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**LITERATURE REVIEW**

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.

**Importance of contact lens and ocular surface contact lens discomfort**

Because of the benefits of contact lenses over spectacles, such as, improved optical quality for vision correction and a higher quality of life, the number of people who wear them has steadily increased over time. 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. Any of these can be used in combination. 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). This discomfort could be caused by a variety of factors including medications, food, hydration, alcohol consumption, smoking, physiological/fatigue, and the physical qualities of contact lens solution. (Dumbleton, Caffery, & Dogru, 2013). Contact lens–related causes include the material, design, and care of the contact lens. Environmental related causes include patient-specific factors, compliance, and ocular surface conditions (Nichols, Redfern, & Jacob, 2013).

**Prevalence of contact lens wear**

A study reported that the global prevalence of current CLs’ users is 40.5%. Most of the wearers (80.2%) used soft lenses. The yearly type of lenses, followed by each of the daily and monthly types were the commonest used lenses (Ibrahim, Seraj, Khan, Baabdullah, & Reda, 2018). Using the population-based survey, an estimated 40.9 million persons in the United States aged ≥18 years wear contact lenses (16.7% of U.S. adults); 93.0% of contact lens wearers reported wearing soft contact lenses (lenses made of soft, flexible plastics that allow oxygen to pass through to the cornea) (Cope, et al., 2015). Out of 321 contact lens wearers in Abuja (Nigeria), most contact lens wearers were females (91%) and only 9% were males (Ezinne, Austin, Ilechie, & Mashige, 2019). Similar findings were recorded in reviews of contact lens prescribing habits in 27 countries including: Australia, Canada, United Kingdom, United States of America, Germany, Greece, Italy, Japan, Netherland, New Zealand, Sweden, Singapore and Norway except Spain where there was 48% female contact lens wearers and 52% male (Morgan, et al., 2015). Thite et al (2013) also showed that 67% of contact lens wearers in India were females (Thite, Noushad, & Kunjeer, 2013). Moreover, the use of contact lenses has always remained high in females than males since the inception of the international prescribing trends project which began in 1996 (Ezinne, Austin, Ilechie, & Mashige, 2019). In a previous study within an academic population in Ghana, the proportion of spectacle wearers reporting a history of contact lens wear was 3.3% (Abokyi, Manuh, & Otchere, 2017).

**Importance and type of contact lens solutions available**

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). They are categorized as either multipurpose solutions (MPS) or hydrogen peroxide (HP)–based systems. 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 J. , 2017). Ophthalmic HP care systems have a saline base solution so that they are designed to break down to oxygen with a saline base after neutralization of the peroxide. Although all HP systems require neutralization of the peroxide before a lens can be placed on the eye, newer HP systems are incorporating additional chemicals designed to condition contact lens surfaces and to improve patient comfort.

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 components 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, 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. It might be challenging to strike the right balance between these elements in order to ensure patient safety and compliance (Lyndon & Senchyna, 2007). First-generation disinfectants for hydrogel materials included chlorhexidine and thimerosal, but significant numbers of patients developed allergic and/or toxic reactions to these products, resulting in diffuse corneal staining, bulbar and palpebral hyperemia, corneal infiltrates and palpebral conjunctivitis (Sibley, 1989). As a result, manufacturers needed to create products that killed common ocular pathogens that accumulated on hydrogel contact lenses while being safe to use on the ocular surface. Modern care regimens have primarily used five disinfectants; hydrogen peroxide, polyhexamethylene biguanide, polyquaternium-1, alexidine, and amidoamine (Lyndon & Senchyna, 2007).

Hydrogen peroxide solutions for contact lens care have been used for many years and are seen by many as the gold standard for lens disinfection. A concentration of 3% hydrogen peroxide is that which is typically found, but some products may use much lower concentrations, in which the peroxide is used as a preservative (Lyndon & Senchyna, 2007).

Polyhexamethylene biguanide (PHMB) is a relatively large molecular weight (1,500–2,000) biocide used in many MPS systems. Polyhexamethylene biguanide has a strong cationic charge and is effective in small concentrations against both gram-negative and gram-positive bacteria as well as Acanthamoeba at concentrations of 1ppm (Yanai, Ueda, Nishida, Toyohara, & Mori, 2011). PHMB may absorb into the lens matrix and discharge into the patient's eye over time due to its ionicity and attraction factors. This "uptake and release" can affect disinfection effectiveness, corneal staining, and CLD (Kuc & Lebow, 2018).

Polyquaternium-1 (Polyquad) is another biocide commonly used in MPS. Like PHMB, Polyquad possesses a cationic mechanism of action, and this contributes to uptake and release. However, this charge-driven absorption is very formula dependent and may be affected by additional ingredients such as Aldox (myristamidopropyl dimethylamine) or citrate, which balance these ionic forces.43 Polyquad also has a larger molecule weight (7,000) than PHMB, which may help reduce a toxic uptake and release mechanism (Lyndon & Senchyna, 2007) but its mode of action is similar to that of PHMB, in that it attacks the plasma membrane of pathogens (Codling, Hann, Maillard, & Russell, 2005).

A recent addition to the marketplace used a novel preservative within the ophthalmic field, called alexidine. This agent is a cationic bisbiguanide that has a long history of use in oral mouthwashes (Carlson, Porter, & Alms, 1977) and has been shown to be highly effective against a variety of bacteria (Chaumer & Gilbert, 1989) and also *Acanthamoeba* (Borazjani & Kilvington, 2005)It is similar in structure to chlorhexidine, with additional ethylhexyl end-groups. It is more rapid in its antimicrobial action than chlorhexidine and so was used in much lower concentrations than those required for chlorhexidine and also exhibits excellent fungicidal activity (Lyndon & Senchyna, 2007). Myristamidopropyl dimethylamine (MAPD) is used under the tradename Aldox and its a cationic amidoamine also known as stearamidopropyl dimethylamine and has been shown to have both antifungal and antiamoebic activity (Codling, Hann, Maillard, & Russell, 2005; 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.

Ethylenediamine tetra acetic acid (EDTA) is a cationic chelating agent that binds free metals and enhances antimicrobial activity of disinfectants and is found in the majority of multipurpose products. Its mechanism of action is believed to involve the sequestration of ions such as calcium and magnesium that normally compete with positively charged preservative molecules for active sites on microbial cell walls. As a consequence, microbes become more susceptible to preservative penetration (Lyndon & Senchyna, 2007). Hydroxyalkyl phosphonate is marketed under the tradename Hydranate. A sequestering agent, Hydranate forms a complex with calcium, breaking the links between the deposits and the lens, as well as between the different protein elements. As a multifunctional molecule with multiple negative charges, it is attracted to tear proteins and, by attaching to the proteins and separating them from the lens through repulsive forces, the deposits are removed from the lens and then dispersed (Lyndon & Senchyna, 2007).

Propylene glycol is an organic compound (a diol alcohol) that is hygroscopic and miscible with water, acetone and chloroform and is manufactured by the hydration of propylene oxide. It is conventionally used as a moisturizer in medicines, cosmetics, food and tobacco products, as a medical and sexual lubricant (personal lubricant), as a humectant food additive (E1520), in hand sanitizers, antibacterial lotions and saline solutions and as a main ingredient in many cosmetic products, including baby wipes, bubble baths and shampoos. It’s an agent that enhances water retention on the surface of hydrogel lenses (Lyndon & Senchyna, 2007).

**Influence of surfactant on the surface tension of a contact lens solution and contact lens discomfort**

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). The surfactant then combines with these deposits to form micelles which are more easily suspended in the surrounding liquid. The micelles are then removed during the rinsing procedure. The 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). Because of the unique hydrophobic surface of Silicone Hydrogel contact lenses, surfactants have improved the wettability of the generally hydrophobic surface properties of these lenses (Lyndon, et al., 2013). This concept is substantiated when evaluating contact angle measurements for different combinations of contact lenses and care systems containing wetting agents, comparing them with blister pack measurements. All lenses containing wetting agents showed improved wettability (Lira & Silva, 2017).

The most common surfactants found in lens care solutions consist of two distinct groups –poloxamines sold under the trade name Tetronic and poloxamers sold under the trade name Pluronic. Every company that deals in contact lens solution have a specific surfactant and specific level of that surfactant that they use in their products. Specific examples include Pluronic F87 (poloxamer 237), Pluronic F127 (poloxamer 407), Pluronic 17R4, Tetronic 1107 (ReNu MultiPlus), Tetronic 1304 (Alcon OptiFree products) and Tetronic 1307. Other surfactants include isopropyl alcohol (isopropananol) found in CIBA Vision’s Miraflow, Tyloxapol (a viscous polymer of the alkyl aryl polyether alcohol type) found in AMO’s Complete MoisturePlus, and Cremophor RH40 (Aqualube) in CIBA Vision’s Focus Aqua (Lyndon & Senchyna, 2007).

A 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). Another 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). 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).

**The need to know the 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. The lesser the surface tension of the solution the more potent and efficient in cleaning the contact lens (Goudeau, Galy, Fulchiron, & Barrat, 2000). 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).

**Variations in surface tension among some contact lens solutions**

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).

**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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