Corneal infiltrative events (CIEs) result from single or multiple clusters of immune cells (primarily neutrophils but also lymphocytes and macrophages) that have migrated from the limbal vasculature to the cornea.1,2

The presentation of contact lens-related CIEs is variable and ranges from small, generally asymptomatic, peripheral lesions limited to the corneal epithelium to central stromal ulcers that may result in pain and loss of vision.3 Both asymptomatic and symptomatic CIEs are relatively common4 and can be costly; in the United States in 2010,5 there were 32,031 non-severe (score more than eight out of 10 relevant signs and symptoms, based on the Aasuri, Venkata and Kumar6 matrix) and 17,248 severe (score more than eight out of 10 relevant signs and symptoms and typically requiring intervention; also based on the Aasuri, Venkata and Kumar6 matrix) contact lens-related CIEs, with an overall associated cost of $58 million.5,6 Symptomatic CIEs can result in substantial patient burden, including interruption of contact lens wear, visits to an optometrist, ophthalmologist and/or emergency department and loss of work time.5

Several factors are associated with increased risk for CIEs, including male gender,7,8 age up to 50 years,9,10 overnight contact lens wear,10,11,12 contact lens wear six days or more per week9,10,12 contact lens wear six days or more per week9,12 and bacterial adhesion to contact lenses (lens bioburden).8,12–15 These risk factors have repeatedly been shown to have a high degree of correlation with CIEs.

Studies reveal that lens cases can act as conduits for lens contamination, with the lens acting as a vector, transferring bacteria from the lens case to the eye.16–19 A recent review of the literature (11 studies over the past two decades) listed a range of 24 to 81 per cent positive bacterial bioburden in lens cases.17
Biofilm, the protective medium that functions to enhance the antibiotic and antiseptic resistance of bacteria, serves to improve their adherence to lens case surfaces. Biofilm is also a frequent factor in the failure of lens care products to effectively protect against lens case contamination. After becoming established in a lens case, biofilm can become resistant to the biocidal activity of lens care products; this can result in colonisation on the lens of resistant bacteria in the case, which can then be transferred onward to the ocular surface. In particular, Gram-negative bacteria such as *Delftia*, *Stenotrophomonas* and *Achromobacter* are prone to forming biofilms. Assessment using 16S ribosomal RNA gene sequencing of lens bioburden in lens cases from patients with contact lens-related corneal disease, found *Delftia*,

| Lens care solution (brand; manufacturer) | Formulation | Manufacturer-recommended soak time |
|------------------------------------------|-------------|-----------------------------------|
| PHMB*/PQ-1 (Biotrue; Bausch + Lomb)      | Hyaluronan, sulfobetaine, poloxamine, boric acid, sodium borate, edetate disodium and sodium chloride and preserved with a dual disinfection system polyaminopropyl biguanide* 0.00013 per cent and polyquaternium 0.0001 per cent | Four hours |
| Alexidine/PQ-1 (RevitaLens OcuTec; Abbott Medical Optics) | Alexidine dihydrochloride 0.00016 per cent and polyquaternium-1 0.00030 per cent as preservatives/ disinfectants, boric acid, sodium borate decahydrate, Tetronic 904, edetate disodium, trisodium citrate dihydrate, sodium chloride and purified water | Six hours |
| PQ-1/MAPD-1 (Opti-Free PureMoist; Alcon) | Sodium citrate, sodium chloride, boric acid, sorbitol, aminomethylpropanol, disodium ethylenediaminetetraacetic acid, two wetting agents (Tetronic 1304 and Hydroglide Moisture Matrix [EOBO-41- polyoxyethylene-polyoxybutylene]) with Polyquad (polyquaternium-1) 0.001 per cent and Aldox (myristamidopropyl dimethyamine) 0.0006 per cent preservatives | Six hours |
| PQ-1/MAPD-2 (Opti-Free RepleniSH; Alcon) | Sodium citrate, sodium chloride, sodium borate, propylene glycol, Tearglyde proprietary dual action reconditioning system (Tetronic 1304 nonanoyl ethylenediaminetriacetic acid) with Polyquad (polyquaternium-1) 0.001 per cent and Aldox (myristamidopropyl dimethyamine) 0.0005 per cent preservatives | Six hours |
| PQ-1/MAPD-3 (Opti-Free Express; Alcon) | Sodium citrate, sodium chloride, boric acid, sorbitol, aminomethylpropanol, Tetronic 1304, with edetate disodium 0.05 per cent, Polyquad (polyquaternium-1) 0.001 per cent and Aldox (myristamidopropyl dimethyamine) 0.0005 per cent preservatives | Six hours |

*The disinfectant polyaminopropyl biguanide is a type of polyhexamethylene biguanide (PHMB).

Table 1. Multipurpose solutions evaluated for biocidal activity

| Multipurpose solution formulation | *Achromobacter xylosidans* (mean log reduction) | *Delftia acidovorans* (mean log reduction) | *Stenotrophomonas maltophilia* (mean log reduction) |
|----------------------------------|-----------------------------------------------|------------------------------------------|-----------------------------------------------|
| PHMB/PQ-1                        | 2.90*                                         | 4.60†                                    | 3.50*                                         |
| Alexidine/PQ-1                   | 3.67†                                         | 4.80‡                                    | 5.00NA                                        |
| PQ-1/MAPD-1                      | 0.13                                          | 2.97                                     | 1.23                                          |
| PQ-1/MAPD-2                      | −0.03                                         | 1.40                                     | 1.33                                          |
| PQ-1/MAPD-3                      | 0.20                                          | 2.93                                     | 1.20                                          |

PHMB/PQ-1 manufacturer recommended soak time = four hours; all others = six hours. Mean log reductions in bold indicate statistical significance.

NA = As alexidine results had no variation, comparisons with this formulation used median results. Median p ≤ 0.05 versus PQ-1/MAPD-1, -2, -3.

*p ≤ 0.05 versus PQ-1/MAPD-1, -2, -3.

†p ≤ 0.01 versus PQ-1/MAPD-1, -2, -3.

‡p ≤ 0.001 versus PQ-1/MAPD-1, -2, -3.

Table 2. Stand-alone testing against corneal infiltrative event-associated bacterial strains
Stenotrophomonas and Achromobacter in significant amounts in contact lens cases from patients with CIEs compared with cases from control patients.\textsuperscript{18} Studies have found that Gram-negative isolates have demonstrated resistance to multiple polyquaternium-1 (PQ-1)/myristamidopropyl dimethylamine (MAPD) multipurpose solutions.\textsuperscript{20–22} The first of these studies to demonstrate this resistance was Willcox and colleagues\textsuperscript{22} in lens cases exposed to a PQ-1/MAPD solution. Additionally, comparing PQ-1/MAPD solutions (PQ-1/MAPD-1, -2 and -3; Table 1), a polyhexamethylene biguanide (PHMB)-based and a hydrogen peroxide-based solution system showed that lens cases containing PQ-1/MAPD-2 had significantly higher mean colony-forming units (CFUs) of Gram-negative bacteria (\textit{D. acidovorans}, \textit{Stenotrophomonas maltophilia} and \textit{Achromobacter Group A}) than did lens cases containing any other solution.\textsuperscript{22}

Multipurpose solutions are formulated to reduce the potential for microbial insult to the ocular surface and are successful insofar as they effectively reduce the vectored transmission of microbes from a lens case via a contact lens to the wearer’s eye. The present study assessed the biocidal efficacy of different multipurpose solutions, using International Organization for Standardization (ISO) 14729 as a guideline in stand-alone conditions against three Gram-negative bacterial strains closely associated with CIEs, as well as in lens cases and in lens cases with a lens.

**METHODS**

**Materials**

**MULTIPURPOSE SOLUTIONS**

Three unique formulations were tested: one multipurpose solution formulation containing preservative agents PHMB and PQ-1 (Bausch & Lomb Incorporated: Biotrue), one containing alexidine dihydrochloride (alexidine) and PQ-1 (AMO: RevitaLens OcuTec) and three multipurpose solutions based on PQ-1/MAPD combinations (Alcon: Opti-Free PureMoist, PQ-1/MAPD-1; Opti-Free RepleniSH, PQ-1/MAPD-2; Opti-Free Express, PQ-1/MAPD-3) (Table 1).

**BACTERIAL STRAINS**

The challenge organisms, \textit{Achromobacter xylosoxidans} (ATCC 27061), \textit{Delftia acidovorans} (ATCC 17438) and \textit{Stenotrophomonas maltophilia} (clinical isolate) were used for stand-alone testing as well as testing of the multipurpose solutions in lens cases and in lens cases with a lens, as they are increasingly identified in CIEs diagnosed from contact lens wearers.\textsuperscript{18} Each organism was prepared according to ISO 14729. Organic...
Biocidal activity of multipurpose solutions Callahan, Kovacs, Lynch and Rah

Table 3. Testing against corneal infiltrative event-associated bacterial strains in a lens case

| Multipurpose solution formulation | Achromobacter xylosoxidans (mean log reduction) | Delftia acidovorans (mean log reduction) | Stenotrophomonas maltophilia (mean log reduction) |
|-----------------------------------|-----------------------------------------------|------------------------------------------|-------------------------------------------------|
| Four-hour soak                    |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.23*                                         | 4.73*                                    | 4.87†                                            |
| Alexidine/PQ-1                    | 4.50†                                         | 4.33*                                    | 4.97†                                            |
| PO-1/MAPD-1                       | 0.57                                          | 1.80                                     | 0.93§                                            |
| PO-1/MAPD-2                       | 0.40                                          | 0.33                                     | 0.70                                             |
| PO-1/MAPD-3                       | 0.73                                          | 1.77                                     | 1.07‡                                            |
| Six-hour soak                     |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.93‡                                         | 4.90‡                                    | 4.97†                                            |
| Alexidine/PQ-1                    | 3.93‡                                         | 4.90‡                                    | 4.97†                                            |
| PO-1/MAPD-1                       | 0.33                                          | 1.87                                     | 1.20                                             |
| PO-1/MAPD-2                       | 0.27                                          | 0.60                                     | 0.73                                             |
| PO-1/MAPD-3                       | 0.53                                          | 1.53                                     | 1.50§                                            |
| 24-hour soak                      |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.93†                                         | 4.90‡                                    | 4.97*                                            |
| Alexidine/PQ-1                    | 4.93†                                         | 4.90‡                                    | 4.97*                                            |
| PO-1/MAPD-1                       | 1.70§                                         | 3.10§                                    | 2.53§                                            |
| PO-1/MAPD-2                       | 0.13                                          | 0.07                                     | 0.67                                             |
| PO-1/MAPD-3                       | 1.83§                                         | 2.37§                                    | 2.47§                                            |
| 7-day soak                        |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.93**                                        | 4.90§                                    | 4.97**                                           |
| Alexidine/PQ-1                    | 4.93**                                        | 4.90§                                    | 4.97**                                           |
| PO-1/MAPD-1                       | 4.93**                                        | 3.83**                                   | 4.97**                                           |
| PO-1/MAPD-2                       | –0.1                                          | -0.87                                    | -0.27                                            |
| PO-1/MAPD-3                       | 4.93**                                        | 4.07**                                   | 4.97**                                           |

Mean log reductions in bold indicate statistical significance.

*p ≤ 0.05 versus PQ-1/MAPD-1, -2, -3.
*p ≤ 0.01 versus PQ-1/MAPD-1, -2, -3.
*p ≤ 0.001 versus PQ-1/MAPD-1, -2, -3.
*p ≤ 0.05 versus PO-1/MAPD-2.
*p ≤ 0.05 versus PO-1/MAPD-1, -2.
*p ≤ 0.01 versus PO-1/MAPD-2.
*p ≤ 0.01 versus PO-1/MAPD-2, -3.
*p ≤ 0.001 versus PQ-1/MAPD-2.

Biocidal activity in test tubes of the five multipurpose solutions against the three Gram-negative bacterial strains associated with CIEs (A. xylosoxidans, D. acidovorans and S. maltophilia). Test organisms were resuspended in 10 per cent organic soil to yield a final concentration of approximately 5.0 × 10^5 CFUs/ml. Efficacy was evaluated at manufacturers’ recommended soak times: PHMB/PQ-1 for four hours and alexidine/PQ-1, PQ-1/MAPD-1, PQ-1/MAPD-2, PQ-1/MAPD-3 for six hours.23–27

**BIOCIAL EFFICACY TESTING OF MULTIPURPOSE SOLUTIONS IN A LENS CASE**

Biocidal testing (three separate assays) was performed on each multipurpose solution directly in the manufacturer-provided polypropylene lens cases, each of which was aseptically filled with 3.0 ml of the respective manufacturer’s multipurpose solution. Each solution was inoculated with the challenge organisms, A. xylosoxidans, D. acidovorans or S. maltophilia, resuspended in 10 per cent organic soil at a final concentration of approximately 5.0 × 10^5 CFU/ml. Cases were vortexed and 1.0 ml of test solution was aliquoted from the lens case well; test solutions were neutralised with Dey Engley Broth (Remel, a division of Thermo Fisher Scientific, Lenexa, Kansas, USA) and plated with trypticase soy agar (Becton Dickinson and Co, Sparks, Maryland, USA) at four, six and 24 hours, as well as at seven days for recovery of organisms. Surviving microbes were enumerated and log reduction values relative to the inoculum control were calculated. Three lots of each multipurpose solution were tested on three separate days.

**BIOCIAL EFFICACY TESTING OF MULTIPURPOSE SOLUTIONS IN THE PRESENCE OF A LENS**

Testing with etafilcon A contact lenses was based on ISO 18259 (system biocidal).3 Lenses were placed in the manufacturer-provided polypropylene lens cases and were inoculated with 0.1 ml of test inoculum of the challenge organisms, A. xylosoxidans, D. acidovorans or S. maltophilia, resuspended in 10 per cent organic soil at a final concentration of approximately 5.0 × 10^5 CFU/ml and left in contact with the test lens for five to 10 minutes. Only one side of the lens case was used and a separate case was used at each time (four, six and 24 hours,

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as well as at seven and 30 days). Each manufacturer-provided polypropylene lens case was aseptically filled with 3.0 ml of the respective manufacturer’s multi-purpose solution. The lens was completely immersed in the solution and the lens case was capped, taking care not to agitate the contents of the case to eliminate potential contamination of the lens cap. Prior to each time point, lens cases were vortexed, after which the lens was removed and one millilitre was aliquoted from the lens case well. Test solutions were neutralised with Dey Engley Broth and plated with trypticase soy agar for recovery of organisms. Surviving microbes were enumerated and log reduction values relative to the inoculum control were calculated. All assays were performed in triplicate.

**Calculations and statistical analysis**

Log reduction values were calculated by determining CFU counts, after which the mean log value for each lens care solution was subtracted from its mean log value at baseline to obtain the log reduction, as follows:

\[
\text{Log reduction} = \log_{10}(\text{mean baseline CFU}) - \log_{10}(\text{mean lens care solution CFU})
\]

Log reductions among PHMB/PQ-1, alexidine/PQ-1 and each PQ-1/MAPD solution were compared using an analysis of variance. Statistical significance between solutions was determined using a two-sided, two-sample t-test with a type I error rate of 0.05.

**RESULTS**

For most of the test conditions and times, the PHMB/PQ-1 and alexidine/PQ-1 solutions showed statistically greater biocidal activity compared with the three PQ-1/MAPD formulations. Overall, log reductions against challenge organisms ranged from 4.97 (no microbial recovery) to −0.87 (regrowth).

**Stand-alone efficacy testing of multipurpose solutions at manufacturer-recommended soak times**

When tested against Gram-negative bacterial strains associated with CIEs at manufacturer-recommended soak times, PHMB/PQ-1 achieved a greater than 3-log reduction against *D. acidovorans* and *S. maltophilia* and a 2.9-log reduction against *A. xylosoxidans*, while alexidine/PQ-1 achieved greater than 3-log reductions against all three organisms. Biocidal activity for each of the three PQ-1/MAPD formulations at manufacturer-recommended soak times was less than 3-log reduction against these bacterial strains; for PQ-1/MAPD-2 against *A. xylosoxidans*, there was regrowth (Table 2 and Figure 1).

**Biocidal efficacy of multipurpose solutions in a lens case at manufacturer-recommended and extended soak times**

Multipurpose solutions tested against Gram-negative bacterial strains associated with CIEs in a lens case at their respective manufacturer-recommended soak times showed PHMB/PQ-1 and alexidine/PQ-1 achieving greater than 3-log reductions against all three organisms. PQ-1/MAPD-1, -2 and -3 did not achieve a greater than 3-log reduction against any bacterial strain at their manufacturer-recommended soak time (Figures 2A and 2B). At extended soak times (24 hours and seven days), multipurpose solutions also demonstrated the efficacy seen at manufacturer-recommended soak times for PHMB/PQ-1 and alexidine/PQ-1 and showed improved efficacy of PQ-
MAPD-1 and PQ-1/MAPD-3 compared with PQ-1/MAPD-2 (Table 3 and Figure 3).

Biocidal efficacy of multipurpose solutions in a lens case in the presence of a lens at manufacturer-recommended and extended soak times

For multipurpose solution testing in a lens case in the presence of an etaflcon A lens, both PHMB/PQ-1 and alexidine/PQ-1 demonstrated greater than 3-log reductions against the Gram-negative bacterial strains associated with CIEs at nearly all times (Figure 4). The one exception was alexidine/PQ-1 against A. xylosoxidans (2.73 logs) at four hours (less than the recommended soak time for this solution). The three PQ-1/MAPD-based multipurpose solutions demonstrated lower biocidal efficacy, particularly at the early (up to 24 hours) times (Table 4).

DISCUSSION

Despite increasing evidence that CIEs are an acute inflammatory response to bacterial toxins, enzymes and/or metabolic byproducts accumulated on the contact lens surface, our understanding of the role of these organisms in the aetiology of CIEs is far from complete. In fact, no microorganisms are found on lenses of about 22 per cent of patients experiencing CIEs.

A study by Cheung and colleagues showed that both S. maltophilia and D. acidovorans were resistant to PQ-1/MAPD-based multipurpose solutions but not to PHMB/PQ-1, PHMB, peroxide or alexidine/PQ-1 multipurpose solution formulations. In the Cheung and colleagues study, three strains each of S. maltophilia and D. acidovorans were tested with frequently used multipurpose solutions and pereoxide care systems. A six-hour soak in PQ-1/MAPD-2 resulted in a less than 1-log kill for all S. maltophilia strains and substantial regrowth for two strains by seven days. There was also a less than 1-log kill for D. acidovorans at 24 hours and substantial regrowth at seven to 14 days. In contrast, four hours of exposure to alexidine/PQ-1, PHMB/PQ-1, PHMB- or peroxide-based solutions resulted in 4.0 or more log reductions in these organisms, with no regrowth for up to 21 days. The ability of these bacteria to survive and replicate in PQ-1/MAPD-based multipurpose solutions may result in biofilm in contact lens cases.

For stand-alone testing against A. xylosoxidans, D. acidovorans and S. maltophilia at manufacturer-recommended soak times, the five multipurpose solutions showed varying degrees of biocidal efficacy. PHMB/PQ-1 achieved greater than 3-log reductions for D. acidovorans and S. maltophilia, but achieved only a 2.90 log reduction for A. xylosoxidans, while alexidine/PQ-1 achieved greater than 3-log reductions against all three organisms. None of the MAPD-based formulations achieved more than 3-log reductions. Interestingly, PHMB/PQ-1 and alexidine/PQ-1 both achieved greater than 3-log reductions against all three CIE-associated Gram-negative organisms, when tested in lens cases and in lens cases with a lens at their respective manufacturer-recommended soak times; however, results were not significant compared with results of stand-alone testing for these two multipurpose solutions. In lens cases and in lens cases with a lens at their manufacturer-recommended soak time, none of the three MAPD-based multipurpose solutions achieved a greater than 3-log reduction (Tables 3 and 4).

For the extended soak periods (24 hours or more) against the bacterial strains in lens cases without a lens present (up to seven days) and in lens cases with a lens present (up to 30 days), PHMB/PQ-1 and
Biocidal activity of multipurpose solutions

| Multimpurpose solution formulation | Achromobacter xylosoxidans (mean log reduction) | Delftia acidovorans (mean log reduction) | Stenotrophomonas maltophilia (mean log reduction) |
|-----------------------------------|-----------------------------------------------|-----------------------------------------|--------------------------------------------------|
| **Four-hour soak**                |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 3.53†                                          | 4.03†                                    | 4.43†                                             |
| Alexidine/PQ-1                    | 2.73§                                          | 4.57*                                    | 4.03†                                             |
| PO-1/MAPD-1                       | 0.33                                           | 2.33§                                    | 1.33                                              |
| PO-1/MAPD-2                       | 0.17                                           | 1.30                                     | 0.63                                              |
| PO-1/MAPD-3                       | 0.53                                           | 2.00                                     | 1.47                                              |
| **Six-hour soak**                 |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.27†                                          | 4.50*                                    | 4.77*                                             |
| Alexidine/PQ-1                    | 3.20*                                          | 4.00††                                   | 4.50†                                             |
| PO-1/MAPD-1                       | 0.93                                           | 1.80                                     | 1.93                                              |
| PO-1/MAPD-2                       | 0.27                                           | 1.03                                     | 0.80                                              |
| PO-1/MAPD-3                       | 0.80                                           | 2.10§                                    | 1.90§                                             |
| **24-hour soak**                  |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.33†                                          | 4.40†                                    | 4.87*                                             |
| Alexidine/PQ-1                    | 4.07*                                          | 4.57†                                    | 4.87*                                             |
| PO-1/MAPD-1                       | 1.50                                           | 2.57**                                   | 2.80§                                             |
| PO-1/MAPD-2                       | 0.47                                           | 1.03                                     | 1.27                                              |
| PO-1/MAPD-3                       | 1.73§                                          | 2.90**                                   | 2.33                                              |
| **7-day soak**                    |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.73**                                         | 4.57**                                   | 4.87§                                             |
| Alexidine/PQ-1                    | 4.73**                                         | 4.57**                                   | 4.87§                                             |
| PO-1/MAPD-1                       | 4.73**                                         | 4.17**                                   | 4.89§                                             |
| PO-1/MAPD-2                       | -0.23                                          | -0.40                                    | 1.80                                              |
| PO-1/MAPD-3                       | 4.73**                                         | 4.57**                                   | 4.87§                                             |
| **30-day soak**                   |                                               |                                          |                                                  |
| PHMB/PQ-1                         | 4.67§                                          | 4.57§                                    | 4.87                                              |
| Alexidine/PQ-1                    | 4.73**                                         | 4.57§                                    | 4.87                                              |
| PO-1/MAPD-1                       | 4.10§                                          | 4.57§                                    | 4.73                                              |
| PO-1/MAPD-2                       | -0.20                                          | -0.23                                    | 2.20                                              |
| PO-1/MAPD-3                       | 4.73**                                         | 4.57§                                    | 4.87                                              |

Mean log reductions in bold indicate statistical significance.

* p ≤ 0.05 versus PQ-1/MAPD-1,-2,-3.
† p ≤ 0.01 versus PQ-1/MAPD-1,-2,-3.
‡ p ≤ 0.001 versus PQ-1/MAPD-1,-2,-3.
§ p ≤ 0.05 versus PQ-1/MAPD-2.
¶ p ≤ 0.05 versus PQ-1/MAPD-1,-2.
†† p ≤ 0.01 versus PQ-1/MAPD-2.
†‡ p ≤ 0.001 versus PQ-1/MAPD-2.
* p ≤ 0.05 versus PQ-1/MAPD-2.
†† p ≤ 0.05 versus PQ-1/MAPD-2.

Table 4. Testing against corneal infiltrative event-associated bacterial strains in a lens case with a lens

alexidine/PQ-1 achieved greater than 3-log reductions against each organism at each time. Despite the ability of the etafalcon A lens to take up PHMB and MAPD, results of this study showed that the overall trend, across all times and organisms tested, was one of minimal impact on biocidal efficacy of the multipurpose solutions analysed, when compared with the results of testing in lens cases without a lens. With a lens in the case, alexidine/PQ-1 showed lower biocidal activity against A. xylosoxidans at four hours, although it did achieve a greater than 3-log reduction at its manufacturer-recommended soak time of six hours. This may suggest the presence of a lens delay in the kinetics of the biocidal effect, perhaps related to biocide uptake by the contact lens, as seen in other studies.32

Our results may reflect the fact that all five multipurpose solutions tested were formulated with two biocides and given that all five contain PQ-1 at concentrations of 0.001 per cent (all three PQ-1/MAPD formulations) or lower (alexidine/PQ-1, 0.0005 per cent; PHMB/PQ-1, 0.0001 per cent) (Table 1), our data could suggest that the differences in efficacy may be related to the properties of the second biocide in the multipurpose solution formulation, as has been found in other studies.32 Both the PHMB- and alexidine-containing multipurpose solutions showed superior biocidal efficacy compared with MAPD-based multipurpose solutions, especially against the CIE-associated Gram-negative A. xylosoxidans, D. acidovorans and S. maltophilia. The lack of biocidal efficacy of MAPD-based multipurpose solutions at all but the longer soak times in our study suggests the strains we tested may be more resistant to the biocidal effects of MAPD-based multipurpose solutions.

Our study did not account for such patient behaviour as ‘topping off’ or for introduction of additional bacteria, as might be seen when patients repeatedly remove and reinsert contact lenses into the same lens case well containing old or topped-off solution. Because of our testing methods (aliquot), we also cannot account for the possibility that the respective manufacturers’ cases used in this study may have been susceptible in varying degrees to bacterial colonisation, which may have played a role in the results achieved in our study.33 For testing with the lens in the lens case, etafalcon A daily wear hydrogel lenses (J & J Vision Care) were used, as they have been shown to take up appreciable amounts of PHMB and MAPD.39 Further biocidal efficacy testing with silicone hydrogel lenses having different uptake and release profiles of antimicrobial agents may be of interest.
In conclusion, our results show that the biocidal efficacies of PHMB/PQ-1 and alexidine/PQ-1 were quicker in onset and more consistent against organisms tested, across times. PHMB/PQ-1 and alexidine/PQ-1 had significantly greater log reductions of organisms, when compared to the three PQ-1/MAPD solutions at their respective manufacturer-recommended soak times (for the lens care products in our study, four hours and six hours), whether in stand-alone conditions in test tubes, in lens cases or in lens cases with an etafilcon A lens. Only at extended soak durations (seven days or more soak time, without or with a lens in the case), were two of the three MAPD-based formulations able to achieve consistent and similar log reductions as seen with PHMB/PQ-1 and alexidine/PQ-1.

Patients should be advised to develop and maintain a lens-care regimen in accordance with manufacturer guidelines for the products they use and it remains vital for optometrists, ophthalmologists and allied healthcare providers to continue to counsel patients on the most appropriate lens care products for their lenses, as well as best practices regarding contact lens wear and hygiene.

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1. David B, Callahan DE, Bair JA, Norton SE. Evaluation of the biocidal efficacy of multipurpose solutions against challenges with gram-negative organisms in a lens case. Poster presented at: ARVO; May 5–9, 2013; Seattle, Washington, USA.

2. Merchea MM, David B, Callahan D, Bair J. Efficacy of multipurpose solutions against gram-negative clinical isolates associated with infiltrative keratitis. Poster presented at: American Academy of Optometry, 2012, Phoenix, Arizona, USA.

3. Walsh PA, David BC, Callahan DE, Bair JA, Norton SE. Biocidal efficacy of multipurpose solutions against gram-negative organisms in the presence of a lens. Poster presented at: American Academy of Optometry; October 23–26, 2013; Seattle, Washington, USA.

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Biocidal activity of multipurpose solutions Callahan, Kovacs, Lynch and Rah