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Research article

Physical properties of soft contact lens multipurpose solutions commercially available in Ghana

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ABSTRACT

Purpose: To investigate the physical properties of commercially available multipurpose soft contact lens solutions in Ghana.
Methods: pH (Kelilong ICL-099 pH meter, China), osmolality (OSMOMAT 3000, GONOTEC, Germany), surface tension (Sigma 700 Tensiometer, Sweden), and viscosity (CFOC-200 Viscometer, Cannon Company, USA) of various soft contact lens multipurpose solutions (MPS) were measured in triplicates at room temperature. Viscosity measurements were also taken at 34 °C ocular surface temperature. The solutions examined were Opti-Free Replenish (OFR), Trufresh (TF), Avizor (AV), Freshlook (FL), and Refresh (RF).
Results: Several solutions were largely hypo-osmotic in the range of 108–231 mOsm/kg, the exception being Avizor, which had osmolality values that were closer to human tears (301 ± 0.58 mOsm/kg). The range of pH values of the solutions (6.33–8.24, mean (SD) = 7.53 ± 0.18) fell within the reported tolerable range for the ocular surface (6.20–9.00). Surface tension values ranged from 35.86 to 42.27 mNm with a mean of 38.49 ± 2.32 mNm. The average viscosity of most solutions at room temperature (25 °C) was 1.44 ± 0.49 cP with a range of 1.04–2.15 cP. Significantly lower values ranging from 0.79 to 1.58 cP were obtained at ocular surface temperature (34 °C), $p = 0.0001$).
Conclusions: The physical properties of many of the solutions used as MPS in Ghana are markedly variable. Nevertheless, pH, surface tension, and viscosity fall within the acceptable limits of ocular physiological tolerance; except for osmolality, which majority were outside the reported tolerable range for the ocular surface. This information may partly explain the reason some patients exhibit strong preferences for certain care systems and should aid clinical decision-making when prescribing eye care systems to patients.

1. Introduction

Contact lenses are gradually evolving into an extremely practical alternative to spectacles in Ghana and many parts of the world [1–3]. Current estimates show that the vast majority of Ghanaians use soft contact lenses, a number that is increasing every year [4]. Multipurpose solutions (MPS) represent the majority of contact lens systems used for the care of soft contact lenses including silicone hydrogel and traditional hydrogel lenses [5]. Their convenience and low cost make them a popular choice. Hydrogen peroxide-based

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Table 1
Principal components of soft contact lens solutions investigated.

Manufacturer	Solution	Preservative (%)	Neutralizing Agents	Other reported Agents (e.g., surfactants, chelating agents and buffers)
Alcon	Opti-Free Replenish	0.001 % Polyquaternium-1 (Polyquad); 0.0005 % myristamidopropyl dimethylamine (Aldox)	–	Sodium citrate, sodium chloride, sodium borate, propylene glycol; poloxamine (Tetronic 1304); non-anoyl ethylene diaminetriacetic acid.
CIBA vision	Freshlook	0.0001 % Polyhexanide	–	Sodium chloride, poloxamer 407, disodium hydrogen phosphate, disodium edentate, sodium dihydrogen phosphate.
Silver Line Laboratories	Trufresh	0.0001 % Polyhexanite	HPMC (Hydroxypropyl methylcellulose)	Water, sodium hyaluronate, poloxamer, edetate disodium, sodium chloride, boric acid, borax, and potassium chloride.
OPTIKA Co. Ltd	Refresh	(0.005 %) Purite (Stabilized Oxychloro Complex)	–	Sodium chloride, tetronic surfactant, sodium phosphate, carboxymethylcellulose sodium, boric acid, sodium borate decahydrate, potassium chloride, calcium chloride, magnesium chloride.
Avizor SA, Spain	Avizor	–	–	EDTA (EthylenediaminetetraaceticAcid) 0.10 %, Poloxamer 0.25 %, Polyhexanide 0.0002 % in isotonic buffered solution.

solutions are extremely rare in developing countries [6]. They are typically composed of a combination of agents at different concentrations in a single all-in-one care system, cleaning, rinsing, disinfection, and storage of the soft contact lenses, to potentially aid patient comfort during contact lens wear [6]. It is possible that there is significant variability in physical properties between individual products that may influence both patient comfort and preference for one care system over another [7]. The Tear Film and Ocular Surface Society (TFOS) "Contact Lens Discomfort Workshop" advised that avoiding contact lens care systems with high osmolarity or low pH may reduce stinging and contact lens discomfort [8].

Previous studies have shown that if the pH of an ophthalmic solution varies considerably from the pH range of the tears (6.6–7.8), patients may experience ocular discomfort and stinging [9–11]. Several authors have shown that multipurpose solutions, formulated to be placed on the eye with contact lenses, should have a normal homeostatic range for tear osmolality defined as 275–307 mOsm/kg which is slightly hypotonic to that of the human tears (312–323 mOsm/kg) [11–13]. Higher osmolality values have been associated with greater levels of discomfort including dry eye disease in some studies [14,15]. The attributes of surface tension and the viscosity of contact lens solutions are important in enhancing lens wear comfort. Ophthalmic and contact lens solutions must be of sufficient viscosity to maximize bioavailability. The viscosity of the tear film ranges between 5.0 and 1.5 cP at 25 °C [16] for normal patients while human tears have a surface tension value in the range of 40–46 mN/m [14,17].

The increasing contact lens population in Ghana and many parts of the world brings about a strong focus on comfort during wear. According to the published report from the TFOS "Contact Lens Discomfort workshop", examining the physical properties of contact lens care systems is one of the strategies for ascertaining the factors associated with contact lens discomfort because when properties of the solutions do not fall within acceptable limits, it could result in burning, stinging, and epithelial cell damage [18]. Although the information on the individual components of solutions is relatively easy to find, the physical properties are not provided by manufacturers [11].

In the present study, we aim to measure the pH, osmolality, surface tension, and viscosity of various multipurpose soft contact lens solutions commercially available in Ghana, and use the results to determine if the properties are within the tolerable range for the ocular surface.

2. Methods

The solutions tested include Opti-Free Replenish (OFR) (Alcon, USA), Freshlook (FL) (CIBA VISION, USA), Trufresh (TF) (Silver Line Laboratories, India), Refresh solutions (RF) (OPTIKA Co Ltd, Korea), and Avizor (AV) (Avizor SA, Spain). These solutions are widely used in Ghana. The individual components of the solutions as documented in literature are detailed in Table 1. Two bottles of each solution were obtained from five large eye care facilities in five different geographical locations of the country which offer contact lens services. The pH, osmolality, viscosity, and surface tension of ten bottles of each solution from the different sources were tested in triplicates, and the mean values were reported.

Solution osmolality was obtained with the single-sample Freezing Point osmometer (OSMOMAT 3000, GONOTEC, Germany) [19] and pH was measured with a waterproof pH meter (Kelilong ICL-099, China). Viscosity measurements were performed with the Cannon-Fiske Opaque viscometer (CFOC-200 Viscometer, Cannon Company, USA) at room temperature (25 °C) and ocular surface temperature (34 °C) to determine whether the increased temperature at the ocular surface will affect the viscosity of the products. Surface tension measurements were taken with a force tensiometer (Sigma 700 Tensiometer, Sweden) [20]. The devices are standard equipment used in the well-equipped Petroleum Engineering Fluid Property Laboratory of the Kwame Nkrumah University of Science and Technology, Kumasi, and the Biochemistry Laboratory of the University of Cape Coast, Ghana, the settings for the research study.

2.1. Data analysis

Data analysis was performed with Statistical Package for Social Sciences for Windows (version 21.0; SPSS Inc., Chicago, IL), with confidence intervals set at 95 % (95 % CI) and statistical significance drawn at an α level of 0.05. Descriptive statistics were used to generate means (± standard deviations). Data of measured values of properties for individual solutions were checked statistically for the assumption of normality using the Kolmogorov-Smirnov test of normality. For each physical parameter, the significance of differences across products was analyzed using a one-way analysis of variance (ANOVA), with a post-hoc Tukey test applied to determine the significance of pairwise comparisons of individual solutions. Additional analysis was performed using a paired *t*-test to determine if the viscosity of individual solutions measured at room temperature (25 °C) would be significantly different from that measured at ocular surface temperature (34 °C).

3. Results

3.1. Normality of measured variables

The assumption of data normality was checked with the Kolmogorov-Smirnov test of normality and all were non-significant: osmolality, $D\ (15) = 0.184$, $p = 0.182$; surface tension, $D\ (15) = 0.167$, $p = 0.200$; pH, $D\ (15) = 0.882$, $p = 0.052$; viscosity, $D\ (15) = 0.886$, $p = 0.058$.

3.2. pH

The pH values of the contact lens solutions are shown in Fig. 1. The pH values of the contact lens solutions ranged from 6.33 to 8.24, with an average value of 7.53 ± 0.18 (mean ± SD). The average pH values of Opti-Free and Trufresh solutions were 8.24 ± 0.01 (mean ± SD) and 7.97 ± 0.00 (mean ± SD) respectively. Refresh recorded an average pH of 6.33 ± 0.00 (mean ± SD) which was significantly lower than other products ($F (4, 10) = 26874.83$, $p = 0.0001$).

3.3. Osmolality

The osmolality values are shown in Fig. 2. The osmolality values of the contact lens solutions ranged from 107.67 to 301.33 mOsm/kg, with an average value of 219.8 ± 18.78 mOsm/kg (mean ± SD). The average osmolality for Freshlook (107.67 ± 0.58 mOsm/kg) and Refresh (176.67 ± 0.58 mOsm/kg) solutions was significantly lower than other products, and Avizor had the highest osmolality value of 301.33 ± 0.58 mOsm/kg ($F (4, 10) = 23146.38$, $p = 0.0001$).

3.4. Surface tension

Surface tension values ranged from 35.86 to 42.27 mNm with an average value of 38.49 ± 2.32 mNm (mean ± SD) as shown in Fig. 3. Refresh (35.86 ± 0.11 mNm) and Opti-Free (36.66 ± 0.14 mNm) were significantly lower ($p = 0.003$) and ($p = 0.007$), respectively, than all other solutions. Trufresh had the highest surface tension values of all the products at 42.27 ± 0.20 mNm ($F (4, 10) = 958.60$, $p = 0.0001$).

3.5. Viscosity

Viscosity values of the contact lens solutions at 25 °C and 34 °C are shown in Fig. 4. The viscosity values of the contact lens solutions at room temperature (25 °C) ranged from 1.04 to 2.15 cP, with an average value of 1.44 ± 0.49 (mean ± SD). Significantly lower values ($F (4, 10) = 71.56$, $p = 0.0001$) ranging from 0.79 to 1.58 cP, with an average of 1.12 ± 0.34 (mean ± SD), were obtained at 34 °C. The most viscous of all the solutions were Freshlook (2.15 cP) and Trufresh (1.89 cP), which were significantly higher ($p = 0.001$) than the other products.

4. Discussion

It is important to public health that information regarding the physical properties of commercially available multipurpose solutions is provided by the manufacturers [8]. The goal of the present study was, therefore, to use high-precision instruments to measure the

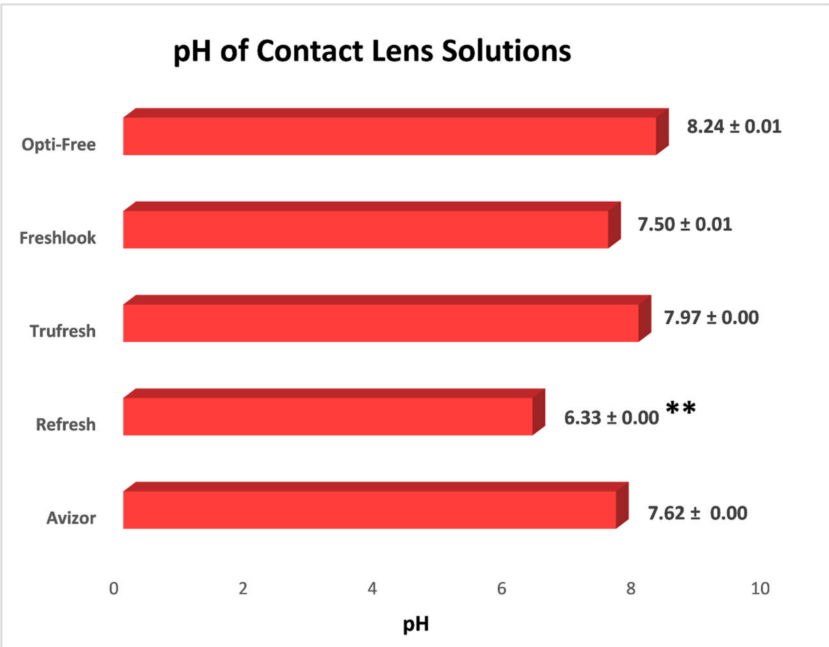

Fig. 1. Bar chart showing mean ± standard deviation of the pH of contact lens solutions, Refresh had a significantly lower mean pH of 6.33 ± 0.00 compared to the other products (**$p < 0.001$, one-way ANOVA with Tukey's post-hoc test).

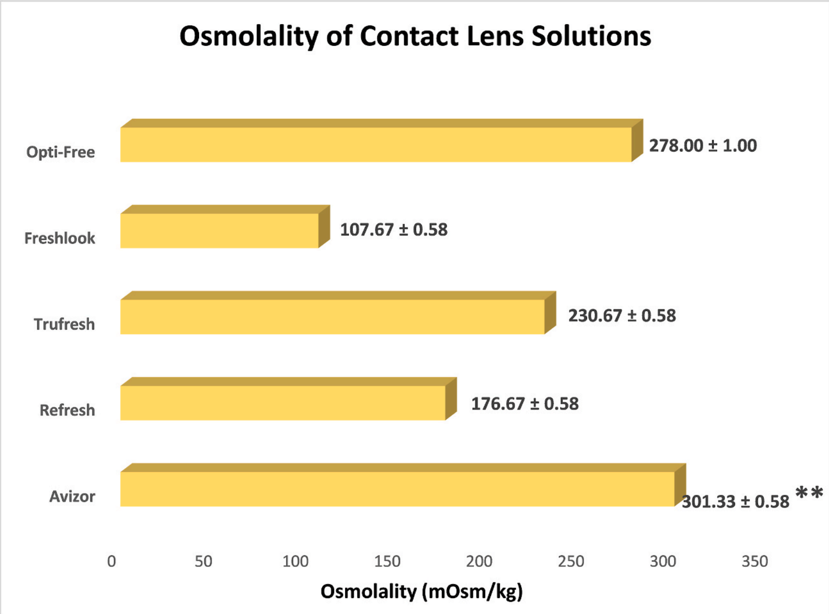

Fig. 2. Bar chart showing mean ± standard deviation of the osmolality of contact lens solutions, Avizor had a significantly higher mean osmolality of 301.33 ± 0.58 compared to the other products (**$p < 0.001$, one-way ANOVA with Tukey's post-hoc test).

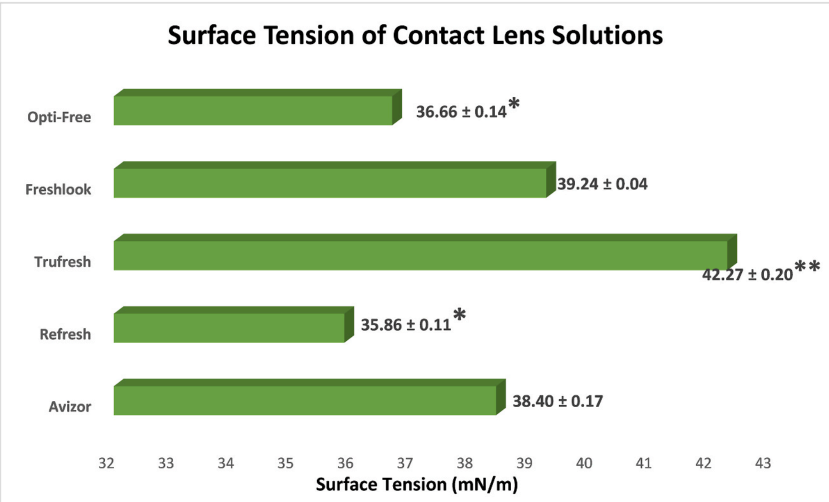

Fig. 3. Bar chart showing mean ± standard deviation of the surface tension of contact lens solutions, Opti-Free and Refresh had lower mean values (*$p < 0.01$, one-way ANOVA with Tukey's post-hoc test). Trufresh drops had a significantly higher mean surface tension of 42.27 ± 0.20 compared to the other products (**$p < 0.001$, one-way ANOVA with Tukey's post-hoc test).

physical properties of soft contact lens care solutions available in the Ghanaian market, to provide useful information that will aid clinical decision-making when prescribing contact lens care systems.

The pH value of human tears is 7.4 ± 0.16 [11,15]. To optimize ocular comfort, the ideal pH value of the contact lens solutions should be in the ocular range of 6.6–7.8; a low (acidic) or alkaline pH may cause discomfort, ocular pain, increased lacrimation as well as induce a decrease in lens hydration that could contribute to a tight-fitting lens [21,22]. In the present study, we found that Opti-Free (pH value 8.24 ± 0.01) and Trufresh (pH value 7.97 ± 0.00) were alkaline, with pH values slightly above the ocular range. Refresh (6.33 ± 0.00) was slightly acidic, with a pH value slightly below the ocular range. The remaining two products, Avizor (7.62 ± 0.00), and Freshlook (7.50 ± 0.01) had pH values within the ocular range, with Freshlook closest to the average pH value of the human tears. However, certain solutions must be kept either above or below neutrality to be effective [22]. Buffers are added to such solutions to maintain a given pH and resist pH changes [23]. The differences in the pH of the solutions may have been caused by the buffers included in the products to achieve the desired pH. Our findings imply that practitioners should have a good in-depth understanding of

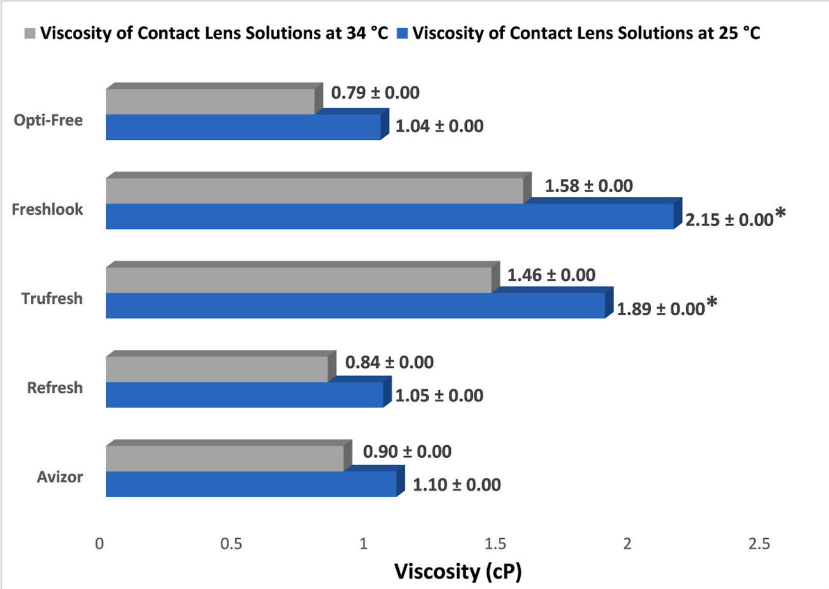

Fig. 4. Bar chart showing mean ± standard deviation of the viscosity of contact lens solutions, Freshlook and Trufresh had a significantly higher mean viscosity at 25 °C compared to the other products (*$p < 0.01$, one-way ANOVA with Tukey's post-hoc test).

the differences in pH values of these products if they are to be used effectively with a given patient. Further research is recommended to explore the extent to which miscellaneous agents included in the products influence their pH.

The osmolality of human tears varies from 312 to 323 mOsm/kg [11]. However, the reported tolerable range of solutions used for the ocular surface is 275–310 mOsm/kg [24]. All products except Avizor (301.33 ± 0.58 mOsm/kg) were hypo-osmolar, compared to the ocular comfort range. The hypo-osmolar range of the tested solutions in the present study is consistent with the findings from a previous study [25]. The difference between the osmolality values in the present study (108–231 mOsm/kg) and the previous study (225–303.5 mOsm/kg) may be attributed to the temperature and storage time of the lens care solutions after production. All the solutions used in the previous studies were collected directly from the production lots and taken to the laboratory whereas those in the present study were collected from contact lens centers. As previously mentioned, a hyperosmolar tear film is related to ocular irritation and DED [10]. Based on our findings, the osmolality of some of the tested solutions should not be of particular concern, as they demonstrated iso- or hypo-osmolar properties. These solutions include various inorganic salts such as sodium and potassium chloride (Table 1) to achieve the desired tonicity and osmolality levels. However, Freshlook (107.67 ± 0.58 mOsm/kg) and Refresh (176.67 ± 0.58 mOsm/kg) had significantly lower osmolalities that could potentially cause corneal swelling leading to patient discomfort, as they are quite lower by a larger measure than the reported tolerable range for the ocular surface [24]. The use of solutions with iso-osmolar properties provides greater comfort and prevents cornea thickness changes [11], however, compromising one property to achieve another is necessary in some cases. For instance, the diluting effect produced by hypo-osmolar agents is effective in inhibiting pH levels [22]. Our findings imply that it would be of great interest to investigate if differences in the pH value of the products are related to their osmolality properties. Also, further studies are recommended to explore the compatibility of miscellaneous agents included in the solutions, with the eye. Nevertheless, hypo and hyper-osmolar solutions that are likely to produce adverse effects must be recognized and avoided by clinicians through proper patient education and instruction.

The viscosity of a solution has the potential to influence patient comfort upon lens insertion or at the end of the day, through interactions between the solution, lens, and the patient's tear film [16,25]. At room temperature (25 °C), contact lens solutions are usually viscous to increase contact time with the eye [26]. It is reported that most contact lens solutions had viscosity values that ranged between 0.96 and 1.26 cP at room temperature, but some go as high as 3 cP [25]. The viscosity of many of the contact lens solutions tested in the present study fell within the reported range for most contact lens solutions, but Freshlook was exceptionally high at 2.15 cP. Previous studies reported that the viscosity of ocular lubricant can be affected by different temperatures [27,28] and may even reduce bioavailability [27]. Therefore, an additional intention of the study was to examine the effect the higher temperature at the ocular surface would have on the lens care solutions. As expected, all the solutions had lower viscosities at the ocular surface temperature (34 °C) than at room temperature (25 °C). Two products (Opti-Free and Refresh) recorded lower viscosity values at ocular surface temperature, this indicates a tendency to evaporate on the eyes which may lead to dryness and patient discomfort [29]. Viscosity-enhancing agents could be incorporated to increase the contact time of the formulations on the eye [26].

The surface tension of contact lens solutions influences the solutions' ability to remove loose debris and deposits from the lens thus enhancing the adherence of the lens to the cornea [25]. Multipurpose soft contact lens solution, approved for contact with the eye, should have a normal range for human tear surface tension in the range of 40–46 mN/m [23], to ensure a stable tear film and tear film break-up time [10]. We found that only Trufresh (42.27 ± 0.20 mN/m) had a surface tension in the physiological range of the tear fluid. Opti-Free (16.66 ± 0.14 mN/m), Avizor (38.4 ± 0.17 mN/m), Freshlook (39.24 ± 0.04 mN/m) and Refresh (35.86 ± 0.11 mN/m) had a surface tension well below the physiological range. While lower surface tension values improve wetting properties, surface tension values too low are likely to produce non-homogenous film thickness on the eye [30]. Surface tension exceeding the physiological range may cause instability of the tear film and is associated with dry eyes [31]. Thus, practitioners should be cautious about increased surface tension in contact lens solutions as this may influence ocular adverse effects caused by a destabilized tear film [32].

Multipurpose solutions tend to have a similar base formulation with a range of miscellaneous agents added according to the desired functions [33]. These include buffers, chelating agents, viscosity-increasing agents, and surfactants [23,33]. Surfactants are incorporated in solutions to lower the surface tension of the solutions [33]. Our findings indicate that many of the multipurpose solutions in the Ghanaian market contain surfactants at a sufficiently high level such that their surface tension is markedly reduced. The variations observed may be due to the product formulations, as one property is compromised to achieve another. It is plausible that the few solutions that did not incorporate surfactants tended to have surface tension values that were high, whereas the solutions that had one or more surfactants had surface tension values that were closer to that of human tears. The physical properties of the tested solutions demonstrated similar results to that of a previous report that investigated the physical properties of similar solutions in the US [25]. Although most values obtained fall within the ocular comfort range, some properties were higher or lower in comparison to other solutions. For instance, the pH of Opti-Free and Trufresh are higher but Avizor is more hyperosmotic, and Freshlook has more viscosity.

4.1. Strengths of the study

It is noteworthy that a comprehensive array of parameters has been measured for each solution, contributing to a thorough and detailed assessment. Furthermore, the contact lens solutions examined in the present study are a good representation of the lens care products widely used in Ghana, as contact lens practice in the country is clinic-based and the majority of wearers receive contact lens services from the five major prescribing clinics the solutions were collected from.

4.2. Limitations of study

It is acknowledged that the study focuses on a limited number of solutions, all designed specifically for the maintenance of soft lenses. This scope restriction may impact the generalizability of the results to other categories of ophthalmic solutions. Other issues need to be considered in the interpretation of the results. The country is geographically divided into sixteen regions but the study surveyed and examined only five types of multipurpose lens care products collected from five regions where contact lens practice is common. There may be other different lens care products commercially available in other regions of the country. Also, because the solutions were not collected from the production lots, temperature and storage time in the eye care centers might have influenced their physical properties. Most importantly, the types of other component agents in each solution may directly affect the eye and the lens material in a different way considering that most of the products examined in the study are commercially successful.

5. Conclusion

In summary, the present study has provided useful information on the pH, osmolality, viscosity, and surface tension of commercially available soft contact lens solutions in Ghana, that are not readily available. There were unique variations in the physical properties of the tested solutions. This novel empirical data should be used to develop clear evidence-based guidance for eye care practitioners on the use of the MPS.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the corresponding author, [N.A.A].

Ethics declarations

- Ethical approval by an ethics committee was not needed for this study because the study did not involve any intervention on humans or animals.
- Informed consent was not required for this study as it did not involve human participants. The research focused solely on investigating the physical properties of contact lens solutions, and as such no human subjects were involved in the data collection process.

CRediT authorship contribution statement

Alex Ilechie: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Naa Adjeley Addo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Elsie Aidoo:** Resources, Methodology, Investigation, Data curation. **Anthony Armah:** Resources, Methodology, Investigation, Data curation. **Fateena Faheem:** Writing – original draft, Resources, Methodology, Investigation, Data curation. **Bismark A.A. Achimah:** Resources, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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