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**LITERATURE REVIEW**

**PHYSICAL PROPERTY OF COMMERCIALLY AVAILABLE CONTACT LENS SOLUTION**

The purpose of this study is to investigate the surface tension of commercially available contact lens solutions in Ghana. This chapter reviews the literature in three main parts; first, it provides information on the benefits and discomfort in contact lens wear. Second is an overview on the prevalence of contact lens wear at the global level, within Africa and Ghana. Third, it reviews contact lens solution, types and their major components. Finally, talks about the influence of surfactants in the lens solutions, surface tension and variations in surface tension among contact lens solutions.

**Contact Lens Solutions**

Contact lens solutions have been in the system since the late 40’s, although they were specifically to be used for rigid gas permeable lenses. Since then, contact lens solution development and optimization, as well as testing and assessment procedures, have evolved quickly to keep up with the development of new contact lens materials and our expanding understanding of the importance of contact lens care regimens in contact lens performance. The ideal characteristics of a contact lens solution are; effective disinfection against a wide variety of pathogenic organisms, non-toxic to ocular tissues, compatible with all contact lens materials, simple to use, rapid disinfection capability, condition lens surface to enhance wettability and in-eye comfort, minimize deposition of tear film components when they are not worn (Lyndon & Senchyna, 2007; Kuc & Lebow, 2018). Contact lens solutions are categorized as either multipurpose solutions (MPS) or hydrogen peroxide (HP)–based systems. This study reviews more on multipurpose solutions. Multipurpose solutions are complex formulations of different chemical components including biocides, wetting agents, surfactants, chelating, and buffering agents that can be exposed directly to the ocular surface (Lyndon, et al., 2013). Some of these components in MPS are included to condition the contact lens surface and to improve patient comfort. In contrast to MPS solutions, hydrogen peroxide–based solutions use 3% peroxide as the principal disinfectant, which cannot be applied directly to the ocular surface. MPS is used by 73% of patients for contact lens disinfection, compared to 27% who use HP (Nichols, 2017).

Changes in modern contact lens care systems have been needed by the evolution of Silicone Hydrogel materials and their unique physical features (increased lipid deposition and reduced surface wettability). Different lens polymers may alter lipid and protein buildup in Silicone Hydrogel lenses, possibly due to surface properties (Zhao, et al., 2009). Furthermore, some contact lens care systems are more consistently linked to the removal of proteins from silicone hydrogels, and differences in contact lens care systems and their interactions with contact lens materials can result in significant clinical, physiologic, and subjective preference differences (Lebow & Schachet, 2003).

**The Properties of a Contact Lens Solution**

A study stated that to understand how contact lens solutions can influence CLD, one must appreciate the different components of care systems and how they interact with contact lenses. Lens care products and their interaction with contact lens materials can induce corneal staining and adversely alter patient comfort responses during contact lens wear (Willcox, et al., 2010). The components of modern contact lens care regimes that influences the physical properties of the solutions are; antimicrobial agents, chelating agents, propylene glycol, buffering agents, and surfactants (Lyndon & Senchyna, 2007; Kuc & Lebow, 2018).

The antimicrobial agent or biocide's principal function is to ensure that a lens is sufficiently disinfected before being put into the eye, usually after an overnight soak. The selection of an appropriate antimicrobial is technically difficult because it must examine three distinct but equally significant factors: efficacy, safety, and convenience. The agent of choice must be effective against a wide variety of pathogens, provide an effective kill against pathogens and not against ocular tissues and be convenient and simple to use for the patient. This process is made more difficult by the fact that an antimicrobial agent in a contact lens solution must perform two distinct functions: first, solution maintenance, and second, contact lens disinfection. Modern care regimens have primarily used five disinfectants; hydrogen peroxide, polyhexamethylene biguanide, polyquaternium-1, alexidine, and amidoamine (Lyndon & Senchyna, 2007).

A variety of chelating agents are added to modern care regimens either to act synergistically with other agents to improve disinfection efficacy or to aid in removal of tear film components, typically proteins. The common chelating agents are; EDTA, Citrate, and Hydroxyalkyl phosphonate (Lyndon & Senchyna, 2007). It might be challenging to strike the right balance between these elements in order to ensure patient safety and compliance (Lyndon & Senchyna, 2007).

**Surface Tension of a Contact Lens Solution**

Surface tension is defined as the difference in surface energies between solvent molecules and polymer membrane surface (Ginn, Noyees, & Jungermann, 1968). In a liquid in contact with a gas one can distinguish between two types of molecules. The first one corresponds to the inner liquid molecules which are completely surrounded by other liquid molecules. In this case the cohesive forces among the inner molecule and the neighbors are balanced. The second case corresponds to the surface molecules, thus, the ones located in the boundary between the liquid and the gas. In this case the surface molecule is not completely surrounded by other like neighboring molecules, so it coheres more strongly with those found at the interface between the liquid and the gas, so each surface molecule is attracted by the inner molecules towards the center of the liquid. Therefore, the outer surface of the liquid stays under tension, thus behaving like an elastic thin film (Lee, Ravindra, & Chan, 2009; Soni, 2019). The effect of the cohesive forces between liquid molecules, results in the surface tension phenomenon. These cohesive forces among molecules of the surface layer determine the shape of the liquid (Soni, 2019). It has been found that for a substance to wet another substance, its surface tension must be lower than the target. Much information has been published regarding the hydrophobicity of the corneal surface before and after mucolytic or abrasive procedures were applied. Holly proposed that the corneal epithelium has a low surface energy and a critical surface tension of 28 mN/m (with no adsorbed mucins) (Glasgow, Marshall, Gasymov, & Abduragimov, 1999). Mucins presumably raise the critical surface tension of the cornea to be more wettable (38 mN/m). However, other studies provide scanning electron microscopic evidence to suggest that methods used in the previous studies cause severe damage to the corneal epithelium and may be flawed on a theoretical basis as well (Cope, Dilly, Kaura, & Tiffany, 1986).

A more recent evidence suggests that the surface tension of the cornea is much higher (67.5–72 mN/m) than previously determined, with minimal change after treatment with mucolytic agents (Sharma, 1993; Glasgow, Marshall, Gasymov, & Abduragimov, 1999). The ST of human tears falls within the range of 42 to 46 mN/m (Tiffany, 1998; Pandit, Nagyova, Bron, & Tiffany, 1999)**.** The standard belief for many years has been that surface tension as a property depend upon the presence of goblet-cell (secreted) mucin dissolved in the aqueous tears, in equilibrium with the gel layer of mucus coating the conjunctival and corneal surfaces. Model mucus solutions closely resembled human tears in their rheological and surfactant behavior (Pandit, Nagyova, Bron, & Tiffany, 1999). The low surface tension of the human tear film gives the tear film the ability to lubricate the eye, removes loose debris and provide comfort to the eye. It has been reported that the surface tension of PMMA materials ranges from 32-46mN/m. Theoretically, contact lens care products should have a surface tension lesser than 46mN/m to be able to perform its function as a cleaner or protein remover. The lesser the surface tension of the solution the more potent and efficient in cleaning the contact lens (Goudeau, Galy, Fulchiron, & Barrat, 2000).

The ability of contact lens solution to posse its characteristics depends on the components of the MPS. One important component is the surfactant. Surfactants or “surface-active agents” are amphiphilic structures, meaning they have hydrophilic heads and hydrophobic tails and are therefore soluble in both organic solvents and water. As a result, they act as both surface cleaners and wetting agents (Kuc & Lebow, 2018). Their effects on CLD have been investigated and are believed to have the greatest positive influence on contact lens comfort of all the care system components (Lyndon, et al., 2013). Because of their unique dual-acting property, surfactants can not only remove surface deposits (Babaei Omali, et al., 2016) but also lower the surface tension of liquids applied to the surface of the contact lens, enhancing wettability (Lyndon & Senchyna, 2007). The surfactant in the contact lens care solution gives the solution an average surface tension making it possible to perform its function as a detergent or cleaner in removing loose debris and deposits (including microorganisms). Surfactants both soften the deposits, preventing them from becoming irreversibly adherent to the lens surface (Phillips, 1980; Lyndon & Senchyna, 2007).

The second function relates to their ability to enhance the wettability of hydrophobic substrates (Ketelson, Meadows, & Stone, 2005; Tonge, Jones, & Goodall, 2001), which is becoming of increasing importance with the development of silicone hydrogel lenses, that are generally more hydrophobic than conventional hydrogel materials (Bruinsma, van der Mei, & Busscher, 2001; Cheng, Muller, & Radke, 2004). As the growth in the numbers of patients wearing silicone hydrogels continues, the importance of surfactants for both their cleaning and enhanced wetting roles is likely to increase (Lyndon & Senchyna, 2007). A recent study stated that specific solution components, storage habits, and an understanding of lens/ solution interactions can lead to discomfort, keratitis, or ultimately a lost patient (Kuc & Lebow, 2018).

Dalton et al (2008) reported that although many of the solutions have similar components, the ST of the solutions evaluated exhibited marked differences. Both one-bottled hydrogen peroxide solutions and multipurpose solutions were considered in the study. The one-bottle systems had relatively low (<40 mN/m) ST values, whereas the neutralized peroxide solutions exhibited higher STs (>40 mN/m). The solutions with the highest values were neutralized AOSept at 70.3 mN/m and SoftWear Saline at 67.9 mN/m, which were not different from each other (p=NS), but were different from all other products (p <0.001). Within the group of neutralized peroxide systems, Clear Care (42.9 mN/m) and Ultra Care (43.2mN/m) were similar to each other (p=NS), but had significantly lower STs than AOSept (p <0.001). The solutions with the lowest ST values were Opti-Free Replenish at 29.7 mN/m and Opti-Free Express at 31.2 mN/m, which were significantly lower than all other solutions (p < 0.05), but were not different from each other (p = NS). Complete Moisture Plus (40.5 mN/m) had the highest ST of any of the one-bottle products (Dalton, Lakshman, Ronan, & Lyndon, 2008).

The surface tension of liquids generally decreases with increase of temperature and becomes zero at critical temperature (when meniscus between the liquid and the vapor disappears). The decrease in surface tension with increase of temperature is due to the fact that with increase of temperature, the kinetic energy of the molecules increases and hence intermolecular attraction decreases (Goudeau, Galy, Fulchiron, & Barrat, 2000; Soni, 2019). It is well known that surface tension usually decreases with increasing temperatures. For example, the cleaning efficiency of water is improved at high temperature because of its lower surface tension, thus becoming a better wetting agent. However, the surface tension that is required to disinfect and clean the contact lens material is the surface tension measured at room temperature rather than the surface tension obtained during contact lens wear since the solutions achieve their purpose when the contact lenses are stored in their cases with the solutions (Soni, 2019).

**Relationship Between Surface Tension and Contact Lens Discomfort**

Contact lenses are primarily used to address refractive problems, as well as for cosmetic and therapeutic reasons. Other reasons to wear contact lenses include the prevention of ocular surface disorders and vocational reasons, such as for athletes. The ability of contact lens to perform its functions is dependent on the contact lens solution. Despite the advantages of contact lenses and their solutions, some individuals experience ocular discomfort. Many contact lens wearers have stopped wearing them temporarily or permanently due to the discomfort they experience while wearing them (Dumbleton, Caffery, & Dogru, 2013).

According to a report published by the Tear Film and Ocular Surface Contact Lens Discomfort Workshop, contact lens discomfort (CLD) is defined as a condition characterized by episodic or persistent adverse ocular sensations related to lens wear, either with or without visual disturbance, resulting from decreased compatibility between the contact lens and the ocular environment, which can lead to decreased wearing time and discontinuation (Nichols, Redfern, & Jacob, 2013). According to the report, contact lens discomfort can be caused by a variety of factors, including the contact lens itself or the surrounding environment (Nichols, Redfern, & Jacob, 2013), medications, food, hydration, alcohol consumption, smoking, physiological/fatigue, and the physical qualities of contact lens solution (Dumbleton, Caffery, & Dogru, 2013).

A study comparing a peroxide- based system with two MPS with wetting agents demonstrated a diminished blink rate and increase in comfort with the solutions containing wetting agents and better comfort, in general, with those without wetting agents (Yang, et al., 2012). Another study comparing two solutions with wetting agents found increased comfort and performance with tetronic 1304 when compared with poloxamine and enhanced comfort in group four lens wearers specifically (Stiegemeier, et al., 2006). A similar more recent study compared poly(oxyethylene)–poly(oxybutylene) (OPTIFREE PureMoist; Alcon) with poloxamine (ReNu Fresh; Bausch & Lomb) and found greater comfort and patient tolerability with poly(oxyethylene)–poly(oxybutylene) in silicone hydrogel–wearing patients (Kuc & Lebow, 2018). Generally, those solutions containing surfactants have surface tension values closer to that of the tears while those solutions without surfactants have surface tension values closer to the value of water (Lyndon & Senchyna, 2007). This indicates that the variations in the surface tension causes some level of ocular discomfort in contact lens wear. The discomfort results from solutions that have a surface tension greater that the 46 mN/m due to their reduced ability to remove protein deposits.

**Instrument**

A study by Dalton et al (2008) took ST measurements with the Cahn Dynamic Contact Angle Analyzer DCA-322 (CAHN Instruments, Madison, WI). But in this study, the instrument that will be used in measuring the surface tension of the solutions is the Attention Sigma Tensiometer with an Attention Software for results analysis (Sigma 700/701). Force tensiometry is a versatile technique for surfactant development and formulation enabling surface and interfacial tension measurements. This reduced attraction at the liquid-gas boundary gives rise to the measurable property of surface tension. The basic principle of every Sigma measurement is to record and analyze the forces exerted onto a probe or solid sample using a sensitive microbalance. When a solid touches the surface of a liquid, the liquid tends to be drawn up in a meniscus. The instrument is connected to a computer with an Attension Software for the analysis. This meniscus creates forces on the solid that are correlated to the surface tension. Using probes that completely wet such as a platinum Du Noüy ring or Wilhelmy plate simplifies the calculations and enables Sigma Force Tensiometers to precisely measure surface and interfacial tension. Correction calculations for rings are made using models from Huh and Mason. The instrument was validity by checking the surface tension of pure water at 25 degrees celsious (ST= 72.48mN/m).

**Summary**

Multipurpose contact lens solution has been the widely used solution in the world due to its unique performance and compatibility with the various contact lens materials available. The ideal characteristics of a contact lens solution are; effective disinfection against a wide variety of pathogenic organisms, non-toxic to ocular tissues, compatible with all contact lens materials, simple to use, rapid disinfection capability, condition lens surface to enhance wettability and in-eye comfort, minimize deposition of tear film components when they are not worn. The contact lens solution is able to execute its function due to the balance in the components of the solution. A balance in the components ensures efficacy, safety and comfort of the contact lens wearer. One of the important components of the solution is the called surfactant. The surfactant has the ability to influence the surface tension of the solution thereby affecting the how the solution is able to wet and remove deposits from the contact lens. A solution has the ability to wet or clean another substance, if the solution has a surface tension smaller than that of the substance. For instance, the surface tension of human tears (42-46mN/m) is less than that of the cornea (67.5-72 mN/m). This enables the human tears to lubricate and remove deposits from the eye, ensuring an ocular comfort. Studies have reported that, the surface tension of contact lens solution varies among the available contact lens solutions. Many individuals have drop out of contact lens usage temporarily or permanently due to ocular discomfort associated with the lens wear. The contact lens wear discontinuation can be largely attributed to contact lens solutions with higher surface tension (AOSept= 70.3mN/m). Therefore, it is very paramount to investigate the surface tension of the multipurpose contact lens solutions available in Ghana.

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