral pH and active chlorine/oxygen species at 0.006% were evaluated: SoluVet® (Health Reg.: Q-0702-001) and EsteriClean® (Health Reg.: Q-0702-006), both provided by Esteripharma S.A. de C.V. EsteriClean® was applied at a 1:50 dilution and SoluVet® at 1:20, following manufacturer specifications.

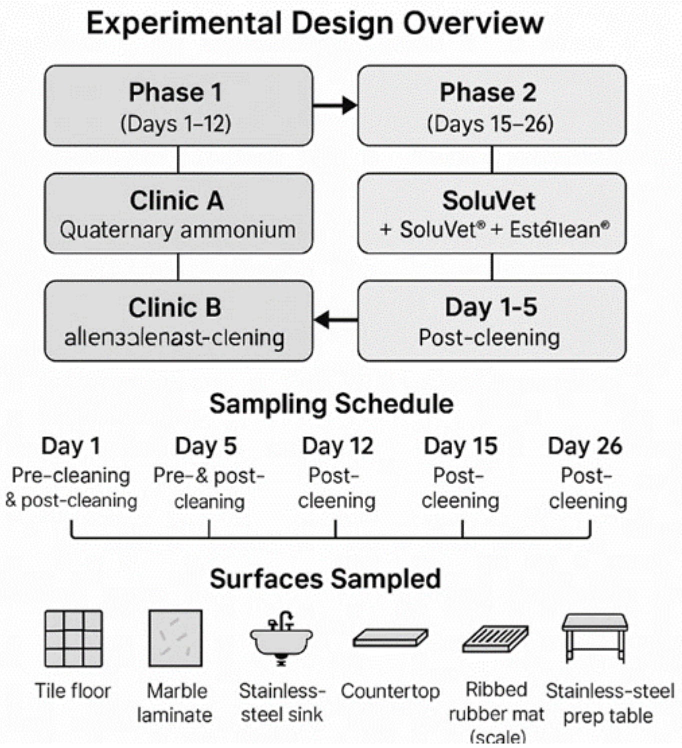

Figure 1: Schematic representation of the two-phase disinfectant rotation, sampling days, and standardized surface categories assessed in Clinics A and B.

The comparative disinfectant was RBM-Q® (quaternary ammonium compound; Health Reg.: 68424-95-3; Red Box®), used at a 1:50 dilution according to manufacturer instructions.

Phase 1: Clinic A used the quaternary disinfectant, while Clinic B used EsteriClean® + SoluVet®. Phase 2: Clinic B used the quaternary disinfectant, while Clinic A used EsteriClean® + SoluVet®.

Sampling procedure

Sampling was performed 30 seconds after the completion of the cleaning procedure, following the standardized methodology recommended by the manufacturer of SRK® Swab Rinse Kits (Coapan, Italy). Each swab tube was labeled with clinic, date, surface type, and study phase.

The sampling workflow adhered to a systematic surface-swabbing protocol (Akwuobu *et al.*, 2021), ensuring uniform coverage of the delimited 1 m^2 area. Samples were immediately refrigerated at 4°C and transported to the microbiology laboratory for processing (Figure 2).

Procedural details strictly followed the routine cleaning protocols already established at each clinic, without modifications.

Microbial quantification

Microbial analysis included:

- Aerobic mesophilic bacteria: quantified by plating following NOM-092-SSA1-1994.
- Total coliforms: quantified by plating according to NOM-113-SSA1-1994.
- All analyses were conducted at the same microbiology laboratory to ensure methodological consistency.

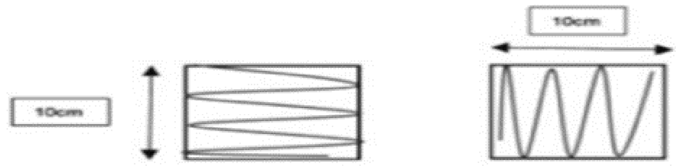

Figure 2: SRK® Swab sampling.
The swabbing pattern followed vertical and horizontal zigzag motions advance with a perimeter of 10 cm. Sampling was carried out in duplicate, i.e. before and after disinfection of each test site on day 1 and 15. On days 5, 12, 19 and 26, duplicate sampling was taken from each test site. test only after disinfection. Collecting a total of 192 samples.

Statistical analysis

Normality of microbial count data was assessed using the Shapiro–Wilk test. Because the data did not follow a normal distribution, the Wilcoxon signed-rank test was applied as the matched-pairs non-parametric method to compare CFU reductions between disinfectants, clinics, and surface types. Reduction percentages for mesophiles and coliforms were calculated for each clinic and surface category. Statistical analyses were performed using JMP® 8.0 (SAS Institute Inc., Cary, NC, USA).

Ethical statement

This study did not involve experimental procedures on live animals or the collection of clinical animal data. Environmental sampling was performed exclusively on inanimate surfaces within veterinary clinics, in accordance with institutional hygiene and biosafety protocols. Ethical approval was therefore not required; however, both participating clinics provided informed authorization to conduct surface sampling.

RESULTS

Coliform growth

In the first stage of the study there was no growth of coliform microorganisms in the samples taken from different surfaces, in the second stage of the study there was growth of coliforms on the surface of the scale at clinic "B" only on day 15 (1600 CFU). prior to cleaning the surface, subsequently there was no growth, in clinic "A" there was growth of coliforms in the sample obtained from the surface of the sink on day 15 (15 CFU) prior to cleaning, in the following samples there was no growth.

Table 1: Mesophilic bacterial counts (CFU) during Phase 1 and Phase 2 in Clinics A and B using two disinfectants.

Variable	Day 1 (pre)	Day 1 (post)	Day 5 (post)	Day 12 (post)	% change	P-value
Phase 1						
Quaternary (Clinic A)	1000	937.5	102.08	1045	+4.5%	0.47 / 0.06 / 0.88
SoluVet®/EsteriClean® (Clinic B)	160.4	22.9	3.33	8.33	–94.8%	0.008* / 0.02* / 0.87
Phase 2						
Variable	**Day 15 (pre)**	**Day 15 (post)**	**Day 19 (post)**	**Day 26 (post)**	**% change**	**P-value**
Quaternary (Clinic B)	699.5	25	324.1	503.3	–28.1%	0.03* / 0.96 / 0.70
SoluVet®/EsteriClean® (Clinic A)	762	27.08	337.5	24.58	–96.7%	0.01* / 0.99 / 0.005*

P-values obtained using the Wilcoxon signed-rank test. a= Clinic A (CVM Dermatología Especializada). b= Clinic B (Hospital Veterinario DERMAVET). Statistically significant differences ($P < 0.05$) indicated with an asterisk. % change: positive values = increase; negative values = decrease.

Table 2: Mesophilic bacterial counts (CFU) by surface type during Phase 1.

Surface	Treatment	Day 1 (pre)	Day 1 (post)	Day 5	Day 12	% change	P-value
Sink	Quaternary	785	110	142.5	20	–97.4%	0.08 / 0.60 / 0.16
	SoluVet®	85	25	0	7.5	–91.2%	0.10 / 0.25 / 0.75
Countertop	Quaternary	47.5	1345	87.5	40	variable	0.97 / 0.03* / 0.31
	SoluVet®	52.5	70	0	7.5	–85.7%	0.95 / 0.02* / 0.75
Preparation table	Quaternary	540	3257.5	65	10	–98.1%	0.72 / 0.24 / 0.15
	SoluVet®	207.5	42.5	20	12.5	–94.0%	0.25 / 0.25 / 0.37
Formica	Quaternary	407.5	92.5	235	272.5	inconsistent	0.30 / 0.78 / 0.56
	SoluVet®	195	0	0	5	–97.4%	0.11 / NA / 0.75
Floor	Quaternary	4050	542.5	17.5	1452.5	variable	0.26 / 0.16 / 0.76
	SoluVet®	280	0	0	0	–100%	0.22 / NA / NA
Scale mat	Quaternary	170	277.5	65	4475	inconsistent	0.62 / 0.21 / 0.75
	SoluVet®	142.5	0	0	17.5	–87.8%	0.22 / NA / 0.75

NA= not applicable (zero baseline). P-values calculated using the Wilcoxon signed-rank test. Statistically significant difference ($P < 0.05$). a = Clinic A (CVM Dermatología Especializada). b = Clinic B (Hospital Veterinario DERMAVET).

Aerobic mesophilic growth

Across both phases, electrolyzed solutions (SoluVet®/EsteriClean®) consistently produced stronger and more sustained reductions in aerobic mesophilic counts compared with the quaternary ammonium disinfectant.

In Phase 1, SoluVet®/EsteriClean® achieved an overall 94.8% reduction from Day 1 pre-cleaning to Day 12, whereas the quaternary disinfectant showed minimal net improvement, with CFU increasing again by Day 12 (+4.5%). These trends are clearly reflected in Table 1, where SoluVet®/EsteriClean® maintained low post-cleaning values throughout the phase (3.33–8.33 CFU), while quaternary-treated surfaces returned to high CFU levels (1045 CFU) by Day 12.

In Phase 2, SoluVet®/EsteriClean® again demonstrated a markedly greater effect, with a 96.7% total reduction between Day 15 pre-cleaning and Day 26 ($P = 0.005$). In contrast, the quaternay disinfectant produced only a partial and inconsistent response, including a rebound in microbial load from 324 CFU to 503 CFU by Day 26.

These patterns remain consistent when analyzing surfaces individually (Tables 2–3). SoluVet®/EsteriClean® maintained very low or zero CFU counts on non-porous surfaces (stainless steel, Formica, preparation table), while the quaternary agent showed greater variability and recurrent increases. The ribbed rubber mat and preparation table classified as high-risk, high-contact surfaces also showed substantially better microbial control under SoluVet®/EsteriClean® treatment.

Overall, the tables demonstrate clear differences between treatments: electrolyzed solutions produced sustained CFU suppression across days, phases, and surface categories, while the quaternary disinfectant showed only short-term reductions with later rebound.

Phase 1 per disinfected Surface

Table 2 shows the effect per day and cumulative effect per treatment on different surfaces. The “tarja” surface in both groups had a statistically significant reduction in the growth of CFU between day 1 and day 5, the quaternary of 93.5% P= 0.03 and being greater with SoluVet®/

EsteriClean® of 100% P= 0.02, on day 12, the quaternary ended with 40 CFU and SoluVet®/ EsteriClean® with 7.5 CFU, showing better effectiveness. On surfaces such as "counter" on day 12 the quaternary had 272.5 CFU and SoluVet®/ EsteriClean® 5 CFU, highlighting that the latter, in the intermediate evaluations there was no growth of mesophiles, something very similar to what is observed on surfaces such as; preparation table (quaternary 1452.5 UFC, SoluVet®/ EsteriClean® 0 UFC), floor (quaternary 4475 UFC, SoluVet®/ EsteriClean® 17.5 UFC) that on day 12 these surfaces disinfected with SoluVet®/ EsteriClean® had less or no growth of mesophilic microorganisms.

Phase 2 per disinfected surface

In the second phase, the experiment where the disinfectant was changed between clinic A and B, the sampling and evaluations were carried out on days 15 before and after disinfection and later on days 19 and 26 post disinfection, it was found that in the "table" surface the quaternary disinfectant had a statistically significant reduction 100% P= 0.02, in contrast to SoluVet®/ EsteriClean® which presented 97.48% reduction ending with 15 CFU, on the "counter" surface SoluVet®/ EsteriClean® reduced 66.7% being significant P= 0.04 (Table 3) concluding with 35 CFU against 695 CFU of the quaternary disinfectant, the preparation table both disinfectants reduced 100% from day 15 before to 15 after disinfection, although it should be noted that by day 26 the surface disinfected with SoluVet®/ EsteriClean® had a 100% statistically significant reduction P= 0.02 concluding with zero CFU, the floor disinfected with ammonium quaternary significantly reduced from day 15 pre to 15 post-disinfection 99.28% P= 0.04 but at the end of the study, when compared to the floor disinfected with SoluVet®/ EsteriClean®, had a 42.6% reduction in CFU versus 2277.5 CFU of the quaternary disinfectant, showing better long-term effectiveness of SoluVet®/ EsteriClean® (Table 3).

RESULTS AND DISCUSSION

Coliform growth

Coliform bacteria were absent on all evaluated surfaces during Phase 1 in both clinics, suggesting adequate baseline hygiene conditions. This aligns with previous reports showing that routine surface cleaning can effectively suppress coliform contamination in veterinary facilities (Willemsen *et al*., 2019). In Phase 2, coliforms appeared only in two isolated pre-cleaning samples: The scale in Clinic B (1600 CFU) and the sink in Clinic A (15 CFU). Both instances resolved immediately after cleaning, with no subsequent growth detected.

This pattern indicates that occasional coliform contamination may be linked to transient lapses in hygiene or environmental re-contamination rather than persistent colonization. Similar sporadic coliform events have been reported in veterinary clinical surfaces, especially those subjected to frequent animal contact (Traverse *et al*., 2015). The rapid elimination of coliforms after applying either disinfectant confirms that both products remained effective in controlling facultative anaerobic bacteria associated with fecal contamination.

Mesophilic reduction

Across both phases, SoluVet®/EsteriClean® consistently produced larger and more sustained reductions in aerobic mesophiles compared with the quaternary ammonium disinfectant. While quaternary ammonium compounds initially reduced microbial load, their efficacy diminished over time, with CFU increasing on several surfaces by the end of each phase. This loss of efficiency has been previously documented and attributed to biofilm persistence and quaternary-resistant strains (Buffet-Bataillon *et al*., 2012).

Table 3: Mesophilic bacterial counts (CFU) by surface type during Phase 2.

Surface	Treatment	Day 15 (pre)	Day 15 (post)	Day 19	Day 26	% change	P-value
Sink	Quaternary	147.5	0	662.5	45	variable	0.23 / 0.75 / 0.25
	SoluVet®	890	20	787.5	0	−100%	0.15 / 0.93 / 0.07
Scale	Quaternary	3062.5	135	17.5	0	−100%	0.08 / 0.28 / 0.19
	SoluVet®	592.5	0	320	20	−96.6%	0.06 / 0.89 / 0.11
Countertop	Quaternary	287.5	12.5	142.5	695	variable	0.14 / 0.75 / 0.75
	SoluVet®	317.5	0	105	35	−89.0%	0.06 / 0.96 / 0.04*
Preparation table	Quaternary	255	0	15	2.5	−99.0%	0.24 / 0.81 / 0.17
	SoluVet®	2232.5	0	82.5	0	−100%	0.19 / 0.97 / 0.02*
Floor	Quaternary	345	2.5	590	2277.5	variable	0.04* / 0.75 / 0.75
	SoluVet®	395	0	135	77.5	−80.4%	0.21 / 0.98 / 0.11

NA = not applicable (zero baseline). P-values calculated using the Wilcoxon signed-rank test. Statistically significant difference (P < 0.05). a = Clinic A (CVM Dermatología Especializada). b = Clinic B (Hospital Veterinario DERMAVET).

Links Researchers

In contrast, electrolyzed superoxidation solutions maintained low microbial counts across days and surfaces. Their broad-spectrum activity has been linked to oxidative damage of the cell membrane and denaturation of microbial proteins (Yan *et al*., 2021), explaining their sustained efficacy. The markedly low CFU counts on high-contact surfaces (e.g., preparation table, counter, floor) align with prior studies showing that neutral-pH electrolyzed solutions outperform conventional disinfectants in environments with continuous organic soil accumulation (Treviño-Garza, 2017).

Comparison across surface types

Surface-level analysis revealed that SoluVet®/EsteriClean® achieved near-total inhibition of mesophilic growth on non-porous surfaces such as stainless steel and Formica, while the quaternary disinfectant demonstrated variable performance. This finding is consistent with research indicating that quaternary ammonium compounds show reduced effectiveness on textured or ribbed surfaces where organic debris can persist (Akwuobu *et al*., 2021). This temporal decline in quaternary ammonium activity, reflected in the progressive rebound of CFU counts and their reduced effectiveness over time, has also been documented in controlled clinical settings where limited reductions in staphylococcal loads were observed despite standardized cleaning protocols (Bennie *et al*., 2022).

On the ribbed rubber mats and stainless-steel preparation table classified as high-risk reservoirs due to frequent contact and challenging textures SoluVet®/EsteriClean® maintained minimal or zero CFU in final evaluations. These results suggest that the oxidative mechanism of action may better penetrate irregular surfaces compared with membrane-active quaternary molecules.

Mechanistic interpretation

Electrolyzed superoxidation generates reactive oxygen and chlorine species capable of broad-spectrum antimicrobial activity, rapid kill times, and degradation of biofilm matrices (Yan *et al*., 2021). These characteristics likely contributed to the consistent microbial reductions observed. In contrast, quaternary ammonium disinfectants rely primarily on membrane disruption, which can be hindered by biofilm presence, organic matter, and the emergence of quaternary-resistant strains (Buffet-Bataillon *et al*., 2012).

Comparison with previous studies

These findings also align with early experimental studies demonstrating the high sanitizing capacity of electrolyzed water on diverse nonporous surfaces (Park *et al*., 2002). Our findings mirror those of Mohapatra *et al*. (2023), who demonstrated a decline in microbial reduction efficiency with prolonged quaternary use in clinical environments. Similarly, Akwuobu *et al*. (2021) documented high contamination persistence on veterinary clinic surfaces cleaned with standard disinfectants, supporting the need for more robust agents such as electrolyzed solutions.

Importantly, the results align with studies showing that electrolyzed oxidizing water maintains superior antimicrobial activity on diverse surfaces, even under organic load (Treviño-Garza, 2017).

Practical implications

The superior and sustained antimicrobial performance of SoluVet®/EsteriClean® suggests important applications for infection control programs in veterinary clinics. Routine use may reduce the risk of healthcare-associated infections, particularly those involving environmental reservoirs and biofilm-producing bacteria. The safety and environmental compatibility of neutral-pH electrolyzed solutions further strengthen their suitability for clinical use.

Limitations and future work

The study focused on mesophilic aerobes and coliforms; future work should include pathogens of veterinary relevance (e.g., MRSP, Pseudomonas aeruginosa). Molecular assays could help determine whether observed reductions correlate with decreased pathogen viability or suppression of antimicrobial-resistant strains. Additionally, evaluating disinfectant performance under different organic load conditions would strengthen external validity.

This study demonstrates that neutral-pH electrolyzed superoxidation solutions (SoluVet®/EsteriClean®) provide superior and more sustained antimicrobial control on veterinary clinical surfaces compared with a quaternary ammonium disinfectant, thereby fulfilling the research objective of evaluating their effectiveness against mesophilic and coliform microorganisms. Electrolyzed oxidizing solutions are known to exert broad-spectrum antimicrobial effects through oxidative disruption of cell membranes, a mechanism that is consistent with the reductions observed in this study (Iram *et al*., 2021). The findings contribute novel, surface-specific evidence to the field of veterinary infection control, highlighting the value of adopting oxidative disinfectants as part of routine biosecurity protocols in small-animal clinics. Given their broad-spectrum activity, environmental compatibility, and consistent performance across surface types, these solutions represent a promising alternative for mitigating the risk of healthcare-associated infections in veterinary settings. Future research should expand this work by incorporating molecular identification of pathogen species, evaluating efficacy under varying organic load conditions, assessing biofilm disruption capacity, and testing the disinfectants in diverse clinical environments to enhance generalizability.

Additionally, long-term surveillance studies and cost-effectiveness analyses would further clarify their practical impact on veterinary public health and clinical operations.

NOVELTY STATEMENT

This study provides the first surface-specific, longitudinal evaluation of neutral-pH electrolyzed superoxidation detergents (SoluVet®/EsteriClean®) compared with a conventional quaternary ammonium disinfectant under real-world conditions in veterinary clinical environments. Unlike previous reports that assess disinfectant efficacy in aggregate or laboratory-controlled settings, this work introduces a standardized classification of high-contact veterinary surfaces and quantifies antimicrobial performance across time, phases, and surface textures. The findings demonstrate not only superior immediate reductions in aerobic mesophilic bacteria but also sustained suppression of microbial rebound on clinically relevant surfaces, including ribbed and high-risk contact areas. By generating robust, surface-oriented evidence using a quasi-experimental rotation design in operational clinics, this study fills a critical gap in veterinary infection control research and offers novel, practice-oriented data to guide evidence-based disinfectant selection and biosecurity protocols in small-animal practice.

AUTHOR'S CONTRIBUTION

CR, AF conceived and designed the experiment. , LM and LR supervised and coordinated the research and provided clinical data. Statistical analysis was conducted by RH, AF. The initial draft of the manuscript was prepared by AF, CR, RH. All authors critically reviewed and approved the final version of the manuscript.

Generative AI and AI-assisted technology statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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