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Contact Lens Maintenance: Lens Care Solutions and Compliance

Introduction

Multi-purpose lens care solutions are the simplest and most convenient method for cleaning, disinfecting, and storing soft contact lenses.[1] Protein deposits have traditionally been the targets of lens care solutions; however, some tear film proteins, when maintained in their active state, have antimicrobial properties that may prove valuable to keeping contact lenses clean.[2] Differences in solution formulations among the commercially available lens care products can result in varying levels of patient comfort and lens disinfection,[3-5] as well as maintenance of certain tear film proteins.[6] It should be noted that effective removal of denatured proteins continues to be important to lens care because they bind to lenses and are opaque, which reduces visual acuity.[7] Denatured proteins can also impact patient ocular health and comfort with contact lens use.[8]

Patient compliance with recommended lens cleaning protocols is essential for minimizing complications with contact lenses. However, compliance with all aspects of contact lens care is low.[9] Eye care specialists can play an important role in ensuring optimal patient compliance with lens care regimens through interactive discussions about the importance of lens care. A thorough understanding of the components of contact lens solutions on the part of practitioners can help guide discussions with patients regarding the importance of using recommended lens cleaning solutions. This article begins with a review of the components of multi-purpose lens care solutions and then discusses important points related to patient compliance.

Tear Film Properties

The natural tear film is essential for killing potential pathogens and flushing debris away from the surface of the eye.[3] Several physical factors affect the composition and performance of the tear film, including pH, osmolality, viscosity, and surface tension.[3] In healthy tears, the pH ranges from 7.3 to 7.7,[10] the osmolality falls between 244 and 344 mOsm/kg,[11,12] viscosity is 1-10 centipoise (cP)[13,14] and the surface tension is 42-46 mN/m.[15] Contact lens solutions differ from one another in these (Table 1) and in other formula properties.[3,4] Differences between normal tear film values and those in contact lens solutions can interfere with the natural tear film and induce a response within the eye, which necessitates the restoration of the natural tear film state. If differences are great enough, it may lead to experiences of ocular discomfort and irritation.[3]

Contact Lens Solution Formulations

Multi-purpose contact lens solutions contain osmolarity agents, chelating agents, buffers, comfort agents, cleaning agents, and disinfecting agents (Table 1).[3,4] Osmolarity and chelating agents are usually the same in all contact lens solutions (Table 1),[3] albeit at slightly different concentrations. Osmolarity, usually maintained with salt (NaCl), plays an important role in patient comfort, with higher levels of osmolality contributing to increased discomfort.[4,16,17] The chelating agent, EDTA, is contained in most multi-purpose contact lens solutions. It is an antimicrobial preservative that binds to metals and enhances the antimicrobial activity of disinfectants. It also may prevent protein deposits from forming on contact lenses[18,19]

Solution formulations vary with respect to the buffering, disinfecting, cleaning and comfort agents used.[3,4] Buffers serve to maintain the desired pH, which can affect user comfort and disinfectant performance.[20] Disinfecting agents function to reduce the number of microbial pathogens to a safe level.[21] Cleaning agents remove loose dirt and debris from the contact lens.[22,23] Comfort agents (e.g., surfactants, humectants) are added to contact lens

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solutions to increase lens wettability, decrease surface tension, and improve comfort.[20,24,25]

Cleaning Agents

As mentioned above, cleaning agents remove dirt and debris from contact lenses. Surfactants, while also utilized as conditioning agents (see below), can also aid in the cleaning of contact lenses.[20,24,25] This class of molecules possesses both hydrophobic and hydrophilic components, enabling them to quickly attach and solubilise different types of debris.[19] In general, surfactants are effective against lipid and inorganic deposits, but have limited effect against bound or denatured proteins.[21]

Comfort and Conditioning Agents

There are a number of agents used to help improve comfort through modification of the lens surface. In contact lens blister packs, surfactants and copolymers are often used to increase initial comfort upon lens insertion.[20] In contact lens solutions, surfactants such as poloxamer and tyloxapol are used to enhance lens wettability.[20,24,25]

How Does the Eye Do It?

Hyaluronan (HA) is a glycosaminoglycan that functions as a natural lubricant throughout the body[26] and has been identified in normal tear film, lacrimal tissue, conjunctiva, corneal epithelium, and vitreous humor.[26-29] Hyaluronan is involved in a wide range of functions, playing important roles in the hydration of the corneal epithelium, cell regeneration, and the stabilisation of preocular tear film.[26] At the molecular level, HA functions by drawing in water molecules, holding up to 1000 times its weight in water.[30] On contact lenses, HA has been shown to remain on silicone hydrogel and hydrogel lenses for up to 20 hours, and is thought to be useful as a conditioning agent for contact lenses.[31] Recent studies have shown that the use of HA as a conditioning agent for hydrogel lenses improves the properties of lens materials to allow for improved retention of eye hydration and decreased protein adsorption.[32]

Protein Management Agents

Protein deposits have traditionally been viewed as targets for removal, but some tear film proteins have antimicrobial properties when in their natural state. Protein management with regard to contact lenses seeks to maintain beneficial proteins in their natural state, while removing denatured protein deposits that may impact ocular health.[2] The accumulation of denatured proteins is associated with dry eye symptoms and decreased contact lens comfort and may lead to contact lens complications, such as giant papillary conjunctivitis and inflammation[5,33] As mentioned previously, removal of denatured proteins from lenses is important because they can also affect visual acuity.[7]

Contact lens solutions vary in their ability to preserve the function of beneficial proteins, such as lysozyme, under protein-denaturing conditions.[6] In a study by Barniak et al (2010) of five contact lens solutions, including a hydrogen peroxide solution, maintenance of viable lysozyme ranged from 4.0% to 90.1%.6 Agents that can help maintain tear film protein function include hydranate and sulfobetaine. If denatured lysozyme induces allergic reactions, then contact lens solutions that prevent lysozyme and lactoferrin denaturation have the potential to reduce the risk of lens complications associated with protein accumulation.[6,34]

There are a variety of agents used in current lens care solutions to specifically remove protein deposits. Enzymatic cleaners are used to reduce protein levels on contact lenses.[21] Another agent, hydranate (hydroxyalkylphosphon ate), is a chelating agent that inhibits the binding of protein to the lens surface by inhibiting the formation of ionic

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bonds.[35] Some buffering agents also aid in the passive removal of protein deposits. For example, sodium citrate, a negatively charged molecule, can bind with positively charged protein molecules, thus helping in their removal from the lens surface.[35] Surfactants also play a role by removing loosely bound protein deposits.[35]

Why Does the Eye Have Tear Film Proteins?

The tear film contains over 400 proteins, which constantly cover the ocular surface – some of which destroy potentially infectious pathogens.[6,36] Proteins serve as part of the eye's first line of defence against microbes. Four key proteins are present in large amounts (15%-20% or more of total protein) in the tear film: lysozyme, lactoferrin, lipocalin, and secretory IgA.[37] Lysozyme, lactoferrin, and lipocalin have antimicrobial properties.[38,39] When in their native state (i.e., non-denatured), the proteins maintain their inherent antimicrobial properties and transparency.

Lysozyme constitutes approximately 90% of the total protein found on worn contact lenses.[6,40,41] Investigators have proposed that when lysozyme binds to the lens surface it undergoes conformational changes, becoming denatured and then acting as an immunological stimulus to induce allergic reactions, such as papillary conjunctivitis.[6,42]

Disinfecting Agents

Contact lens solutions utilize antimicrobial biocides to disinfect lenses, so that they may be safely inserted into the eye, typically following an overnight soak. Three terms frequently used when discussing antimicrobials are sterilisation, preservation, and disinfection.

- Sterilisation is the process by which all organisms, including spores, are killed with no possibility for microbial growth.[43] It is important to note that lens care solutions are sterile, but they do not sterilise contact lenses.
- Preservation refers to components of lens care solutions intended to prevent the growth of micro-organisms while in the bottle. Some contact lens wearers may be sensitive to the preservatives in a contact lens solution. Symptoms of preservative sensitivity include dryness, grittiness, burning, reduced wearing time, and itching.[8]
- Disinfection is the chemical process by which the number of viable micro-organisms on a contact lens is reduced to a level which is neither harmful to ocular health nor to the quality of contact lenses and accessories.[44] Disinfection occurs in the lens case with contact lenses.

Lens care solution formulas are optimised to provide preservation and disinfection. Disinfectants are able to kill bacteria, fungi, and amoeba without killing human cells because human cells have greater stability due to their high cholesterol content (up to 25%) and proportion of saturated fatty acids.[45-47] Several different disinfectant biocides are used in contact lens solutions, including PHMB (polyhexamethylene biguanide/polyaminopropyl biguanide), PQ-1 (polyquaternium-1), myristamidopropyl dimethylamine ([MAPD], an amidoamine), and alexidine dihydrochloride. These disinfectants have varying levels of efficacy in killing bacteria, fungi, and amoeba. Their efficacy is also impacted by the overall formulation of the contact lens solution within which they are included.

Hydrogen peroxide destroys pathogens by oxidation, which results in protein denaturisation, and damages microbial cell membranes. It is highly effective against all micro-organisms when used in a 3% concentration but is non selective in its activity.[48] To avoid ocular irritation, residual peroxide must be neutralised before lens insertion by either a one-step or a two-step process.[48] One of the drawbacks of utilising hydrogen peroxide is the risk of inserting un-neutralised lenses and the lack of antimicrobial activity after full neutralisation (like

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unpreserved saline).[48] Disinfection efficacy with hydrogen peroxide relies heavily on patient compliance, but because peroxide-based systems are preservative free,[48] it may be a good choice for patients sensitive to preservatives.

How Contact Lens Solution Disinfection Abilities Are Tested

Global testing procedures against five specific microbe strains have been established for the testing of lens solution disinfection ability.[21] These procedures deliver accurate estimates of antimicrobial efficacy by utilising precisely controlled and reproducible conditions. Standardised testing procedures have also eased the introduction of lens care solutions into new markets, a process that was previously hampered by multiple, ill-defined testing requirements.[49] Solution testing requirements also provide certainty that disinfection solutions are biocompatible and not so strong that they would damage patients' eyes.[49]

There are two levels of testing: stand-alone and regimen.[21] The stand-alone microbial efficacy test qualifies individual solutions with clear antimicrobial activity as contact lens disinfection products. Standards for disinfection are set by the International Organization for Standardization (ISO) and the United States Food and Drug Administration (FDA). Standard strains (3 bacterial, 2 fungal) from the American Type Culture Collection (ATCC) are used. The ISO/FDA standards in stand-alone testing require a 1-log reduction (90%) for fungi and 3-log reduction (99.9%) for bacteria.[49] In regimen testing, the sum of the average log reductions for the three bacterial organisms must be at least 5.0 logs, with a minimum average of a 1.0-log reduction for each individual bacterial type.[49] (Figure 1)

Figure 1. FDA/ISO Testing for Anti-Microbial Efficacy[49]

Organisms Tested From ATCC
Bacterial Strains •*Pseudomonas aeruginosa* •*Serratia marcescens* •*Staphylococcus aureus*
Fungal Strains •*Candida albicans* •*Fusarium solani*

Stand-Alone Testing Requirements	
Organism	**Kill Rate**
Fungi	1-log reduction (90%)
Bacteria	3-log reduction (99.9%)

Regimen Testing Requirements	
Organism	**Kill Rate**
Bacteria	• Sum of the average log reductions for *P. aeruginosa*, *S. marcescens*, and *S. aureus* must be at least 5 logs • Minimum of 1-log reduction (90%) for each bacterium

Three bacterial strains are evaluated in the stand-alone test: *Pseudomonas aeruginosa, Serratia marcescens*, and *Staphylococcus aureus*.[49] P. aeruginosa, a gram-negative bacterium, is a causative agent of culture-proven cases of lens-associated keratitis.[50] *S. marcescens*, also gram negative, has been implicated in non-ulcerating keratitis and endophthalmitis.[51] *S. aureus* (gram positive) is a leading cause of microbial keratitis, accounting for about one

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quarter of confirmed cases of ulcerative keratitis.[52,53]

Fungal strains evaluated in the stand-alone test include *Candida albicans* and *Fusarium solani. C. albicans* is the most commonly isolated yeast in human disease cases, including corneal infections.[54,55] *F. solani* is a common cause of fungal keratitis in the developing world.[56] Although it has not been considered a frequent cause of disease in more temperate climates, more than 250 cases of Fusarium keratitis were reported worldwide during the 2005–2006 outbreak, including temperate regions of the United States.[56,57]

Other Bacterial Challenges
In addition to those specific organisms tested as specified by the ISO/FDA standards, there are a number of other organisms to consider, such as methicillin-resistant *S. aureus* (MRSA) and *Acanthamoeba* (protista).

MRSA: The term MRSA is used to describe a number of strains of the bacteria S. aureus that are resistant to many antibiotics, including methicillin.[58] Referred to in the media as a "superbug," MRSA has gained attention recently due to a significant increase in MRSA infections, though not necessarily in contact lens wearers. The proportion of ocular infections that were culture-positive for MRSA increased from 29.5% in 2000 to 41.6% in 2005.[59] Currently available contact lens solutions have varying degrees of biocidal ability against MRSA.[60]

Acanthamoeba, one type of amoeba, is a common environmental organism that can cause potential blinding keratitis.[61] In a study of UK domestic tap water, 89% of homes (24/27) contained amoebae, one third of which were *Acanthamoeba*.[61] Acanthamoeba is characterised by two life-cycle stages, an active trophozoite stage during which amoebae are free-moving, feeding, and replicating, and a second dormant phase when they become double-walled cysts during periods of environmental stress.[61] Contact lens solutions differ in their biocidal efficacy against *Acanthamoeba* trophozoites and cysts.[62]

The importance of testing contact lens solution efficacy against *Acanthamoeba* was the focus of a 2009 meeting sponsored by the American Optometric Association and FDA Center for Devices and Radiological Health (FDA-CDRH).[63] Workshop attendees included representatives from the American Optometric Association, FDA, American Academy of Ophthalmology, American Academy of Optometry, and Contact Lens Association of Ophthalmologists. The group discussed test method parameters for evaluating the effectiveness of contact lens care products for protecting against infections caused by *Acanthamoebae*. During the workshop a consensus was reached regarding testing parameters and new criteria for disinfection efficacy test methods. Specifically, the particular *Acanthamoeba* parasite species and strains to test as well as an acceptable threshold for disinfection efficacy were established. While a consensus was reached by the workshop attendees, to date, no changes to the ISO/FDA test standards have been implemented.[63]

Contact Lens Care Compliance and Instructions

Patient Compliance
Patient compliance with appropriate lens care instructions and guidelines plays a key role in minimising the occurrence of ocular infections and inflammations.[9] Compliance-related lens care factors that have been definitively shown to increase the risk for significant/serious keratitis include:[9]

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- Elimination of lens rubbing as part of the lens care program[64]
- Sleeping in lenses
- Wearing lenses beyond their recommended replacement date
- Inadequate disinfection (not soaking lenses in solutions long enough)
- Not handwashing
- Topping-up solution rather than discarding it fully
- Poor case care

Other factors that are currently unproven in the literature, but may lead to increased levels of significant or serious keratitis, include using care products beyond their expiration date and not replacing bottle tops.[9]

Despite findings that most contact lens wearers believe they are compliant, a number of studies have demonstrated that noncompliance with contact lens care ranges between 50% and 99%.[9,60,65] A recent study that asked 2232 patients in the US and Canada about their lens care compliance reported that many patients wear their lenses beyond the recommended period: 12%-13% for daily disposables; 28%-33% for monthlies; 50%-52% for bi-weeklies.[66] As the complexity of the lens care regimens increases, the likelihood that patients are compliant decreases.[9] However, proper and consistent use of even the simplest regimens using multi-purpose lens solutions is unlikely unless practitioners provide adequate instruction on lens care cleaning protocols.[60]

Contact Lens Care

Patients should be advised regarding the importance of accurately following contact lens care regimens during the contact lens fitting process and all subsequent visits and communications.[9,21] There are several important points that should be emphasized.[67] Patients should be advised to replace lenses as recommended by the manufacturer and that following this step not only reduces the risk for complications but has shown to improve both comfort and vision.[66] It is also imperative that patients properly wash their hands prior to handling contact lenses and remove contact lenses from the eye prior to activities where the lens may come in contact with water.[67] With regard to contact lens solution, only recommended disinfecting and cleaning solutions should be used.[67] Rubbing and rinsing of lenses with the contact lens solution, regardless of whether it is a rub or no-rub regimen, is necessary to improve cleaning.[67,68] It is important not to re-use or top off old solution in the case and the proper amount of new solution should be used during each cleaning. Expired solutions should be discarded. Contact lenses should be stored in a clean contact lens case that is rinsed and dried between disinfection cycles and replaced at least once a month.

Conclusions

Differences between normal tear film properties (e.g., pH, osmolality, viscosity, surface tension), and those of contact lens solutions may induce a response within the eye that can cause discomfort and ocular irritation. Contact lens solutions are formulated with cleaning, comfort and disinfecting agents, but different formulations translate to solutions having distinct physical properties, varying levels of comfort, and a range of disinfection abilities. The accumulation of denatured protein deposits on contact lenses can lead to a reduction in visual acuity and comfort. Keeping contact lenses clean and free of these deposits reduces the chances of ocular infection and is important to patient ocular health and overall satisfaction with contact lens use. Keeping tear proteins from denaturing may improve comfort, and contribute to antimicrobial activity, as well. There are two important aspects to consider with contact lens maintenance: (1) the solution used to clean the lenses; (2) patient compliance with the prescribed contact lens and lens care regimens. Practitioners play a key role in recommending the

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contact lens solution that is best suited for the patient and in educating patients about the importance of following recommended lens cleaning regimens, all of which contribute to protecting the ocular health of patients and increasing their satisfaction with contact lens use.

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Tables

Table 1. Physical properties of multi-purpose lens care solutions.[3]

Multi-purpose Solution	pH ±SD	Osmolality ±SD (mOsm/kg)	Viscosity ±SD (cP)	Surface Tension ±SD (mN/m)
Healthy Tears	7.3-7.70	244-344	1-10	42-46
MPS A (borate / poloxamine)	7.50 ± 0.02	285 ± 1	1.15 ± 1.02	44.4 ± 0.2
MPS B (borate / citrate / poloxamine)	7.82 ± 0.02	285 ± 1	1.13 ± 0.03	39.9 ± 0.6
MPS C (borate / citrate / poloxamine)	7.83 ± 1.01	272 ± 2	1.29 ± 0.01	39.2 ± 0.2
MPS D (tromethamine / phosphate / poloxamer)	7.21 ± 0.01	310 ± 1	1.50 ± 0.01	45.5 ± 0.5
MPS E (borate / poloxamine)	7.30 ± 0.01	281 ± 1	1.56 ± 0.02	45.8 ± 0.1
MPS F (borate / poloxamine)	7.30 ± 0.02	283 ± 1	1.23 ± 0.01	45.3 ± 0.2
MPS G (phosphate / poloxamer)	7.19 ± 0.01	292 ± 1	1.20 ± 0.02	49.8 ± 0.3

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Table 2. Components of contact lens solutions and their functions[3,4,18-21,24,25]

Solution Component	Functions
Buffers: Borate, phosphate, citrate	• Maintain pH • Affects disinfecting performance • May impact user comfort, usually upon insertion
Osmolarity agent: NaCl	• Balances osmolality • Higher levels of osmolality cause dry eye discomfort
Chelating agent: EDTA	• Chemically binds proteins and metals • May prevent lens deposits • Antimicrobial preservative
Comfort agents: HPMC, poloxamine, glycols, glycerin, polysaccharides, co-polymers	• Increase wettability • Improve comfort • Decrease surface tension
Surfactants: Poloxamine, poloxamers	• Clean contact lens • Enhance wettability • Effective against lipid and inorganic deposits • Limited effect on bound or denatured proteins
Antimicrobial agents: PHMB, PQ-1, myristamidopropyl dimethylamine (Aldox), alexidine, H_2O_2	• Reduce level of microbial pathogens during disinfection and prevent the growth of micro-organisms in the bottle.
Protein management agents: Sulfobetaine, hydranate	• Maintains/stabilizes tear film protein function (prevents denaturation)

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