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☏ +381 11 4092 776, Fax: +381 11 3348 653
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Veljko Ilić[1,♣], Dejan Ćetković[2], Srđan Poštić[3], Snežana Brković[3], Dragan Ilić[4]

The laboratory investigation of the capillarity of various dental solutions at three temperature levels

Лабораторијско испитивање капиларитета различитих стоматолошких раствора на три температурна нивоа

[1]University of Belgrade, School of Dental Medicine, Department of General and Oral Histology and Embryology, Belgrade, Serbia;
[2]University of Belgrade, School of Dental Medicine, Institute of Anatomy, Belgrade, Serbia;
[3]University of Belgrade, School of Dental Medicine, Department of Prosthodontics, Belgrade, Serbia;
[4]University of Belgrade, School of Dental Medicine, Department of Restorative Dentistry and Endodontics, Belgrade, Serbia

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♣Correspondence to:
Veljko ILIĆ
Department of General and Oral Histology and Embryology, School of Dental Medicine, Dr Subotića Starijeg 8, 11000 Belgrade, Serbia
E-mail: **veljko.ilic@stomf.bg.ac.rs**

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SUMMARY

Introduction/Objective Many oblong micro-spaces of less than 500 µ exist within oral cavity, such as dentine canalicular spaces, gaps, recesses, gingival sulcus etc. Since these spaces are susceptible to food and pathogenic microbe's accumulation, the most dental solutions should be able to penetrate into those micro spaces exhibiting therapeutic effects. The aim of this study was to evaluate and compare the effect of capillarity of several dental solutions at three temperature levels.

Methods The following solutions were examined: ethanol (EA), saline, hydrogen peroxide (HP), sodium hypochlorite (SH), citric acid, ethylene-diamine-tetraacetic acid (EDTA), distilled water, and chlorhexidine. The samples were exposed to the temperature of 20, 38 and 50°C measuring capillary by glass tube of 400 µ diameter. The capillary effects of the solutions were recorded on the graduate capillary tube (mm) and data were statistically processed.

Results The highest raise of capillarity (20–50°C) showed 70% EA (8.8 ± 1.1) and the lowest 2.5% SH (2.1 ± 1.5) and 3% HP (2.1 ± 1.6). The highest capillarity at 50°C showed 17% EDTA (40.1 ± 1.4) while 4% SH showed the lowest one (25.9 ± 2.1) ($p < 0.05$).

Conclusion The level of capillarity of dental irrigating solutions was enhanced with temperature increase in all solutions, but not to the same extent.

Keywords: irrigation; sodium hypochlorite; chlorhexidine; EDTA; surface free energy

САЖЕТАК

Увод/Циљ Дугуљасти микро-простори ужи од 500 *μm* присутни су у усној дупљи у виду тубуларних простора дентина, пулпопериодонталних каналића, гингивног сулкуса, зјапа рестаурације итд. Како су ови простори изложени дејству задржавања хране и патогена, већина денталних раствора би требало да лако продре у њих и делује терапеутски. Из тог разлога је постављен циљ ове студије да се процени ефекат капиларности неколико денталних раствора на три температурна нивоа.

Методе Испитивани су раствори етанола (*EA*), физиолошког раствора, водоник пероксида (*VP*), натријум хипохлорита, лимунске киселине, етилен-диаминотетраацетатне киселине (*EDTA*), дестилована вода и хлорхексидинана, на 20, 38 и 50°*C*, у капиларној цеви промера 400 *μm*. Висина капиларног стуба је забележена на градуисаној капиларној цеви (*mm*) а подаци статистички обрађени.

Резултати Највећи пораст капиларности (20–50°*C*) показао је 70% *EA* (8,8 ± 1,1), а најнижи 2,5% *SH* (2,1 ± 1,5) и 3% *VP* (2,1 ± 1,6). Највиша капиларност добијена је на 50°*C* za 17% *EDTA* (40,1 ± 1,4), а најнижа за 4% *SH* (25,9 ± 2,1) ($p < 0.05$).

Закључак Степен капиларности код свих денталних раствора расте са порастом температуре, али у различитом степену.

Кључне речи: иригација; натријум хипохлорит; хлорхексидин; *EDTA*; слободна површинска енергија

INTRODUCTION

Capillarity is defined as a liquid's property to move along (penetrate) then arrow tubular space against the force of gravity or the voids of a porous material, and depends of liquid nature and surface tension [1]. Considering the nature of the liquid and its density the formula of capillary action is as follows:

$$h = 2\gamma cos\alpha / \rho gd$$

where h is height of the liquid column, γ - liquid-air surface tension, ρ - the liquid density, d - radius of capillary tube, g - gravity acceleration and α - contact angle between liquid column and capillary wall. The h value depends directly on the liquid-air surface tension being directly proportional to this value. The narrower the capillary tube, the more pronounced the capillarity is, especially when $d < 1$ mm and when it does not show the phenomenon of connected vessels. A capillary immersed in liquid shows a concave meniscus. Actually, adhesion occurs between fluid and the capillary wall pulling the liquid up until there is sufficient liquid for gravitational forces to overcome these intermolecular (adhesive) forces.

Knowing this, dentinal tubules could be considered as a capillary model due to their natural diameter (2 - 10 microns) that becomes wider and more passable after citric endodontic solutions treatment [2]. Marginal restoration gap, gingival crevice, periodontal pockets, interdental niches, canalicular pulpal oblong spaces etc. can be considered capillary spaces where dental plaque/microbe might freely enter. For this reason, there were studies related to the capillary penetration of dental disinfectants. For example, Cuningham et al. [3] have been investigating dentine capillarity focusing on depth of endodontic irrigants penetrations since 1973. Adding of the ethanol (EA) to the sodium hypochlorite (SH) they found that small surface tension of EA permits deeper flow than SH in the capillary tube. Since then, many studies appeared related to the dynamics of fluids used in everyday dental practice such as analgesics, solvents, demineralizators, sealers, etc. Such liquids present superior capability to reach aforementioned narrow spaces, if warmed up. Also, papers appeared regarding the influence of liquid concentration and temperature to the antimicrobial and capillarity effect, which are mostly proved with SH solutions [4, 5]. Sirtes et al. worked with 1, 3 and 5% SH at 20, 45, and 60ºC against microbes and found the highest temperature much more effective than other two, indicating an increase in diffusivity with temperature rise [6]. Some authors even advocate the use of gelatinous NaOCl preheated by ultrasonic streaming results in high-quality capillarity of that disinfectant [7]. Hydrogen peroxide (HP) is nowadays very frequent additive to dental solutions-pastes, predominantly as a weak disinfectant, but potent surfactant (bleacher) at 30% concentration [8]. It exposed rise of capillarity between 20 and 37ºC in one study and thus the possibility of penetration through treated substrate [9]. Moreover, strong combination of sporicidal and bactericidal effects of HP (3 - 23.6%) was noted in combination with 25% peracetic acid [10]. Chlorhexidine digluconate (CHX), with appropriate low surface tension (high capillarity) is the useful mean in endodontics, periodontology and as a cleanser for orthodontic braces and fixed restorations. Bearing that in mind, it is important to mention the work of González et al. [11] who found the temperature rise (37 - 40ºC) upon ultrasonic irrigation of CHX meaningful for endodontic treatment.

Concerning aforementioned, the aim of this study was to investigate and compare the power of capillarity of various dental solutions at different concentrations and at three temperature levels.

METHODS

Materials

The study involved the following solutions: 96% and 70% ethanol (EA); 4%, 2.5%, and 0.5% sodium hypochlorite (SH); 30% hydrogen peroxide (HP); 2%, 0.2% (a), and 0.2% (b) chlorhexidine (CHX); saline solution (SS); 10% citric acid (CA); 17% and 2% ethylenediaminetetraacetic acid (EDTA) and distilled water (DW), forming a total of 14 experimental groups, derived or used as of original manufactured preparations: EA (Etanol 96%, Zorka Pharma, Šabac, Serbia); 5.25% SH (Sodium hypochlorite, Cerkamed, Poland); HP (Vodonik peroksid 30%, Zorka Pharm, Šabac, Serbia); CHX (Curasept 2%, Septodont, France); 0.2% CHX(a) (Lacalut active mouth wash, Hamburg, Germany); 0.2% CHX(b) (Curasept mouth wash, Curadent, Milan, Italy); SS (Natrii chloride infundibule, Hemofarm, Vršac, Serbia); CA (Citric acid 10%, Cerkamed, Poland); EDTA (ethylenediaminetetraacetic acid 17%, Cerkamed, Poland); EDTA (Kavipran - 2% ethylenediaminetetraacetic acid, Galenika, Belgrade, Serbia); DW (Aqua destilata, Hemofarm, Vršac, Serbia).

Instruments and measurement method

Glass graded capillary tube 400μm in diameter (LingYan Engineering Co. Ltd, China) was used for capillarity experiments and orthodontic ruler (raster of 0.5 mm) and magnifying glass (4 x) were employed for the measurements of the solutions level (Figure 1).

Preferred place for Figure 1.

The temperature levels of 20, 38, and 50ºC were assembled by alcohol thermometer in the stable ambient laboratory conditions (t = 20°C, 65% humidity). Each sample solution was poured into Erlenmeyer vessel at the level of 22 mm. Capillary glass tube was then plunged into the vessel perpendicular to the vessel bottom. Immediately upon solution rise, the tube was sealed by thumb and the level of meniscus was recorded by red water-resistant marker. Capillarity value was measured from the tip of the glass tube to the red marker point by orthodontic ruler and magnifying glass (± 0.25 mm error). The span value (Δl) was calculated as the difference between capillarity values (h) among all three temperature points (i.e.: Δl_1 = h50 – h20, Δl_2 = h50 – h38, Δl_3 = h38 - h20), for all solutions. Measuring was repeated three times for every experimental solution at all three temperature points.

Statistical analysis

The obtained values were submitted to statistical analysis using SPSS (v17.0, Chicago, IL, USA). Normality of data was checked using Kolmogorov-Smirnov test, then one-way ANOVA test (with repeated measures and multiple comparisons Bonferroni tests) were utilized for within-group and between-group comparison, considering parameters: solution and temperature. The significance was set at $p < 0.05$.

Ethics: The authors declare that the article was written according to ethical standards of the Serbian Archives of Medicine as well as ethical standards of institutions for each author involved.

RESULTS

The obtained capillarity values of studied solutions are presented in Figure 2 and Figure 3. Summary of between-group statistical analysis is presented in Table 1.

All heated solutions expressed increase in capillarity, but 96% EA, 70% EA, 2% CHX, 0.2% CHX(a), 0.2% CHX(b), and 10% CA showed statistically significant rise, especially when heated from 20 to 50°C ($p < 0.05$). The highest capillary value span was recorded for 70% EA (8.8 ± 1.1 mm) while the lowest one was noted for both 2.5% SH and 3% HP respectively (2.1 ± 1.5; 2.1 ± 1.6 mm).

DISCUSSION

Bearing in mind that the capillary effect in the oral cavity can be both, beneficial (spreading of medicamentous solutions into capillary spaces) and detrimental (undesirable attraction of unwanted pathogenic substances into tissue spaces), the goal of this work was to examine various solutions capillarity, especially at the maximum bearable temperature of the oral cavity (~ 50ºC) [12].

The rise of concentration of studied solutions did not follow correspondently rise in capillary height for temperature span of 20 - 50ºC. Namely, with concentration decrease of EA solutions, length span increased. The opposite situation was found for SH and EDTA solutions. The correlation between solution concentration and span value was not found for CHX samples. Commercial preparations of CHX showed different capillarity values where explanation might be due to different addition of corrigens, stabilizing agents such as polyethylene glycol (PEG), propylene glycol, castor oil etc. Before mentioned indicates that the very nature of the dissolved substance in investigated samples might affect to the uneven distribution of capillary values.

Considering the change of capillarity values at investigated solutions for temperature spans of both 20–38ºC and 38–50ºC, it is to note the similar situations; i.e. sometimes, the rise of water partition in the samples resulted in the fall of capillarity span, or the opposite.

The studied solutions resulted in different extent of capillarity rise at all samples due to enhanced velocity of solution molecules and less friction along the glass walls of capillary tube. The different values of capillarity at different solutions could be explained by their nature. Moreover, the water partition of the samples with different substances did not influence the obtained values at the same way: somewhere water enhanced, but somewhere it lessened the capillary power although DW *per se* resulted in very high values of capillarity for all three temperature levels (36.1 – 36.7 – 39.7 mm). Those discrepancies in capillarity change were in some cases statistically significant and in other cases they were not. Additional explanation might be in specifically bonding between water and solvate substances (EA, SH, CHX). In addition, very low capillarity rise for 20 - 50ºC temperature span for all SH concentration, 2% EDTA, 3% HP, and SS indicates that they should not be heated, although there are no literature results if such small capillary rise could significantly influence the pathogens elimination.

The present study is the first report in the literature of the capillarity values of different dental solutions and therefore there are no other studies to compare with. There are many studies about rheological and similar properties of the solutions to apply in dentistry, correlating the nature of solution and tooth tissues. Those solutions' features were presented through the different physical values: viscosity [13], surface tension-surface free energy [14], contact angle [15], wetting [16, 17], as well as temperature dependence to contact angle [18]. Regarding before mentioned, the results of those studies represented through the various physical units should be adequately converted thus allowing the results' comparison. Considering the equation for capillarity determination, it will be interesting to discuss the capillarity value (height of solution column) in correlation to the parameters that could have influence to it, such as surface tension (γ), wetting angle (α) and density (ρ) of the liquid. For instance, the value of surface tension is in reverse proportion to the capillary power of the liquid, while wetting is directly proportional to the capillarity power and in reverse relation to the contact angle value. On that way Lopes et all. [17] applied measurement of contact angle and the surface tension of irrigants calculating the wettability of the studied solutions using Young's equation.

Khattab et al. investigated the density, viscosity, and surface tension of water + ethanol mixtures from 293 to 323 K. They made mathematical conversion of density, viscosity, and surface tension of binary mixture of water + ethanol at 293, 298, 303, 308, 313, 318, and 323 K are reported and compared with the available literature data. This study shows that the Jouyban-Acree model can correlate/predict physicochemical properties of the mixtures of solvents at different temperatures with acceptable error in calculations. Thus, positive correlation was confirmed between contact angle (wetting) and capillarity values [19]. The addition of active substances for surface tension lessening into the CHX solutions gives positive effect, but it does not influence the superior pulp tissue dissolution and better lubricant in root canal [14]. In that way, surfactant can enter the minor lacunar spaces even narrower than 0.5 mm (capillary space). PEG, usually employed as a surfactant, acts as hydrophilic molecule attracting water molecules and inducing more capillarity, and might be used as the experimental additive-surfactant where coarse aggregate solutions affect the permeability of the substrate [20].

It is interesting to mention the study of Rossi-Fedele et al. using pendant drop method to evaluate the effect of an alcohol-based caries detector (Kurakay) on the surface tension of a conventional SH solution at 20ºC by optical recording with a commercially available apparatus. In this manner, the addition of Kurakay significantly reduced the surface tension of SH [14].

The capillary potential can be the most clearly understood at 50ºC, where the greater significant difference among investigated solution was found, compared to those obtained at 20 and 38ºC. Actually, the differences between 20 and 38ºC were not significantly displayed in the most solutions. The explanation that the increase of temperature provoked higher capillary power lies in the fact that all dissolved molecules then become more mobile going along the glass wall of the capillary tube. The high value of EDTA molar mass (338.2 g/mol) might be the reason for low speed of its molecules even when warmed. Hence, there would be no clinical benefit of using warmed EDTA irrigant.

EA solutions along the increase of active ingredient (70–96% ethanol) showed the increase of capillarity at all three temperature levels (28 – 30 – 37; 29 – 36 – 37 mm). The greatest increase of capillary column (h50–h20 span) was found for 70% EA (8.8 mm), presumably making it a better antimicrobial solution compared to 96% EA (8.0 mm). The utilization of 96% EA in our study can be justified by its use in dentistry as a dehydrator, although less antiseptic than 70% EA. One review reported the antimicrobial effect of alcohol solution with the addition of CHX in surgical procedures [21].

On the contrary of EA, SH solutions with increase of chlorine concentration (0.5 - 2.5 - 4% sodium hypochlorite) exhibited simultaneously the weakening of their capillary power although statistically insignificant at all temperature points (0.5%: 26 - 24 - 23; 2.5%: 27 - 26 - 24; 4%: 28 - 27 - 26 mm), hence, the utilization of higher concentration SH irrigants (5.25 and 6%) would result in the similar way. Guerisoli et al. [22] indicated that rise of viscosity i.e., lessening capillarity effect of SH 0.986 - 1.110 times by the increase of its concentration (0.5 - 4%), which is in numerically accordance with the results of our study. Sirtes et al. found that the temperature rise of SH samples (5.25, 2.5, and 1%, from 20 to 40 and 60ºC) do not exposes significant antimicrobial effect on *Enterococcus faecalis* [6].

Regarding the newer data on the chemical nature of surfactants, some authors found amphiphiles with longer hydrocarbon chains more surface-active than solution with shorter hydrocarbon chain, what could be applicable to the capillarity energy. Namely, fluorine ion caries protective agent in the fluorocarbon chain and exposes more hydrophobic effect than hydrocarbon chain itself [23]. Observing the affinity of certain substances for water, Ekholm et al. found by structural analysis that at the surface, the linear-structured alcohol preferred an orientation with the hydrophobic tail pointing out from the surface, whereas the hydroxyl group remains immersed in the water. This phenomenon, regarding the alcohol solutions, is likely transferable to other small molecules with similar structures but other functional groups [24]. In addition to previously mentioned, microbial-derived biosurfactants present the interesting concept in modern dentistry with a potential for future utilization [25].

It is also necessary to search for a suitable *in vivo* model for testing the capillarity of dental solutions, which would be a lot more accurate than the *in vitro* patterns. Also, the question of finding a suitable surfactant to be added to the dental solution still remains open, in order to improve capillary strength and other fluid properties.

CONCLUSION

The greatest capillarity power among investigated solutions was found for 17% EDTA with the lowest one was for SH solutions. The increase of solution concentration considerably influenced the capillarity of EDTA, while the different concentrations of SH and CHX showed relatively identical values of capillarity. Finally, the capillarity of studied solutions significantly increased with the temperature rise, approving the warming of dental solutions up to 50ºC for clinical use in dentistry.

Clinical significance

The obtained results indicate the importance of warming the previously mentioned solutions for clinical practice, even for the solutions where capillarity was weak, due to their certain penetrability and antimicrobial effect on the substrate to be conditioned. The nature of the surface along with liquid movability can be an important factor for capillary power, bearing in mind the roughness of the clinical surface where liquid moves (enamel, dentine, root cement, periodontal tissue, composite restauration, ceramic surface, etc.).

Conflict of interest: None declared.

REFERENCES

1. Qian J, Zhiqiang L, Shi Z. Soil-water retention curve model for fine-grained soils accounting for void ratio-dependent capillarity. Can Geotech J. 2021; 59 (4) doi: 10.1139/cgj-2021-0042.
2. Tunar OL, Kuru BE. Microstructural changes of human dentin tubules after citric acid immersion of specimens treated with different desensitising approaches: An SEM Analysis. Oral Health Prev Dent. 2022; Oct 19; 20 (1):369-378. doi: 10.3290/j.ohpd.b3464895. PMID: 36259440.
3. Cunningham WT, Cole JS, Balekian AY. Effect of alcohol on the spreading ability of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol. 1982; 54 (3):333-5. PMID: 6957829. doi: 10.1016/0030-4220(82)90105-0
4. Pinheiro ET, Karygianni L, Attin T, Thurnheer T. Antibacterial effect of sodium hypochlorite and EDTA in combination with high-purity nisin on an endodontic-like biofilm model. Antibiotics (Basel). 2021; Sep 21; 10(9):1141. doi: 10.3390/antibiotics10091141. PMID: 34572723; PMCID: PMC8469179.
5. Leonardi DP, Grande NM, Tomazinho FSF, Marques-da-Silva B, Gonzaga CC, Baratto-Filho F et al. Influence of activation mode and preheating on intracanal irrigant temperature. Aust Endod J. 2019; Dec 45(3):373-77. doi: 10.1111/aej.12336. Epub 2019 Feb 6. PMID: 30724420.
6. Sirtes G, Waltimo T, Schaetzle M, Zehnder M. The effects of temperature on sodium hypochlorite short-term stability, pulp dissolution capacity, and antimicrobial efficacy. J Endod. 2005; Sep 31(9):669-71. doi: 10.1097/01.don.0000153846.62144.d2. PMID: 16123703.
7. Spironelli CAR. Mastering irrigation in endodontics. Part 2. Jan 1, 2020. https://www.dentistrytoday.com/mastering-irrigation-in-endodontics-part-2/ (cited on 30th of June, 2023)
8. Savić Stanković T, Karadzić B, Latković M, Miletić V. Clinical efficiency of a sodium perborate-hydrogen peroxide mixture for intracoronal non-vital teeth bleaching. Srp Arh Celok Lek. 2020; 148,1-2, 24-30. https://doi.org/10.2298/SARH190504094S.
9. Ilić D, Andjelski Radičević B. The study of capillarity on several dental solutions. Zdravstvena zastita. 2019; 48, 2,1-6. doi: 10.5937/ZZ1902001I.
10. Dvorak G. Disinfection 101, 12-13, 2008, 05. Center for Food Security and Public Health 2160. https://www.cfsph.iastate.edu/Disinfection/Assets/Disinfection101.pdf (cited 30th of June, 2023)
11. González C, Forner L, Llena C, Lozano A. Temperature changes in 2% chlorhexidine gluconate using two activation methods with different intensity levels. J Clin Exp Dent. 2018; May 1; 10 (5):e458-e461. doi: 10.4317/jced.54732. PMID: 29849970; PMCID: PMC5971069.
12. Marques MPM, Batista de Carvalho LAE, Gonçalves D, Cunha E, Parker SF. The impact of moderate heating on human bones: an infrared and neutron spectroscopy study. R Soc Open Sci. 2021; Oct 27;8 (10):210774. doi: 10.1098/rsos.210774. PMID: 34729208; PMCID: PMC8548792.
13. Kim HJ, Park SJ, Park SH, Hwang YC, Yu MK, Min KS. Efficacy of flowable gel-type EDTA at removing the smear layer and inorganic debris under manual dynamic activation. J Endod. 2013; 39(7):910-4. doi: 10.1016/j.joen.2013.04.018. Epub 2013 May 16. PMID: 23791262.
14. Rossi-Fedele G, Guastalli AR. Effect of an alcohol-based caries detector on the surface tension of sodium hypochlorite preparations. Braz Dent J. 2015; 26(1):66-8. doi: 10.1590/0103-6440201300172. PMID: 25672387.
15. Yonemoto Y, Fujii Y, Sugino Y, Kunugi T. Relationship between onset of sliding behavior and size of droplet on inclined solid substrate. Micromachines. 2022; 13, 1849. https://doi.org/10.3390/ mi13111849.
16. Ricci HA, Scheffel DL, de Souza Costa CA, dos Santos FJ, Jafelicci MJr, Hebling J. Wettability of chlorhexidine treated non-carious and caries-affected dentine. Aust Dent J. 2014; 59(1):37-42. doi: 10.1111/adj.12150. PMID: 24697341.
17. Lopes HP, De Faria AR, Alves FR, Elias CN. Wettability of irrigants used in root canal treatment. Dentistry. 2015; 5(3):1. doi:10.4172/2161-1122.1000283 Corpus ID: 52262671
18. Duchemin B, Cazaux G, Gomina M, Bréard J. Temperature-dependence of the static contact angle: A transition state theory approach. J Colloid Interface Sci. 2021; Jun 15; 592:215-226. doi: 10.1016/j.jcis.2021.02.059. Epub 2021 Feb 22. PMID: 33662826.

19. Khattab IS, Bandarkar F,Fakhree MAAA, Jouzban A. Density, viscosity, and surface tension of water+ethanol mixtures from 293 to 323K. Korean J Chem Engng. 2012; 29, 812-17, 2012, https://doi.org/10.1007/s11814-011-0239-6.

20. Heinz H, Pramanik C, Heinz O,Ding Y, Mishra RK, Marchon D, Flatt RJ, Estrela-Lopis I, Llop J, Moya S, Ziolo RF. Nanoparticle decoration with surfactants: Molecular interactions, assembly, and applications, Surface Science Reports. 2017, Volume 72, Issue 1, Pages 1-58, https://doi.org/10.1016/j.surfrep.2017.02.001.

21. Jalalzadeh H, Groenen H, Buis DR, Dreissen YE, Goosen JH, Ijpma FF et al. Efficacy of different preoperative skin antiseptics on the incidence of surgical site infections: a systematic review, GRADE assessment, and network meta-analysis. Lancet Microbe. 2022; Oct; 3 (10):e762-e771. doi: 10.1016/S2666-5247(22)00187-2. Epub 2022 Aug 16. Erratum in: Lancet Microbe. 2022 Oct; 3 (10):e732. PMID: 35985350.

22. Guerisoli DMZ, Silva RS, Pécora JD. Evaluation of some physico-chemical properties of different concentrations of sodium hypochlorite solutions. Braz Endod J. 1998; 3(2): 21- 23

23. Ghosh S, Ray A, Pramanik N. Self-assembly of surfactants: An overview on general aspects of amphiphiles. Biophys Chem. 2020; Oct; 265: 106429. doi: 10.1016/j.bpc.2020.106429. Epub 2020 Jul 8. PMID: 32693319.

24. Ekholm V, Caleman C, Hub JS, Wohlert M. Propensity, free energy contributions and conformation of primary n-alcohols at a water surface. Phys Chem Chem Phys. 2021; Sep 14; 23 (34):18823-29. doi: 10.1039/d1cp02818a. Epub 2021 Aug 20. PMID: 34612420.25.

25. Khairunnisa, Z., Tuygunov, N., Cahyanto, A. et al. Potential of microbial-derived biosurfactants for oral applications–a systematic review. BMC Oral Health. 2024, 24, 707 (2024). https://doi.org/10.1186/s12903-024-04479-0

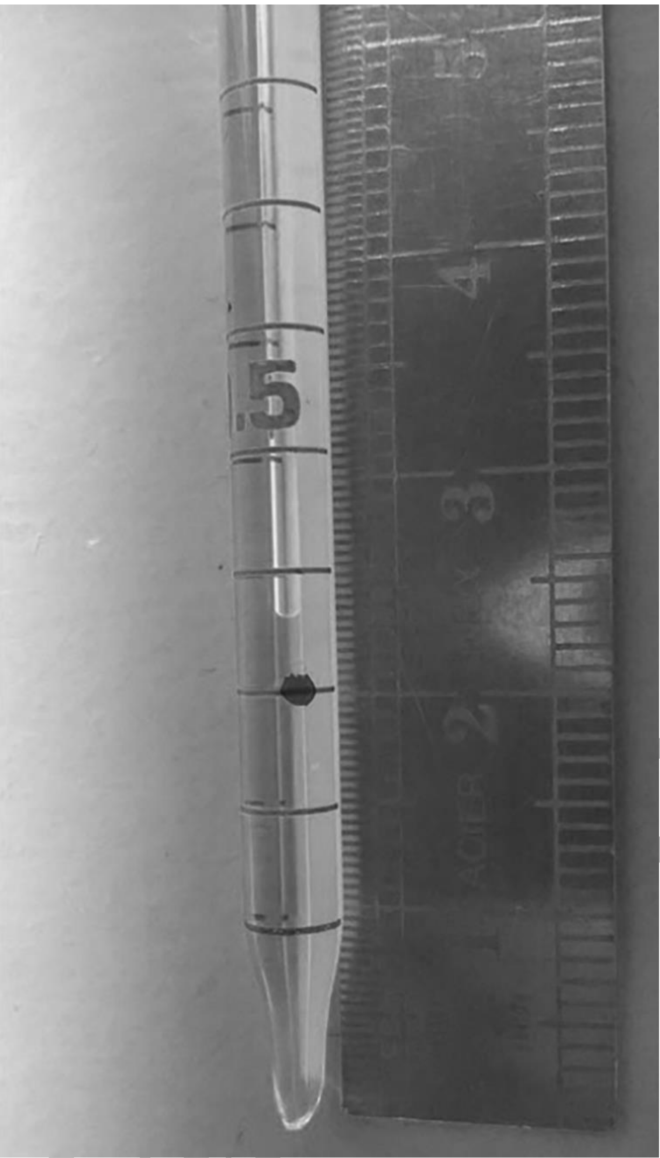

Figure 1. Glass graded capillary tube having a diameter of 400 μm adjacent to an orthodontic ruler

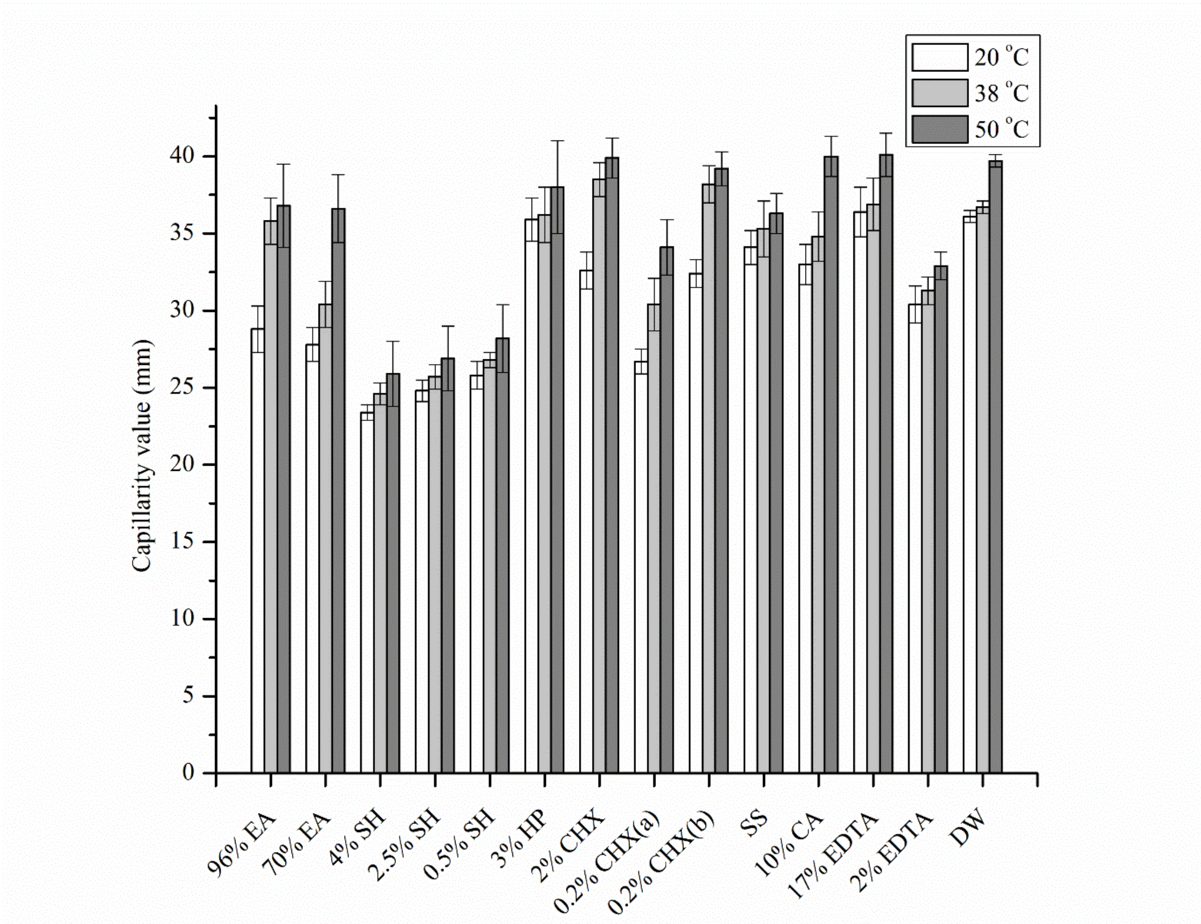

Figure 2. The obtained results of capillarity values (mean ± SD) for investigated solution at three temperature levels;
EA, ethyl alcohol; SH, sodium hypochlorite; HP, hydrogen peroxide; CHX, chlorhexidine; SS, saline solution; CA, citric acid; EDTA, ethylene-ditetra-amino acid; DW, distilled water; respective values (mean ± SD) distributed in the cells; plotted in computer software OriginPro 8.5

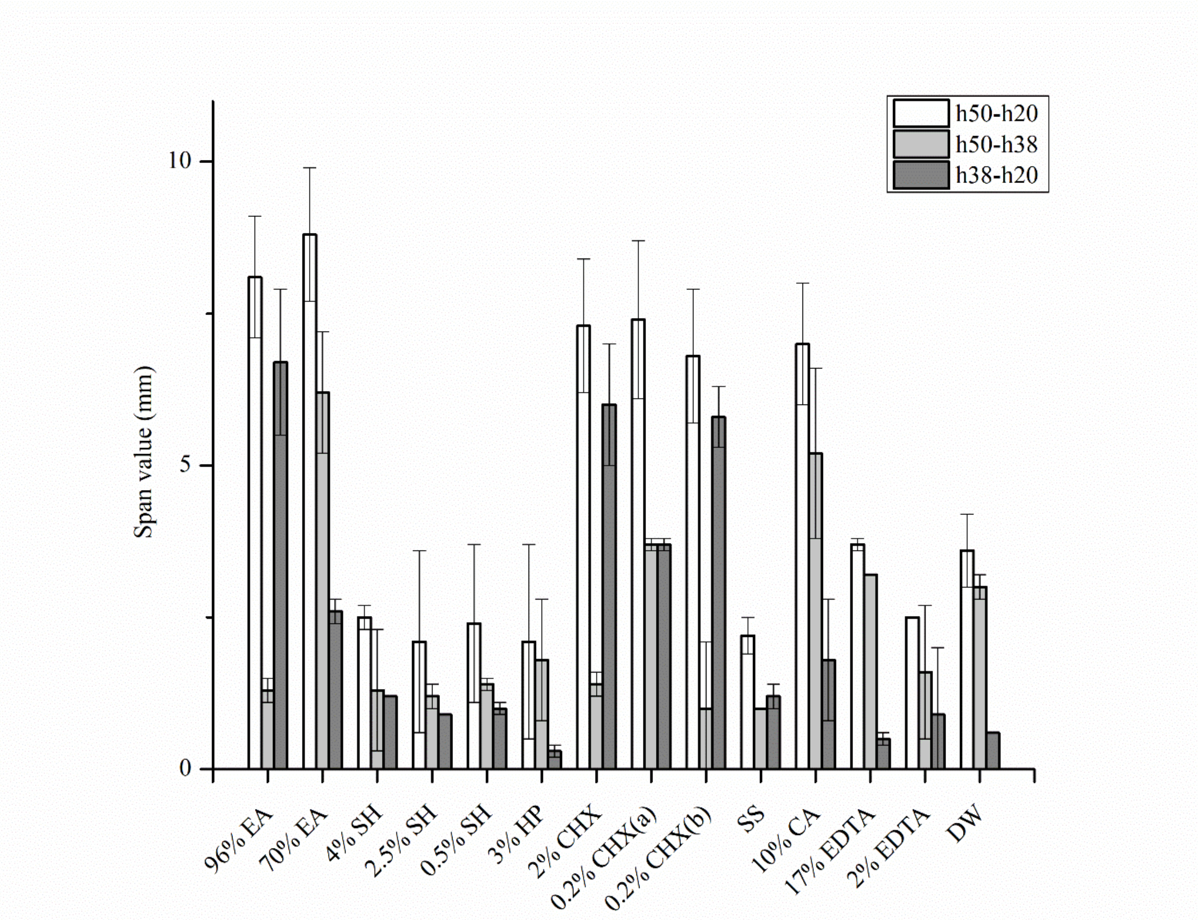

Figure 3. The span values of tested solutions' capillarity (mean ± SD). h50–h20, difference in capillarity values between temperatures of 50°C and 20°C; h50–h38, difference in capillarity values between temperatures of 50°C and 38°C; h38–h20, difference in capillarity values between temperatures of 38°C and 20°C;

EA – ethyl alcohol; SH – sodium hypochlorite; HP – hydrogen peroxide; CHX – chlorhexidine; SS – saline solution; CA – citric acid; EDTA – ethylene-ditetra-amino acid; DW – distilled water;

respective values (mean ± SD) distributed in the cells; plotted in computer software OriginPro 8.5

Table 1. Summary of between-group statistical analysis results at three temperature levels

Solutions		**p-value**		
(I) Group	**(II) Group**	**(I *vs.* II) at 20˚C**	**(I *vs.* II) at 38˚C**	**(I *vs.* II) at 50˚C**
96% EA	70% EA	0.006	0.000	1.000
	4% SH	0.000	0.000	0.000
	2% SH	0.000	0.000	0.000
	0.5% SH	0.000	0.000	0.000
	3% HP	0.000	0.368	0.076
	2% CHX	0.001	0.000	0.000
	0.2% CHX(a)	0.000	0.002	0.000
	0.2% CHX(b)	0.000	0.000	0.000
	SS	0.000	1.000	1.000
	10% CA	0.000	1.000	0.000
	17% EDTA	0.000	0.027	1.000
	0.2% EDTA	0.000	0.006	0.000
	DW	0.000	0.059	0.000
70% EA	4% SH	0.000	0.000	0.000
	2% SH	0.000	0.000	0.000
	0.5% SH	0.000	0.000	0.000
	3% HP	0.000	0.000	0.003
	2% CHX	0.000	0.000	0.000
	0.2% CHX(a)	0.047	1.000	0.000
	0.2% CHX(b)	0.000	0.000	0.000
	SS	0.000	0.000	1.000
	10% CA	0.000	0.000	0.000
	17% EDTA	0.000	0.000	1.000
	0.2% EDTA	0.000	1.000	0.000
	DW	0.000	0.000	0.000
4% SH	2% SH	0.000	1.000	0.619
	0.5% SH	0.000	0.032	0.000
	3% HP	0.000	0.000	0.000
	2% CHX	0.000	0.000	0.000
	0.2% CHX(a)	0.000	0.000	0.000
	0.2% CHX(b)	0.047	0.000	0.000
	SS	0.000	0.000	0.000
	10% CA	0.000	0.000	0.000
	17% EDTA	0.000	0.000	0.000
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	0.000	0.000
2% SH	0.5% SH	0.002	1.000	0.060
	3% HP	0.000	0.000	0.000
	2% CHX	0.000	0.000	0.000
	0.2% CHX(a)	0.000	0.000	0.000
	0.2% CHX(b)	0.000	0.000	0.000
	SS	0.000	0.000	0.000
	10% CA	0.000	0.000	0.000
	17% EDTA	0.000	0.000	0.000
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	0.000	0.000
0.5% SH	3% HP	0.000	0.000	0.000
	2% CHX	0.000	0.000	0.000
	0.2% CHX(a)	0.514	0.000	0.000
	0.2% CHX(b)	0.000	0.000	0.000
	SS	0.000	0.000	0.000
	10% CA	0.000	0.000	0.000
	17% EDTA	0.000	0.000	0.000
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	0.000	0.000

3% HP	2% CHX	0.000	0.193	0.004
	0.2% CHX(a)	0.000	0.000	0.014
	0.2% CHX(b)	0.000	1.000	0.564
	SS	0.000	1.000	0.000
	10% CA	0.000	1.000	0.000
	17% EDTA	1.000	1.000	0.908
	0.2% EDTA	0.000	0.000	0.000
	DW	1.000	1.000	0.001
2% CHX	0.2% CHX(a)	0.000	0.000	1.000
	0.2% CHX(b)	0.000	1.000	1.000
	SS	0.000	0.001	0.000
	10% CA	0.000	0.000	1.000
	17% EDTA	0.000	1.000	0.000
	0.2% EDTA	1.000	0.000	0.000
	DW	0.000	0.984	1.000
0.2% CHX(a)	0.2% CHX(b)	0.000	0.000	1.000
	SS	0.000	0.000	0.000
	10% CA	0.000	0.000	1.000
	17% EDTA	0.000	0.000	0.000
	0.2% EDTA	0.000	1.000	0.000
	DW	0.000	0.000	1.000
0.2% CHX(b)	SS	0.000	0.016	0.000
	10% CA	0.635	0.001	0.387
	17% EDTA	0.000	1.000	0.000
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	1.000	1.000
SS	10% CA	0.001	1.000	0.000
	17% EDTA	0.000	1.000	0.736
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	1.000	0.000
10% CA	17% EDTA	0.000	0.260	0.000
	0.2% EDTA	0.000	0.000	0.000
	DW	0.000	0.517	1.000
17% EDTA	0.2% EDTA	0.000	0.000	0.000
	DW	1.000	1.000	0.000
0.2% EDTA	DW	0.000	0.000	0.000

EA – ethyl alcohol; SH – sodium hypochlorite; HP – hydrogen peroxide; CHX – chlorhexidine; SS – saline solution; CA – citric acid; EDTA – ethylene-ditetra-amino acid; DW – distilled water

One-way ANOVA and multiple comparisons Bonferroni test, $p < 0.05$

