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ORIGINAL ARTICLE

Activity of multipurpose contact lens solutions against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Serratia marcescens* and *Candida albicans* biofilms

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Abstract

Introduction: The use of contact lenses has progressively increased around the world, thereby increasing the risk of complications. The most serious complication is microbial keratitis (corneal infection) that can progress to a corneal ulcer.

Methods: Fourteen multipurpose contact lens solutions were tested on mature biofilms comprising *Staphylococcus aureus, Pseudomonas aeruginosa, Serratia marcescens* and *Candida albicans*, using the minimum disinfection times recommended by the manufacturers. The biofilm was induced in the lens case, and 24 h later, the solutions were added. Activity against planktonic and sessile cells was evaluated and quantified as colony forming units per millilitre. The minimum concentration for biofilm eradication was defined as a 99.9% reduction in viable cells.

Results: Although most solutions exhibited activity against planktonic cells, only five of the 14 solutions produced a significant reduction in the *S. marcescens* biofilm. No solution achieved the minimal biofilm eradication of *S. aureus*, *P. aeruginosa* and *C. albicans*.

Conclusion: Multipurpose contact lens solutions provide greater bactericidal and/or fungicidal activity on planktonic cells than biofilms. The minimal eradication biofilm concentration was only achieved for *S. marcescens*.

KEYWORDS
bacterial keratitis, contact lens, corneal ulcer, disinfection, multipurpose contact lens solution

INTRODUCTION

The use of contact lenses is progressively increasing around the world.[1] In developed countries, their use may approach 10% of the population.[2] This increase is due to the aesthetic use of soft contact lenses to avoid wearing glasses, as well as for visual rehabilitation when glasses do not provide an adequate improvement in vision as occurs in patients with keratoconus and post-corneal transplant.[3] In such situations, rigid gas-permeable lenses are frequently required.

It has been estimated that between 40% and 91% of patients do not follow medical guidelines regarding contact lens care.[4] The lens case is frequently the most contaminated item for contact lens wearers, with contamination being identified in up to 80% of cases.[4] Consequently, case contamination has been identified as the main risk factor for keratitis.[4] Microbial keratitis is the most serious complication for contact lens wearers, with an infection rate of 4–6 per 10,000 lens wearers.[5] The risk of vision loss due to microbial keratitis related to contact lens wear is between 0.3 and 0.9 per 10,000 wearers when all types of contact lenses are included.[5]

It is well known that adhesion and colonisation by microorganisms, particularly bacteria and fungi, on contact lenses and storage cases, as well as suction cups used to remove rigid gas-permeable lenses, are potential sources of ocular contamination.[5] These microorganisms tend to form a biofilm on a colonised surface, characterised by adhesion to the surface and/or adhesion among the microorganisms themselves. The formation of this biofilm is associated with increased antibiotic resistance compared with the planktonic (free living) form, and may pose a risk factor for the development of corneal infections associated with contact lens use.[6]

The organisms in the biofilm alter their metabolic and reproductive rates, becoming more resistant to disinfection.[7] Moreover, many products used to disinfect contact lenses focus only on the growing cells. Planktonic cells, which are cited in the United States Food and Drug Administration (FDA) guidelines for testing of contact lens disinfecting solutions, are much easier to kill than biofilm cells.[7] Currently, for FDA approval, contact lens solutions must demonstrate a reduction of 3 log dilutions and 1 log dilution for the planktonic forms of bacteria and fungi, respectively.[8] However, few studies have investigated the effectiveness of contact lens solutions on biofilms.[9] Furthermore, there is no international regulation regarding the ability of contact lens solutions to prevent or disrupt biofilm formation.[7] Relatively small amounts of biofilm can be removed by following the manufacturers' guidelines (rinsing and air-drying), and the lens case is often the most contaminated item of all lens accessories.[10] Therefore, this study aimed to evaluate the antimicrobial efficacy of 14 multipurpose contact lens solutions (MCLS) on both planktonic cells and biofilms of *Staphylococcus aureus, Serratia marcescens, Pseudomonas aeruginosa* and *Candida albicans*.

Key points

- Contact lens cases can harbour bacteria that are difficult to eradicate as they form a protective layer called a biofilm, thereby preventing the action of contact lens disinfectant solutions.
- Many contact lens disinfection solutions showed poor effectiveness in eliminating those bacteria that formed a biofilm, allowing them to multiply in the case.
- Proper care for contact lens cases is important to prevent the proliferation of bacteria and the formation of biofilms to minimise the risk of infections.

METHODS

This in vitro study was performed in two phases: quantitative antimicrobial analysis of MCLS and analysis of the antimicrobial activity of the MCLS on biofilms. In all tests, the planktonic bacterial or fungal cells and the biofilms remained in contact with the contact lens solutions for the exposure times recommended by the manufacturers, which varied between 4 and 6 h for the 14 solutions tested here (see Table 1 and Table S1). These solutions were chosen because they are available in Brazil, but most are available worldwide.

Bacterial and fungal viability tests were performed by direct exposure of the contact lens solutions to bacterial and fungal cells suspended in phosphate buffered saline (PBS) solution at pH 7.2. *S. aureus* ATCC 25923™, *P. aeruginosa* ATCC 27853™, *S. marcescens* (clinical sample) and *C. albicans* ATCC 10231™ were tested individually at a final concentration of 3×10^6 colony forming units (cfu)/mL. For this test, 100 µL of 0.5 McFarland solution (3×10^8 cfu/mL) was diluted in 9.9 mL of PBS. In glass vials, 1.8 mL of each contact lens solution was individually aliquoted, followed by the addition of 200 µL of the microorganism PBS solution (final concentration of microorganisms: 3×10^5 cfu/mL). The flasks were vortexed for 30 s, then kept static at a temperature of 25°C for the period recommended by the manufacturer of each brand. One millilitre of solution from each vial was aliquoted into another glass vial containing 1 mL of Dey and Engley (D/E) neutralising agar solution (Neogen® Culture Media, neogen.com) and vortexed for 30 s. At the end of agitation, 100 µL was plated on tryptone soy agar (TSA) plates in triplicate to count viable cells. For cfu counting, we have included serial dilution, beginning from 0 (pure) to 1,000,000,000×.

TABLE 1 Multipurpose contact lens solutions (MCLS) tested on planktonic cells and biofilms with the Manufacturer's Minimum Recommended Disinfecting Time (MMRDT).

	MCLS		
Number	**Brand**	**Manufacturer**	**MMRDT (h)**
1	Bio Soak	Teuto	4
2	Ultra Sept	Kley Hertz	4
3	Limp Lent	Vita Medic	4
4	Bio True	Baush & Lomb	4
5	Opto Care	Kley Hertz	4
6	Única Sensitive	Avizor	4
7	Opti-Free RepleniSH	Alcon	6
8	Opti-Free PureMoist	Alcon	6
9	Clear Lens Solution Multiuse	Opto Lentes	4
10	Renu Sensitive	Baush & Lomb	4
11	Renu Fresh	Baush & Lomb	4
12	Clear Lens Solution	Opto Lentes	4
13	Clear Lentes Solution	Opto Lentes	4
14	Boston Simplus	Baush & Lomb	4

Biofilm formation of the aforementioned microorganisms was induced in lens storage kits, and the microorganisms were tested individually. Figure 1 demonstrates the presence of a biofilm in the lens storage case using crystal violet stain. From a 0.5 McFarland turbidity solution, 1 mL of this broth was diluted in 9 mL of tryptic soy broth for a final concentration of 10^7 cfu/mL. For each kit, 4 mL of the broth was aliquoted per well, totalling 8 mL per kit. For each solution, two kits were used per microorganism (tested in quadruplicate). After 24 h of incubation at 37°C, the broths were discarded. The wells were washed with 1 mL

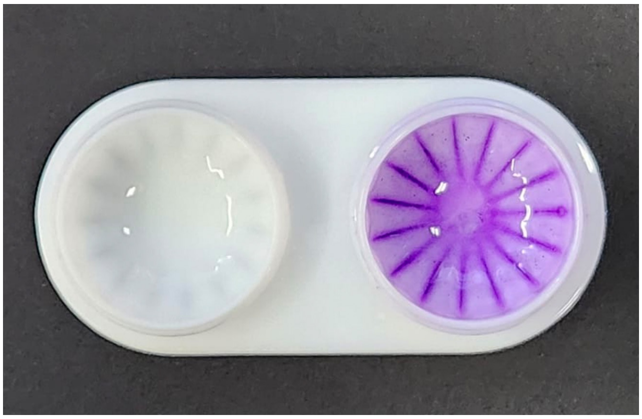

FIGURE 1 An example of a biofilm (*Staphylococcus aureus*) observed in a contact lens storage case coloured by crystal violet.

of saline solution to remove planktonic cells, followed by the addition of 4 mL of each contact lens solution per well and again incubated at 37°C for the time recommended by each manufacturer. After the recommended exposure time, the contact lens solutions were discarded and swabs (Global Trade®, globaltradebr.com.br) used for mechanical removal of the biofilms. The swabs were placed individually in 15 mL sterile conical tubes containing 10 mL of D/E neutralising agar and vortexed for 30 s. From these tubes, serial dilutions were performed for cultivation on TSA plates, in which 100 μL was plated and incubated at 37°C for 24 h. The minimum concentration for biofilm eradication was determined as 99.9% of viable cell reduction. NaCl 0.9% was used as a control solution.

The number of microorganisms on the plates were expressed as the median and interquartile ranges (25%–75%).

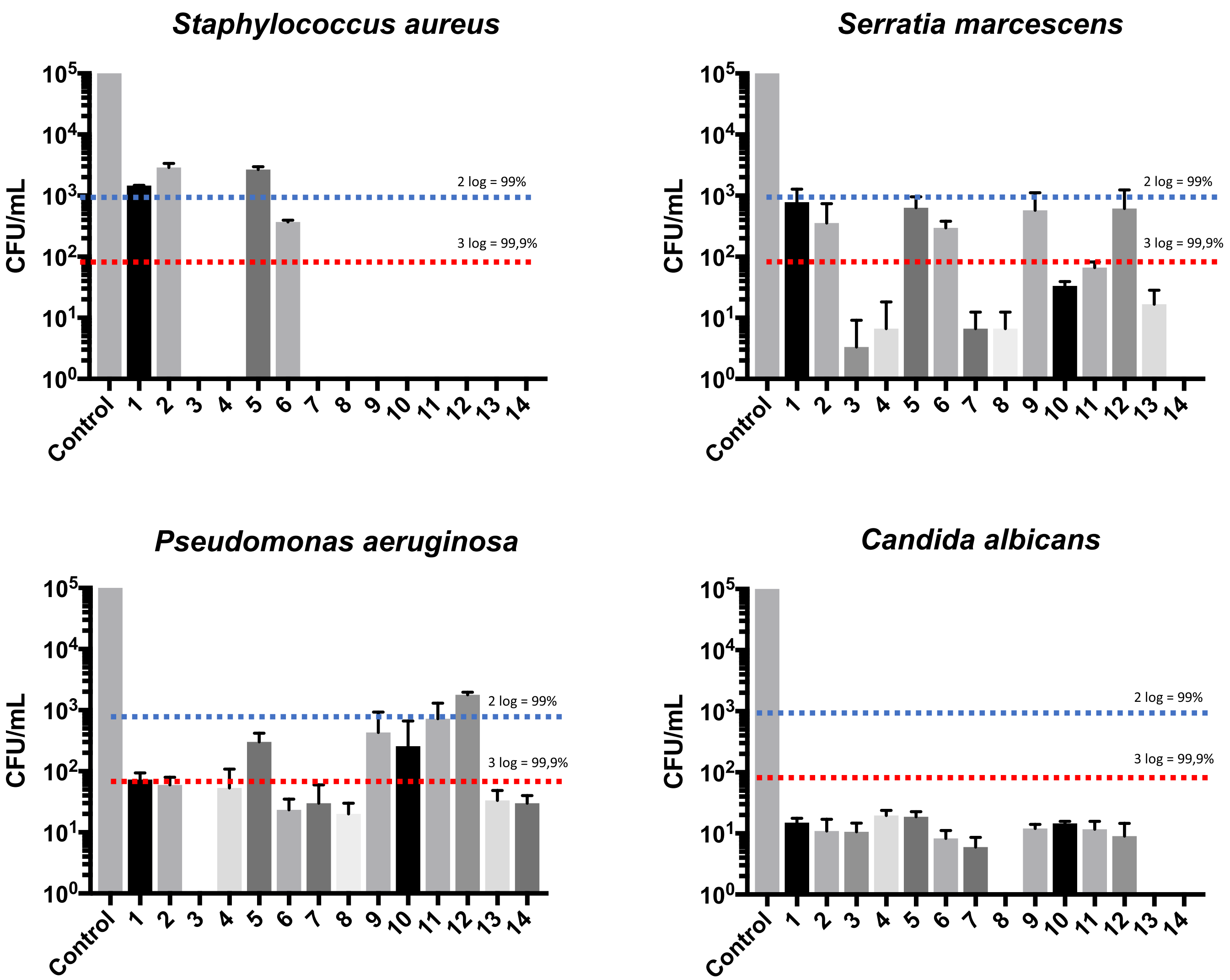

FIGURE 2 Antimicrobial activity of multipurpose contact lens solutions on planktonic cells for the four microorganisms examined here. The blue and red dashed lines represent two and three log reductions, respectively, compared with the control group. The *x*-axis indicates the 14 solutions tested, namely: (1) Bio Soak (Teuto), (2) Ultra Sept (Kley Hertz), (3) Limp Lent (Vitamedic), (4) Bio True (Bausch & Lomb), (5) Opto Care (Kley Hertz), (6) Única Sensitive (Avizor), (7) Opti-Free Replenish (Alcon), (8) Opti-Free PureMoist (Alcon), (9) Clear Lens Solution Multiuse (Optolentes), (10) Renu Sensitive (Bausch & Lomb), (11) Renu Fresh (Bausch & Lomb), (12) Clear Lens Solution Cleaning (Optolentes), (13) Clear Lentes Solution Conservated (Optolentes) and (14) Boston Simplus (Bausch & Lomb). cfu, colony forming units.

To compare the effect of the different contact lens solutions on the activity of planktonic cells and biofilms, a non-parametric test was applied due to the non-normal distribution of the data. $p<0.05$ was considered to represent a statistically significant difference in cell counts between the solutions. Statistical analysis was conducted using GraphPad Prism 7.0 (graphpad.com/).

RESULTS

Figure 2 shows the antimicrobial activity of the MCLS against planktonic cells. For the direct antimicrobial evaluation of *S. aureus*, all solutions achieved a reduction of microorganisms compared with the control ($p<0.05$). With the exception of solutions 1 (Bio Soak® – teuto.com.br), 2 (Ultra Sept® – hertzfarma.com.br), 5 (Opto Care® – hertz farma.com.br) and 6 (Única Sensitive® – avizor.com), all other solutions reduced the number of microorganisms to zero. For *S. marcescens*, all solutions achieved a reduction of at least 2 log units compared with the control. A reduction of at least 3 log units was observed for solutions 3 (Limp Lent® – vitamedic.ind.br), 4 (Bio True® – bausch.com.br), 7 (Opti-Free RepleniSH® – alcon.com), 8 (Opti-Free PureMoist® – alcon.com), 10 (Renu Sensitive® – renu.com), 11 (Renu Fresh® – renu.com) and 13 (Clear Lens Solution® – optolentes.com.br). Solution 14 (Boston Simplus® – renu.com.br) reduced the *S. marcescens* count to zero, while solution 9 (Clear Lens Solution Multiuse® – optolentes.com.br) reduced the count by 2 log units.

The antimicrobial evaluation of *P. aeruginosa* revealed that all solutions reduced the number of microorganisms ($p<0.05$). Those solutions that obtained a reduction of ≥3 log units were solutions 1 (Bio Soak®), 2 (Ultra Sept®), 4 (Bio True®), 6 (Única Sensitive®), 7 (Opti-Free RepleniSH®), 8 (Opti-Free PureMoist®), 13 (Clear Lens Cleaning Solution®) and 14 (Boston Simplus®). Only solution 3 (Limp Lent®) reduced the *P. aeruginosa* count to zero.

For *C. albicans*, all MCLS reduced the count by >3 log units, exceeding the FDA requirement for fungi of a reduction >1 log unit. Three solutions reduced the count to zero: solution 8 (Opti-Free PureMoist®), 13 (Clear Lens Cleaning Solutions®) and solution 14 (Boston Simplus®).

Figure 3 illustrates the antimicrobial activity of the MCLS against biofilms. Evaluation of the solutions on the *S. aureus* biofilm revealed that solutions 5 (Opto Care), 6 (Única Sensitive® – avizor.com), 7 (Opti-Free RepleniSH®) and 8 (Opti-Free PureMoist®) provided some reduction in the count ($p<0.05$), but only solutions 7 (Opti-Free RepleniSH®) and 8 (Opti-Free PureMoist®) achieved a reduction >1 log unit. Counts similar to or higher than the control were seen for the remaining solutions. Hence, the 3-log reduction required for bacteria was not achieved by any of the solutions. For the *S. marcescens* biofilm, with the exception of solutions 12 (Clear Lens Conservative Solution®, optolentes.com.br) and 13 (Clear Lens Cleaning Solution®), all solutions provided reductions >2 log units. The MCLS that reduced counts by at least 3 log units were solutions 5 (Opto Care®), 7 (Opti-Free RepleniSH®), 8 (Opti-Free PureMoist®), 11 (Renu Fresh®) and 14 (Boston Simplus®). Solutions 5 (Opto Care®) and 8 (Opti-Free PureMoist®) achieved significant reductions ($p=0.0006$ and 0.02, respectively). For the *P. aeruginosa* biofilm, with the exception of solution 12 (Clear Lens Conservative Solution®), all demonstrated some degree of reduction in the count ($p<0.05$). A reduction of 1 log unit was achieved by solutions 1 (Bio Soak®), 2 (Ultra Sept®), 3 (Limp Lent®), 4 (Bio True®), 5 (Opto Care®) and 14 (Boston Simplus®). No solution provided a reduction ≥2 log units (Figure 3, Graph C). No MCLS achieved a reduction of 1 log unit on the *C. albicans* biofilm. With the exception of solutions 5 (Opto Care®), 7 (Opti-Free RepleniSH®), 8 (Opti-Free PureMoist®), 11 (Renu Fresh®) and 14 (Boston Simplus®) that achieved significant reduction in *S. marcescens*, the remaining solutions were ineffective in reducing the biofilms formed by other microorganisms.

Table 2 shows the effectiveness of each MCLS based on the criteria used for FDA approval of contact lens solutions (i.e., a 3 log unit reduction for bacteria and a 1 log unit reduction for fungi), based on the International Standards Organization (ISO) 14,729. Regarding the biofilms, no solution was effective against all four pathogens simultaneously using the FDA criteria for the evaluation of planktonic cells or microorganism concentration.

DISCUSSION

Evaluation of the antimicrobial action of a large number of MCLS on the concentration of microorganisms revealed that Limp Lent®, Bio True®, Opti-Free RepleniSH®, Opti-Free PureMoist®, Clear Lens Cleaning Solution® and Boston Simplus® achieved the best results regarding simultaneous impact on the four microorganisms tested here.

In a previous study, Szczotka-Flynn et al.[11] examined the antimicrobial action of five contact lens solutions, namely Renu Multiplus® and Renu with MoistureLoc® (Bausch& Lomb), Complete MoisturePlus® (Advanced Medical), AQuify® (Ciba Vision) and Opti-Free RepleniSH® (Alcon) on both planktonic cells and the biofilm formed on silicone hydrogel lenses composed of Lotrafilcom A. All solutions were effective against the growth of planktonic *P. aeruginosa*, *S. marcescens* and *S. aureus*.[11] However, with regard to the biofilm, the solutions preserved with biguanide were generally ineffective (Renu fresh® [Bausch & Lomb], Renu sensitive® [Bausch & Lomb], Bio true® [Bausch & Lomb], Boston simplus® [Bausch & Lomb], Bio soak® [Teuto], Ultra sept® [Kley Hertz] and Opto care® [Kley Hertz]). The solution preserved with polyquaternium-1 (Opti-Free RepleniSH® [Alcon]) was effective against *P. aeruginosa* and *S. aureus* biofilms, but not against the *S. marcescens* biofilm. In the present study, the MCLS were also more effective against planktonic cells than the formed biofilm, although there were differences between these two investigations. In the present study, we performed biofilm induction using

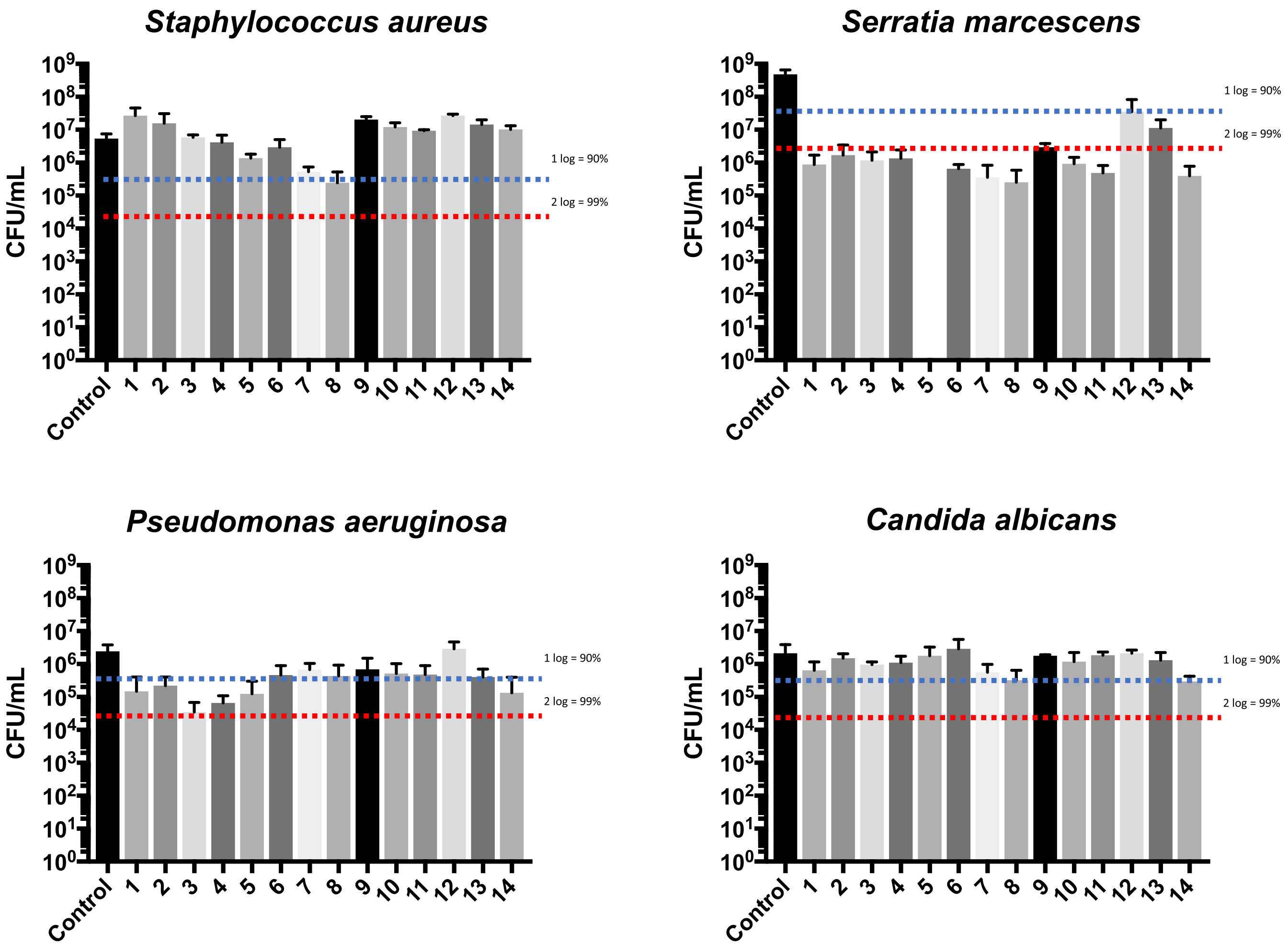

FIGURE 3 Antimicrobial activity of MCLS against biofilms for the four microorganisms examined here. The dashed lines represent 1 and 2 log unit reductions compared with the control group. For *Pseudomonas aeruginosa* and *Candida albicans*, the dashed lines represent 1 log reduction. The *x*-axis indicates the 14 solutions tested, namely: (1) Bio Soak (Teuto), (2) Ultra Sept (Kley Hertz), (3) Limp Lent (Vitamedic), (4) Bio True (Bausch & Lomb), (5) Opto Care (Kley Hertz), (6) Única Sensitive (Avizor), (7) Opti-Free Replenish (Alcon), (8) Opti-Free PureMoist (Alcon), (9) Clear Lens Solution Multiuse (Optolentes), (10) Renu Sensitive (Bausch & Lomb), (11) Renu Fresh (Bausch & Lomb), (12) Clear Lens Solution Cleaning (Optolentes), (13) Clear Lentes Solution Conservated (Optolentes) and (14) Boston Simplus (Bausch & Lomb). cfu, colony forming units.

standardised kits whereas Szczotka-Flynn et al.[11] induced a biofilm on silicone hydrogel contact lenses. Nevertheless, similar results were obtained.

In a study by Lin et al.,[12] five commercially available solutions (Boston Simplus®, Boston Advance®, Opti-free, Menicare GP® and Lobob®) were tested against *P. aeruginosa* and methicillin-resistant *S. aureus* (MRSA). The Boston Simplus solution displayed the most potent anti-staphylococcal activity, whereas the Menicare GP® solution exhibited the most potent anti-pseudomonal activity. Other solutions were less effective against *P. aeruginosa* than against MRSA. The results indicated that solutions preserved with biguanide demonstrated greater anti-staphylococcal activity whereas solutions preserved with EDTA (ethylenediaminetetraacetic acid) exhibited greater anti-pseudomonal activity. In the current investigation, five solutions that were ineffective against *P. aeruginosa* contained both biguanide and EDTA; hence, the presence of EDTA does not appear to be a determining factor for the effectiveness of the solutions against *P. aeruginosa*. Here, Limp Lent solution, which reduced the *P. aeruginosa* count in the concentrated microorganism form to zero contained polyvinylpyrrolidone and polyhexanide. With regard to our results on *S. aureus*, we cannot confirm that biguanide was the determining factor affecting anti-staphylococcal action because Bio Soak®, Ultra Sept® and Opto Care® contained both biguanide and EDTA, while Única Sensitive® containing polyhexanide and EDTA exhibited no action on the direct form of *S. aureus*.

Solutions containing simple associations such as EDTA and biguanide (Renu fresh® [Bausch & Lomb], Renu sensitive® [Bausch & Lomb], Bio true® [Bausch & Lomb], Boston simplus® [Bausch & Lomb], Bio soak® [Teuto], Ultra sept® [Kley Hertz] and Opto care® [Kley Hertz]), or EDTA and polyhexanide (Unica sensitive® [Avizor], Limp lent® [Vitamedic] and Clear lens solution cleaning® [Optolentes], Clear lens solution Conservative® [Optolentes] and Clear lens solution Multiuse® [Optolentes]), were ineffective against the four pathogens simultaneously, when tested on a concentrate

TABLE 2 Effectiveness of multipurpose contact lens solutions (MCLS) on planktonic forms based on the FDA definition for the four microorganisms examined here.

	Planktonic cells			
MCLS	*Staphylococcusaureus*	*Serratia marcescens*	*Pseudomonas aeruginosa*	*Candida albicans*
1	NE	NE	E	E
2	NE	NE	E	E
3	E	E	E	E
4	E	E	E	E
5	NE	NE	NE	E
6	NE	NE	E	E
7	E	E	E	E
8	E	E	E	E
9	E	NE	NE	E
10	E	E	NE	E
11	E	E	NE	E
12	E	NE	NE	E
13	E	E	E	E
14	E	E	E	E

Note: The left-hand column indicates the following 14 solutions tested: (1) Bio Soak (Teuto), (2) Ultra Sept (Kley Hertz), (3) Limp Lent (Vitamedic), (4) Bio True (Bausch & Lomb), (5) Opto Care (Ley Hertz), (6) Única Sensitive (Avizor), (7) Opti-Free Replenish (Alcon), (8) Opti-Free PureMoist (Alcon), (9) Clear Lens Solution Multiuse (Optolentes), (10) Renu Sensitive (Bausch & Lomb), (11) Renu Fresh (Bausch & Lomb), (12) Clear Lens Solution Cleaning (Optolentes), (13) Clear Lentes Solution Conservation (Optolentes) and (14) Boston Simplus (Bausch & Lomb).

Abbreviations: E, effective; FDA, Food and Drug Administration; NE, non-effective.

of microorganisms. However, it is important not to use the results from the present study to compare with tests used for FDA approval, because of the different methodology. The concentration of planktonic cells here varied with the biofilm. This was a greater demand than that required for the standard testing of solutions to meet FDA approval.

In the investigation of Rosenthal et al.,[13] poor adherence to lens hygiene, such as the absence of friction, varying the volume of solution used for rinsing the lenses or the total absence of rubbing and rinsing of the lenses before subjecting them to disinfection with the contact lens solution was simulated. Additionally, five microorganisms were tested: *S. aureus, P. aeruginosa, S. marcescens, C albicans* and *Fusarium solani*. The results revealed that Opti-Free Express® MCLS containing polyquaternium-1 and Aldox demonstrated superior antimicrobial capacity compared with solutions containing polyhexamethylene biguanide. These results are in agreement with the findings of the present investigation.

Nevertheless, the results obtained here must be analysed carefully, as most validation tests use standardised strains, so that products can be compared with one another and over time. But in real life, the resistance of the same species of microorganisms can vary. For instance, Hume et al.[14] evaluated different strains of *S. marcescens* and observed that the effectiveness was variable among clinical isolates. The use of a single laboratory strain may be insufficient to provide assurance that the disinfection solution will be effective against clinical isolates.

In the present study, because there are no established criteria for evaluating the formed biofilm, we applied the same criteria used for the planktonic cells. With the exception of Opto Care®, Opti-Free RepleniSH®, Opti-Free PureMoist®, Renu Fresh® and Boston Simplus® that reduced *S. marcescens* significantly, the remaining solutions were ineffective in reducing the biofilms formed for other microorganisms.

Some solutions achieved <3 log unit reductions for bacteria. Considering the four microorganisms tested here, there was a reduction of at least 1 log unit (90% reduction) with two or more solutions for each microorganism, with the exception of the *C. albicans* biofilm where no solution achieved the minimum reduction of 1 log unit. When considering *C. albicans* in isolation, the solutions were quite effective against planktonic cells, with a reduction exceeding 1 log unit in all cases; however, no solution achieved a reduction above 1 log unit for the biofilm. These results indicate that the *C. albicans* biofilm is more resistant to antimicrobial action than its planktonic form. This suggests a heightened risk of fungal colonisation once the biofilm has been formed. There is no consensus regarding the minimum concentration for biofilm eradication. Use of the term 'eradication' suggests that all biofilm viable cells should be killed. However, the definition varies from 100% killing activity to a 2 log unit reduction or 95% reduction in a cell's viability.[15] We used a 3 log unit of cell viability (i.e., 99.9% reduction of cell viability reduction), although this is not a standard definition.

The exposure time appears to be an important factor regarding MCLS activity. In a previous study, MCLS were tested against *P. aeruginosa, S. aureus* and *C. albicans*.[16] The activity against biofilms was examined after different periods of MCLS exposure (6, 12, 24, 36 and 48 h). The results showed that for the first 6 h, only Opti-Free® MCLS achieved a 3 log unit reduction for the contact lens biofilm These findings imply that an exposure time ≤ 6 h is inadequate to eradicate a biofilm of bacteria or fungi from contact lenses. The solution showing the highest activity against *P. aeruginosa* and *S. aureus* was Opti-Free®, followed by Bio-True® and Renu® after 24 h, while the solution with the highest activity against *C. albicans* was Renu®, followed by Opti-Free® and Bio True® after 48 h. It is important to emphasise that the MMRDT indicated by the manufacturer varies from 4 to 6 h. Therefore, for daily use, this is the minimum duration for which contact lenses need to be exposed to the solution. Accordingly, solutions need to achieve maximum bactericidal or fungicidal effect during this stipulated period, and not over a longer period of time, as the latter would not generally be adopted in clinical practice.

Use of MCLS for the MMRDT alone is not sufficient to prevent contamination. For optimal contact lens wear, it is important to educate patients regarding good adherence to hygiene. Guidelines should include the following: (1) Wash and dry your hands before handling contact lenses, while avoiding water residue on your hands; (2) Clean the lenses with a multipurpose solution after removing them, applying light mechanical friction followed by rinsing the lenses with the same solution; (3) Disinfect the lens case with the MCLS for the MMRDT; (4) After disinfection, the solution that was in the case must be discarded and refreshed daily; (5) Soft contact lenses must be discarded according to the schedule established by the manufacturer, that is, daily, fortnightly, monthly or annually; (6) Avoid contact with tap water due to the risk of *Acanthameba* keratitis and (7) The case and suction cups should be cleaned weekly and replaced at least every 3 months.

In this study, the MCLS currently available on the Brazilian market were more effective against planktonic cells than biofilms. In clinical practice, the biofilm form of microorganisms is more likely to be encountered and, therefore, can perpetuate the cycle of microbial proliferation that may culminate in keratitis (corneal ulcer). As such, the eyecare practitioner must guide the patient appropriately regarding the disposal and frequent changing of lens cases and suction cups, discarding of contact lenses at the correct time as well as the importance of rubbing the contact lens prior to disinfection. These measures may mitigate the inherent risk. Future research is required to develop innovative products that provide an effective antimicrobial action on biofilms.

AUTHOR CONTRIBUTIONS

Jamile Reimann Mendonca: Conceptualization (equal); investigation (equal); writing – original draft (equal); writing – review and editing (equal). **Leticia Ramos Dantas:** Conceptualization (equal); investigation (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal). **Felipe Francisco Tuon:** Conceptualization (equal); investigation (equal); formal analysis (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal).

FUNDING INFORMATION

None.

CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

All data are available upon request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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