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

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SUMMARY

Introduction/Objective Many oblong micro-spaces of less than 500 μm 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, 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 commonly used dental solutions at three temperature levels.

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

Results Seventy-percent EA showed the highest raise of capillarity (20–50°C; 8.8 ± 1.1) and 2.5% SH (2.1 ± 1.5) and 3% HP (2.1 ± 1.6) showed the lowest. The highest capillarity at 50°C was showed by 17% EDTA (40.1 ± 1.4) while 4% SH showed the lowest capillarity (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

INTRODUCTION

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

$$h = 2\gamma\cos\alpha / \rho g d$$

where h is height of the liquid column, γ – liquid–air surface tension, ρ – the liquid density, d – radius of the capillary tube, g – gravity acceleration, and α – contact angle between the liquid column and the capillary wall. The h value depends on the liquid–air surface tension being 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 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, Cunningham 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, demineralizers, 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. [6] worked with 1%, 3%, and 5% SH at 20°C, 45°C, and 60°C against microbes and found the highest temperature much more effective than other two, indicating an increase in diffusivity with temperature rise. Some authors

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even advocate the use of gelatinous NaOCl preheated by ultrasonic streaming, resulting in high-quality capillarity of that disinfectant [7]. Hydrogen peroxide (HP) is nowadays a very frequent additive to dental solutions/pastes, predominantly as a weak disinfectant, but potent surfactant (bleacher) at 30% concentration [8]. It exposed the rise of capillarity between 20°C and 37°C 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 (37–40°C) 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 of different concentrations, at three temperature levels.

METHODS

Materials

The study involved the following solutions: 96% and 70% EA; 4%, 2.5%, and 0.5% SH; 30% HP; 2%, 0.2% (a), and 0.2% (b) 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

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

The temperature levels of 20, 38, and 50°C 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 a red water-resistant marker. Capillarity value was measured from the tip of the glass tube to the red marker point by an orthodontic ruler and a 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.

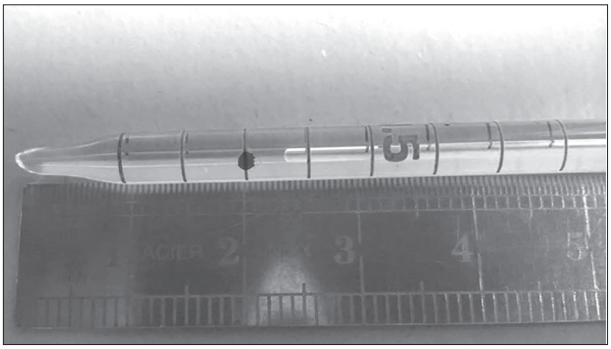

Figure 1. Graduated glass capillary tube with a diameter of 400 μm adjacent to an orthodontic ruler

Statistical analysis

The obtained values were submitted to statistical analysis using SPSS Statistics, Version 17.0 (SPSS Inc., Chicago, IL, USA).

Normality of data was checked using the Kolmogorov–Smirnov test, then one-way ANOVA test (with repeated measures and multiple-comparisons Bonferroni tests) was utilized for within-group and between-group comparison, considering the following parameters: solution and temperature. The statistical 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 Figures 2 and 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°C 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 (2.1 ± 1.5; 2.1 ± 1.6 mm, respectively).

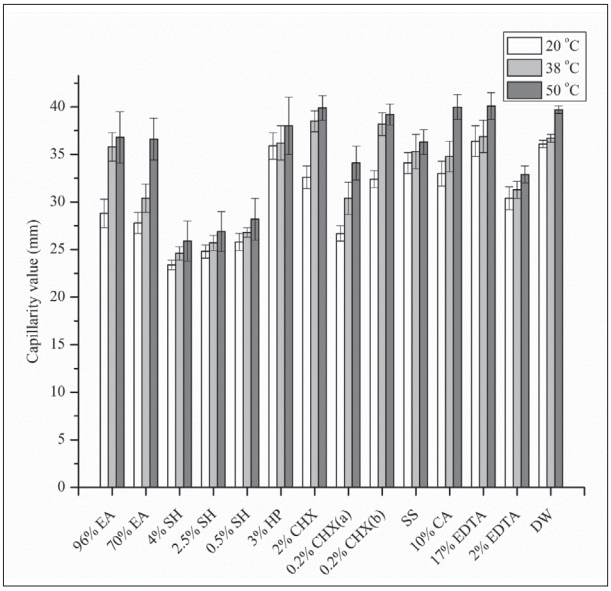

Figure 2. The obtained results of capillarity values (mean ± SD) for investigated solution at three temperature levels;

EA – ethyl alcohol; SH – sodium hypochlorite; HP – hydrogen peroxide; CHX – chlorhexidine; SS – saline solution; CA – citric acid; EDTA – ethylenediaminetetraacetic acid; DW – distilled water;
respective values (mean ± SD) distributed in the cells; plotted in computer software OriginPro 8.5

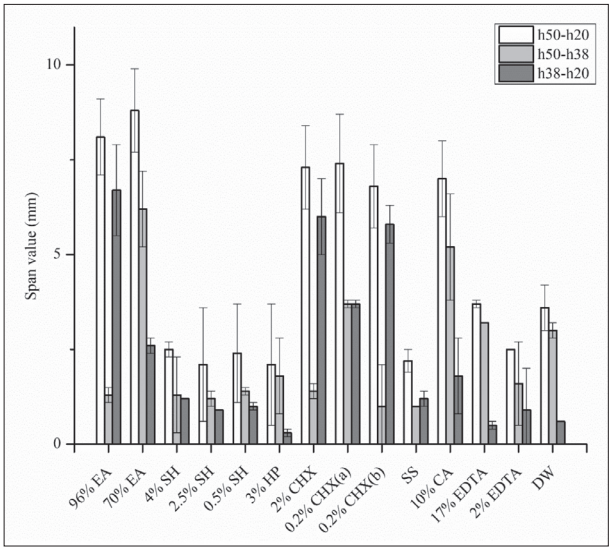

Figure 3. The span values of tested solutions' capillarity (mean ± SD). h50–h20, difference in capillarity values between temperatures of 50°C and 20°C; h50–h38, difference in capillarity values between temperatures of 50°C and 38°C; h38–h20, difference in capillarity values between temperatures of 38°C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

EA – ethyl alcohol; SH – sodium hypochlorite; HP – hydrogen peroxide; CHX – chlorhexidine; SS – saline solution; CA – citric acid; EDTA – ethylenediaminetetraacetic acid; DW – distilled water;
respective values (mean ± SD) distributed in the cells; plotted in computer software OriginPro 8.5

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 (~ 50°C) [12].

The rise of concentration of studied solutions did not follow correspondently the rise in capillary height for the temperature span of 20–50°C. 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 and stabilizing agents such as polyethylene glycol (PEG), propylene glycol, castor oil, etc. Aforementioned indicates that the very nature of the dissolved substance in investigated samples might cause the uneven distribution of capillary values.

Considering the change of capillarity values at investigated solutions for temperature spans of both 20–38°C and 38–50°C, it is to note 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 the capillary tube. 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, and 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 specifical bonding between water and solvate substances (EA, SH, CHX). In addition, very low capillarity rise for the 20–50°C temperature span for all SH concentrations, 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 elimination of pathogens.

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 the solution column) in correlation to the parameters that could have influence on it, such as surface tension (γ), wetting angle (α), and density (ρ) of the liquid. For instance, the value of surface tension

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 – ethylenediaminetetraacetic acid; DW – distilled water; one-way ANOVA and multiple comparisons Bonferroni test, $p < 0.05$

is in reverse proportion to the capillary power of the liquid, while wetting is directly proportional to the capillary power and in reverse relation to the contact angle value. In this way Lopes et al. [17] applied the measurements of the contact angle and the surface tension of irrigants, calculating the wettability of the studied solutions using Young's equation.

Khattab et al. [19] 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 and compared the data with the available literature data. This study shows that the Jouyban–Acree model can correlate/

predict physicochemical properties of 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 a study by Rossi-Fedele and Guastalli [14] using pendant drop method to evaluate the effect of an alcohol-based caries detector (Kurakay; Kuraray Co., Ltd., Tokyo, Japan) on the surface tension of a conventional SH solution at 20°C 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 most clearly understood at 50°C, where the greater significant difference among investigated solution was found, compared to those obtained at 20°C and 38°C. In fact, the differences between 20°C and 38°C were not significant in 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, respectively). 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 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].

In contrast to EA, SH solutions with an increase of chlorine concentration (0.5 – 2.5 – 4% SH) 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 the rise of viscosity, i.e., the lessening of the capillarity effect of SH 0.986–1.110 times by the increase of its concentration (0.5–4%), which is in numerical accordance with the results of our study. Sirtes et al. [6] found that the temperature rise of SH samples (5.25%, 2.5%, and 1%, 20–40°C and 60°C) do not exhibit significant antimicrobial effect on *Enterococcus faecalis*.

Regarding the newer data on the chemical nature of surfactants, some authors found amphiphiles with longer hydrocarbon chains more surface-active than solutions with shorter hydrocarbon chains, which could be applicable to the capillarity energy. Namely, the fluorine ions in the fluorocarbon chain serve as a caries-protective agent, exhibiting a stronger hydrophobic effect than the hydrocarbon chain alone [23]. Observing the affinity of certain substances for water, Ekholm et al. [24] 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 significantly more accurate than the *in vitro* patterns. Also, the question of finding a suitable surfactant to be added to the dental solution in order to improve capillary strength and other fluid properties still remains open.

CONCLUSION

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

Clinical significance

The obtained results indicate the importance of warming the aforementioned 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.

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Лабораторијско испитивање капиларитета различитих стоматолошких раствора на три температурна нивоа

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САЖЕТАК

Увод/Циљ Дугуљасти микропростори 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 задржавању хране и патогена, већина денталних раствора требало би лако да продре у њих и делује терапеутски. Из тог разлога је циљ ове студије био да се процени ефекат капиларности често коришћених денталних раствора на три температурна нивоа.

Методе Испитивани су раствори етанола, натријум-хипохлорита, водоник-пероксида, хлорхексидина, физиолошког раствора, лимунске киселине, етилен-диамино-тетраацетатне киселине и дестиловане воде, на 20, 38 и 50° *C*, у капиларној цеви промера 400 *μm*. Висина капиларног стуба је забележена на градуисаној капиларној цеви (*mm*), а подаци су статистички обрађени.

Резултати Највећи пораст капиларности (20–50° *C*) показао је 70% етанол (8,8 ± 1,1), а најнижи 2,5% натријум-хипохлорит (2,1 ± 1,5) и 3% водоник-пероксид (2,1 ± 1,6). Највиша капиларност добијена је на 50° *C* за 17% етилен-диамино-тетраацетатну киселину (40,1 ± 1,4), а најнижа за 4% натријум-хипохлорит (25,9 ± 2,1) ($p < 0,05$).

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

Кључне речи: иригација; натријум-хипохлорит; хлорхексидин; етилен-диамино-тетраацетатна киселина; слободна површинска енергија