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Analysis of *P. aeruginosa* disinfectant sensitivity and microbial adhesions to worn cosmetic contact lenses☆

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ABSTRACT

Purpose: To compare the sensitivity of two genotypes of *P. aeruginosa* to various disinfectant solutions and analyze the attached bacteria on worn cosmetic contact lenses (cosCLs).
Methods: In this prospective study, healthy volunteers wore etafilcon (brown), nelfilcon (gray), or hilafilcon (black) cosCLs and microbial adhesion analysis was performed. A rub-off test determined pigment dislodgement. Disinfectant sensitivity to Optifree Replenish (Alcon), Optifree Pure Moist (Alcon), Renu Fresh (Bausch & Lomb), and AoSept Plus (Ciba Vision) was tested at various disinfection times and compared between various genotypes and Type III secretion (T3S) system mutants.
Results: Of the 1152 cosCLs collected, 364 were culture positive (32%). The highest rate of culture-positive lens was hilafilcon (chi square, $P = 0.0001$). Hilafilcon also had a significantly greater number of isolates than etafilcon ($P < 0.0001$). Hilafilcon was the only lens to fail the rub-off test. Cytotoxic strains were significant more resistant to Renu Fresh than were invasive strains, even at 100% of recommended disinfection time ($P = 0.0005$). Of the tested disinfectants, Renu Fresh was significantly less effective in killing both genotypes of *P. aeruginosa* compared to AoSept Plus at all time points (25%, 50%, 75%, and 100% recommended disinfection time, $P = 0.0001$, 0.0001, 0.0005, and 0.0005, respectively). When the T3S system was dysfunctional, mutant strains were all susceptible to disinfectants ($P = 0.0001$ for both invasive and cytotoxic strains).
Conclusion: Pseudomonas species is commonly found on cosCLs of asymptomatic individuals. Wearers of cosCLs that dislodge pigments may be predisposed to microbial contamination. Cytotoxic strains are more resistant to disinfectant solutions, especially to Renu Fresh. *P. aeruginosa* disinfectant resistance requires a functional T3S system.

1. Introduction

Microbial keratitis due to *Pseudomonas aeruginosa* may cause blindness if not treated promptly and appropriately [1]. *P. aeruginosa*, an opportunistic pathogen commonly found in the environment, is the most commonly isolated gram-negative organism to cause microbial keratitis, particularly among contact lens wearers [2]. The incidence of contact lens-related microbial keratitis (CLMK) is reported to be approximately 3.5–20.9 per 10,000 wearers, depending on the contact lens material and wearing schedules [3–5]. Unfortunately, this incidence is expected to rise with emmetropic individuals wearing cosmetic contact lenses (cosCLs) [6,7]. Efforts to understand the complex interaction between contact lens materials, the initiation mechanisms of CLMK, and bacterial-host immune response still leave many questions unanswered.

Various studies have shown that the amount of bacterial adhesion is significantly affected by both the virulence factors of the bacterium and the type of contact lens material. Among the multitude of virulence factors, the Type III secretion (T3S) system, a contact-dependent protein secretion pathway among gram-negative bacteria, is of particular clinical interest. The T3S system allows bacterial secretion of exotoxins that have been associated with significant host cell damage and clinical disease [8–10]. The T3S system is composed of a specialized protein export system that forms a needle-like complex between the bacterial

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and host cells for the secretion and transport of four exotoxins: ExoS, ExoU, ExoT, and ExoY [10]. As most strains carry the *exoT* and e*xoY* gene, two genotypes of *P. aeruginosa* are distinguished by their secretion of either ExoU or ExoS [11]. *P. aeruginosa* strains that possess the *exoS* gene encoding the protein ExoS, but not the *exoU* gene, can invade corneal epithelial cells and are thus known as invasive strains [11–14]. On the other hand, *P. aeruginosa* strains that are *exoU* positive and *exoS* negative are known as cytotoxic strains because they cause acute host cell lysis through the production of ExoU, a phospholipase [13,15]. Strains isolated from CLMK cases showed a significant correlation between the presence of cytotoxic strains and contact lens wear [16–18]. The T3S system has been demonstrated to significantly affect *P. aeruginosa* adhesion to non-pigmented soft contact lenses, as loss of function decreases overall *P. aeruginosa* adhesion [19]. It is therefore suspected that the different T3S genotypes of *P. aeruginosa* may also affect the adhesion to pigmented soft contact lenses, because pigment molecules within the lens matrix may alter the surface properties of the lens and consequently affect its propensity to adhere bacteria [20].

The possible resistance of *P. aeruginosa* strains to chemical disinfectants is suspected to have contributed to the high frequency of cytotoxic pseudomonal strains in CLMK cases [21,22]. One early report found that cytotoxic strains are less sensitive to common contact lens multiple purpose solutions [23]. Since cytotoxic strains can form strong biofilms as soon as 30 min after incubation, biofilm formation may have protected *P. aeruginosa* against the disinfecting solutions [16,24–26].

In this prospective study, identification of microbial adhesions was determined for three types of cosCLs worn by asymptomatic volunteers. Pigment dislodgement was tested for all three types of cosCLs. *P. aeruginosa* sensitivity on worn cosCLs to four disinfectant solutions was also analyzed and compared between different T3S system strains.

2. Material and methods

2.1. Contact lens materials

Three cosmetic hydrogel materials were used in this study: etafilcon (Acuvue Define, Johnson & Johnson, New Brunswick, NJ, USA), nelfilcon (Freshlook Colorblends, Alcon, Fort Worth, TX, USA), and hilafilcon (Naturelle, Bausch & Lomb, Bridgewater, NJ, USA). Lens specifications according to manufacturers' product information are shown in Table 1.

2.2. Participants and wearing schedules

Volunteers willing to wear the provided daily disposable contact lenses for at least 8 h were recruited into the study. Inclusion criteria included: (1) age 20–35 years; (2) myopia less than -6.00 D and astigmatism less than -1.50 D; and (3) previous soft contact lens wear discontinued for at least 2 weeks. Exclusion criteria included: (1) previous rigid gas permeable lens or orthokeratology wear; (2) any ocular disease requiring topical medication; (3) any systemic disease that may affect the ocular surface; and (4) pregnancy. The aim and purpose of this study were thoroughly explained and written informed consent obtained from all volunteers. This study was approved by the relevant Institutional Review Board and adhered to the tenets of the Declaration of Helsinki.

Each volunteer wore one type of cosCL for 21 days in both eyes, then stopped all contact lens wear for 14 days (wash out period) before wearing the next type of cosCL for 21 days. The subjects repeated the process until all three types of cosCLs had been worn. The order of cosCL worn by each subject was randomized. These experienced contact lens wearers were instructed to wash and dry their hands before insertion of the lenses each morning. After wear each day, the contact lenses were collected aseptically by trained staff, then placed in sterile containers. All used contact lenses were checked for completeness of lens with no tears or chipped pieces. The used lenses were then subjected to experiments involving microbial identification, *P. aeruginosa* adhesion tests, and disinfection solution sensitivity tests.

Table 1
Cosmetic soft contact lens specifications.

US adopted name	Etafilcon A	Nelfilcon A	Hilafilcon B
Proprietary Name	Acuvue 2 Define Accent style (black)	Freshlook Colorblends (gray)	Naturelle (black)
Manufacturer	Johnson & Johnson	Ciba Vision	Bausch & Lomb
Material	Hydrogel	Hydrogel	Hydrogel
Color	Brown	Gray	Black
Color processing	Sandwiched	Embedded	Micro-encapsulated
Water content (%)	58	69	59
Dk/t	25	26	24

2.3. Identification of bacteria colonization to worn contact lenses

Worn contact lenses were retrieved with aseptic forceps and placed in 1 ml of sterile phosphate buffered saline (PBS) stored in aseptic containers. The lenses were transported to the laboratory for maceration by tissue homogenizer (Polytron Homogenizer PT 4000, Kinematica AG, Luzern, Switzerland) in 1 ml of PBS. Serial dilution was then performed and aliquots of 100 ul were plated onto tryptone soya agar and chocolate agar plates. The plates were incubated aerobically at 37 °C in CO2 incubators for 12 h. Identification of the organisms was done by Gram's stain, using standard biochemical methods [27] or colorimetry methods using Vitek2 Compact (BioMerieux, Marcy l'Etoile, France).

2.4. Bacterial strains and culture conditions

Standard strains (PAK, PA103, 6294, 6206) and mutant strains (PAKΔ*pscC,* courtesy of Stephen Lory, Harvard University, and PA103Δ*pscC,* courtesy of Timothy L. Yahr, University of Iowa) were stored in frozen stocks until needed. Previously-characterized clinical keratitis isolates (2007AX44, 2007A01, 2007AD46, 2002AP68) were also used. [19] Frozen stocks were defrosted and loops of bacterial solution were plated onto tryptone soya agar and incubated overnight. The strains were confirmed as *P. aeruginosa* by green pigment production and positive cytochrome oxidase test (BD Oxidase Reagent Droppers, BD Bioscience, Franklin Lakes, NJ, USA). A single colony was subcultured and inoculated into 15 ml of tryptone soya broth supplemented with 1% glycerol, 100 mM monosodium glutamate, and 2 mM EGTA as inducing conditions. The bacteria were harvested by centrifugation at 9600*g* for 10 min. The resulting pellet was washed once with 5 ml of normal saline and re-suspended to concentrations as required for experimentation.

2.5. Rub-off test

All three types of unused cosCLs were subjected to a rub-off test, following methods previously described by Chan et al. [20] In brief, the concave and convex surfaces of unused lenses were rubbed with normal saline-wetted cotton swabs for 20 times each. Pigment dislodgement was identified by observation of transference of color pigment onto the cotton swab tip. If no pigment was found after 20 rubs, the contact lens was labelled as passing the rub-off test. Six lenses of each type were tested.

2.6. Sensitivity of P. aeruginosa to disinfectant solutions

Disinfectant solutions tested in this study included Optifree Replenish (i.e. Replenish, Alcon, Fort Worth, Texas, USA), Optifree Pure

Moist (i.e. Pure Moist, Alcon, Fort Worth, Texas, USA), Renu Fresh (i.e. Renu, Bausch & Lomb, Bridgewater, NJ, USA), and AoSept Plus (i.e. AoSept, Ciba Vision, Duluth, GA, USA). The manufacturer's recommended disinfection times were 6 h for Optifree Replenish, Optifree Pure Moist, and AoSept Plus. Renu Fresh required 4 h for disinfection. Lenses not passing the rub-off test were selected for experimentation. Worn contact lenses were incubated with 1 ml of ~10^8 bacteria for 2 h, then washed thrice by careful dipping in 3 ml of PBS. The lenses were then transferred to a fresh well (24-well tissue culture plate, Sarstedt, Leicester, UK) and soaked with 1 ml of disinfectant solution at 25%, 50%, 75% and 100% of manufacturer's suggested disinfection time. Next, the disinfectant solution was removed and 1 ml of Dey-Engley neutralizing broth (Sigma-Aldrich, St. Louis, MO, USA) was added [21,22]. The wells were allowed to sit at room temperature for 15 min. The lenses were then macerated and 0.1 ml aliquots were plated onto tryptic soy agar to determine the quantity of viable bacteria still present on the lenses. The experiments were repeated at least three times and the results averaged.

2.7. Statistical analysis

All data were entered into an Excel data sheet and analyzed using SAS 9.4 (SAS Institute Inc, Cary, NC, USA). Chi square test was used to compare the culture-positive rates and the number of isolates for all three types of cosCLs. Wilcoxon sign rank test was used for non-parametric data analysis. P values less than 0.05 were considered as significant.

3. Results

3.1. Demographics of participants

A total of 24 female volunteers participated in this study. The average age was 30.6 years (range 28–34 years). All participants had previous experience of wearing hydrogel contact lenses; 11 had previously wore daily disposable hydrogel contact lenses. Another 11 had worn monthly disposable hydrogels and two participants had worn planned disposable hydrogel contact lenses. No participants had worn extended wear contact lenses. Because the test excluded non-working days and national holidays, the total number of retrievable contact lenses was 2400 (816 etafilcon lenses, 768 nelfilcon lenses, and 816 hilafilcon lenses).

3.2. Microbial analysis of worn cosmetic contact lenses (cosCLs)

A total of 1152 contact lenses (384 lenses of each type) were tested consecutively to identify the attached microorganisms. A total of 364 lenses had positive cultures, giving a total culture-positive rate of 31.6%. The culture-positive rates for etafilcon, nelfilcon, and hilafilcon were 21.6%, 33.1%, and 40.1% respectively. Hilafilcon had a significantly higher number of culture-positive lenses than the other two types of lenses (P = 0.0001, chi-square test). Table 2 shows the frequency of isolation of each type of microorganism for each type of contact lens. Of the 376 total isolates found, gram-positive and -negative isolates accounted for 85% and 13% of the total, respectively. Yeast was found in 1.3% of the isolates. The percentage of gram-positive and -negative isolates found on each type of cosCL is shown in Fig. 1. For both gram-positive and -negative organisms, hilafilcon had the highest number of isolates identified. For all isolates, significantly more were found on hilafilcon lenses than on etafilcon lenses (*P < 0.0001, chi-square test, Fig. 1C). Although most lenses had one type of microorganism isolated, 9 lenses had more than one type of isolate. The most commonly identified microbe on all cosCLs of asymptomatic lens wearers was coagulase negative staphylococcus (CNS), comprised mainly of commonly found skin commensal bacterium. The next highest identified microbe was *Pseudomonas* species (sp), accounting for approximately 12% of all identified isolates. The Pseudomonas species included *P. aeruginosa*, *P. flurorescens, P. oryzihabitans,* and *P. maltophilia (S. maltophilia)*. Other non-identified non-fermenting gram-negative bacilli were found mainly on hilafilcon lenses. Taking account of all gram-negative bacilli, hilafilcon lenses generally had a higher likelihood of gram-negative bacilli attachment compared to etafilcon and nelfilcon lenses, although the difference did not reach statistical significance.

Table 2
Identification of microbial organisms on worn cosmetic contact lenses.

Organism	Isolates (N, %)	Etafilcon	Nelfilcon	Hilafilcon
Gram-positive				
Staphylococcus coagulase-negative	310	69 (22.3)	112 (36.1)	129 (41.6)
Micrococcus sp	4	0 (0)	2 (50)	2 (50)
Streptococcus sp	3	3 (100)	0 (0)	0 (0)
Bacillus spp.	4	0 (0)	4 (100)	0 (0)
Total	321 (85.4)	72 (22.4)	118 (36.8)	131 (40.8)
Gram-negative				
Pseudomonas sp	46	11 (23.9)	14 (30.4)	21 (45.7)
Undetermined Gram-negative bacillus	4	0 (0)	0 (0)	4 (100)
Total	50 (13.3)	11 (22)	14 (28)	25 (50)
Yeast	5	2 (40)	0 (0)	3 (60)
Total	5 (1.3)	2 (40)	0 (0)	3 (60)

3.3. Pigment dislodgement of hilafilcon lenses

Fig. 2 shows the results of the rub-off test of all three types of cosCLs. Unlike the etafilcon and nelfilcon lenses, all six of the hilafilcon lenses tested failed the rub-off test, with pigments on the convex surface transferring to the tip of cotton swabs in less than 20 rubs on all tested lenses.

3.4. Type III secretion system modulates P. aeruginosa sensitivity to contact lens disinfectant solutions

Table 3 compares the disinfection ability of different disinfectant solutions to strains of cytotoxic or invasive *P. aeruginosa* on worn hilafilcon lenses (the only lens that did not pass the rub-off test). At 100% recommended time, Optifree Pure Moist, Optifree Replenish, and Aosept Plus disinfectants were able to kill nearly all bacteria. However, Renu Fresh, even at 100% of recommended disinfection time, had a significant number of viable bacteria present, as compared to Aosept Plus (P = 0.0005†, Wilcoxon sign rank test). Survival of cytotoxic strains was significantly greater in Renu Fresh at 25%, 75%, and 100% of recommended disinfection time, compared to invasive strains (P = 0.0008*, 0.026*, 0.0005*, respectively, by Wilcoxon sign rank test). With the T3S system dysfunctional, mutant strains with either the cytotoxic (PA103Δ*pscC*) or invasive (PAKΔ*pscC*) background were all susceptible to all types of disinfectant solutions. Compared to the wild type strains, both mutant strains had significantly fewer bacteria survive at all time points (P = 0.0001 for both invasive and cytotoxic strains, Wilcoxon sign rank test). A functional T3S system may be necessary for the increased resistance to disinfection solutions, especially for cytotoxic strains.

4. Discussion

The increasing popularity of cosCLs raises concerns of worsening ocular surface health, especially among younger wearers who seek beauty over vision correction [6,7,28,29]. Blinding corneal infections due to cosCL wear are increasingly reported [7,28–30]. Recent reports indicate that cosCL wearers have nearly six times the risk of developing

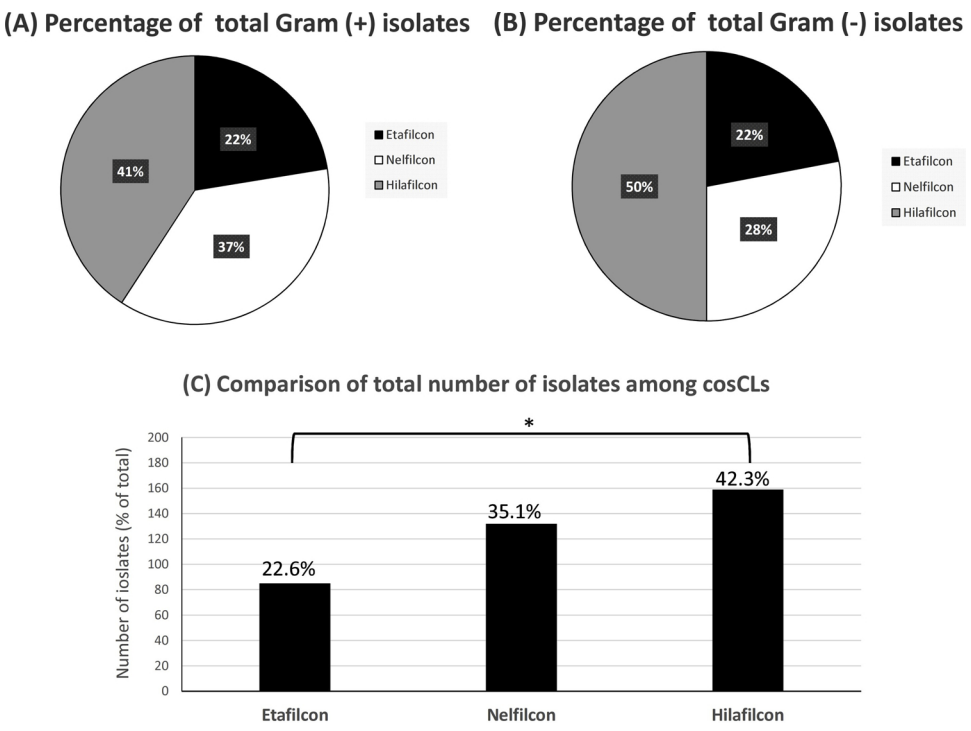

Fig. 1. Analysis of total isolates found on cosCLs. (A) Hilafilcon lenses had the highest percentage with Gram positive isolates. (B) Among all Gram negative isolates, hilafilcon accounted for 50% of the isolates. (C) Hilafilcon had a significantly higher percentage of isolates found on the lens compared to etafilcon (*P < 0.0001, Chi-square test).

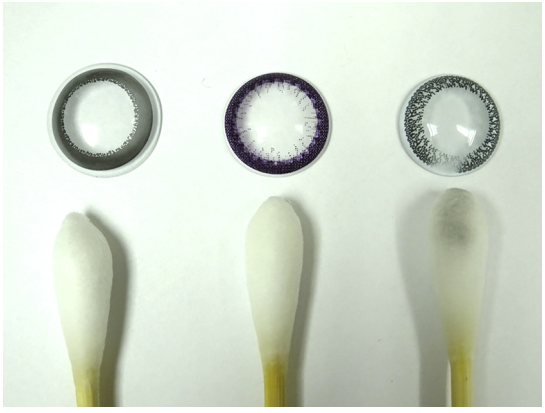

Fig. 2. Both etafilcon and nelfilcon passed the rub-off test with no color loss after 20 rubs. The pigments on the convex surface of hilafilcon lenses transferred to the cotton swab tip failing the rub-off test.

microbial keratitis than regular contact lens wearers [31]. Therefore, this prospective randomized study was conducted to determine the microbiota on cosCLs of asymptomatic healthy volunteers that may predispose them to future infections.

Analysis of organisms on cosCLs found that CNS and pseudomonal species were respectively the first and second most frequently isolated microorganisms. Previous studies involving cultures of contact lenses retrieved from patients with corneal infiltrative events showed that gram-negative bacteria accounted for about 62% of the total incidence [32]. Among these, *P. aeruginosa* was highly associated with contact lens colonization [32]. Over half of cosCL-associated corneal ulcers found were due to *P. aeruginosa* infections [28]. The high association between *P. aeruginosa*-induced keratitis and contact lens wear is well established [3,19,33–35]. However, it is unexpected that *P. aeruginosa* is also found on contact lenses of asymptomatic wearers With *P. aeruginosa* attached to these contact lens, the bacteria is in a strategically favorable position for opportunistic infections of the cornea.

In this study, pseudomonas sp. was found to frequently colonize all three type of cosCLs. Among the three types of cosCLs tested in the present study, hilfilcon was the only lens that failed the rub-off test, as pigments on the front surface of the lens dislodged after several rubs. Imaging of cosCL surfaces with scanning electron microscopy found an association between increased surface roughness and the presence of transferable pigments [36]. The higher adherence of *P. aeruginosa* to hilafilcon cosCLs may be related to the increased surface roughness due to pigment printing and exposed pigments on the lens surface. A previous study also found that cosCLs with easy pigment loss had greater adhesion of *P. aeruginosa* compared to the same contact lens material but without pigmentation [20]. Therefore, both the surface roughness and the transferability of these pigments may be related to the higher incidence of *P. aeruginosa* infection with cosCL wear [36].

Since hilafilcon lenses had a greater chance of pseudomonal adhesion, this study also tested the sensitivity of *P. aeruginosa* strains to different disinfectant solutions. A previous study found that both the T3S system and artificial tear fluids significantly affect pseudomonal adhesion to contact lenses [19]. Although previous studies have shown that the cytotoxic genotype was strongly associated with clinical contact lens-associated keratitis [16,19,37,38], this study found no significant difference in the quantity of cytotoxic vs invasive pseudomonal adhesion to contact lenses. Since biofilm formation on contact lenses surfaces may affect the bacterial sensitivity to disinfectants [39–41], this study used both invasive and cytotoxic genotype strains to determine if disinfectant sensitivity differs between the two genotypes. For this reason, standard strains, T3S system mutant strains, and clinical cytotoxic and invasive isolates attached to worn contact lenses were used as the challenge organisms, instead of stock suspensions.

Although these cosCLs were designated as daily disposable lenses, cosCLs wearers often do not follow the manufacturer's recommendations [7]. If the lenses are reused, improper lens care may contribute to the increased risk of corneal infection. Of the disinfection solutions tested, hydrogen peroxide-based systems are the most effective at eradicating adhered *P. aeruginosa,* even at less than suggested disinfection time. With shorter-than-recommended disinfection time, the multipurpose disinfection solution Renu Fresh was least effective at killing both genotypes of *P. aeruginosa*. More of the cytotoxic strains were able to survive, even at 100% of recommended disinfection time with Renu Fresh. Cytotoxic strains were also significantly more resistant to Renu

Table 3
Disinfectant sensitivity between invasive and cytotoxic strains of *P. aeruginosa* (mean CFUx10^4).

CFUx10^4	Renu Fresh				PureMoist				Replenish				Aosept			
% recommended disinfection time	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
Invasive																
PAK	12.5	4	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0
6294	68.5	28.3	10.34	9.18	0	0	0	0	0	0	0	0	0	0	0	0
2007AX44	22	5.13	3.3	6.45	1.25	0.75	0	0	0	0	0.5	0.25	0	0	0	0
2007A01	206.75	222.25	99.7	11.48	0	0	0	0	0	0	0	0	0	0	0	0
Mean ± SD	77.44[†] ± 89.6	64.92[†] ± 105.5	28.34[†] ± 47.8	6.78[†] ± 4.9	0.44 ± 0.6	0.31 ± 0.4	0	0	0	0	0.13 ± 0.3	0.06 ± 0.1	0	0	0	0
Cytotoxic																
PA103	4.85	1.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6206	1508	90.78	70.35	63.75	0	0	0	0	0	0	0	0	0	0	0	0
2007AD46	259.25	88.58	80.58	80.3	0	0.01	0	0	0	0	0	0	0	0	0	0
2002AP68	511	275.25	136.2	82.2	0.04	0	0	0	0	0	0	0	0	0	0	0
Mean ± SD	570.75[*,†] ± 658.1	113.97[†] ± 115.3	71.78[*,†] ± 55.9	56.56[*,†] ± 38.6	0.01 ± 0.02	0.003 ± 0.01	0	0	0	0	0	0	0	0	0	0
Mutants																
PAK*ΔpscC*	0[‡]	0[‡]	0[‡]	0[‡]	0	0	0	0	0	0	0	0	0	0	0	0
PA103*ΔpscC*	0[§]	0[§]	0[§]	0[§]	0	0	0	0	0	0	0	0	0	0	0	0

[*] $P < 0.05$, invasive vs cytotoxic.
[†] $P < 0.05$, Renu Fresh vs Aosept of same genotype.
[‡] $P < 0.05$, Invasive wild type vs mutant strain.
[§] $P < 0.05$, Cytotoxic wild type vs mutant strain.

Fresh disinfectant than were invasive strains. An early paper published in 2001 also found that cytotoxic strains were more resistant to disinfection solutions [23]. The present study further tested mutant strains of both cytotoxic and invasive genotypic backgrounds to determine the role of the T3S system in conferring bacterial disinfectant resistance. Mutant strains were found unable to survive all tested disinfection solutions, even at less than suggested disinfection times. A functional T3S system is therefore required for the increased resistance or virulence of *P. aeruginosa*.

There are several limitations to this study. First, it was beyond the scope of this study to conduct a comparative analysis of microbial adhesions to non-pigmented contact lenses in the same individual. However, several review articles have reported microbial contamination of hydrogel lenses. On average, coagulase negative staphylococci and pseudomonas sp. were found in 16–55% and 0–42% of total isolates, respectively [39,42]. Comparative analysis of non-pigmented lenses with pigmented counterparts will be of interest for future investigation. Secondly, the number of colony-forming units (CFU) per lens was not recorded in this study. Previous reports have found a generally low CFU count for aseptically-removed lenses (usually less than 5 CFU/lens) [39]. Greater CFU count has been reported to be associated with pathogenic species [39]. Lastly, the Aosept Plus disinfectant was not used in conjunction with the platinum disc for *P. aeruginosa* disinfectant sensitivity analysis, which may not exactly mimic the actual cleansing regimen. Nonetheless, the high disinfectant efficacy of hydrogen peroxide has been previously demonstrated [43–45].

In conclusion, this study revealed that pigment-dislodging cosCLs may have greater propensity to adhere microorganisms. Pseudomonal species were frequently found adhering to cosCLs of asymptomatic wearers. Pigment exposure with increased surface roughness may cause increased adherence of *P. aeruginosa*, and therefore contribute to a greater risk of corneal infection. Cytotoxic strains were more resistant than invasive strains to multipurpose disinfection solutions. A functional T3S system is required for this greater resistance. Increased public awareness with strict regulations for cosCLs distribution should be enforced to prevent avoidable vision loss due to cosCL wear.

Declaration of Competing Interest

The authors have no proprietary or commercial interest in the research presented herein.

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