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Viscosity of endodontic irrigants: Influence of temperature

Claudio Poggio[1], Matteo Ceci[1], Riccardo Beltrami[2], Marco Colombo[1], Alberto Dagna[1]

[1]Department of Clinical, Surgical, Diagnostic and Pediatric Sciences, Section of Dentistry, University of Pavia, [2]Department of Brain and Behavioral Sciences, Section of Statistics, University of Pavia, Pavia, Italy

ABSTRACT

Background: The aim of this study was to assess the influence of temperature on the viscosity of different endodontic irrigants.

Materials and Methods: The measurements of viscosity of 3% hydrogen peroxide, 0.9% sodium chloride, aqueous solution of 0.2% chlorhexidine (CHX) and 0.2% cetrimide, 5% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA) at different temperatures (22°C, 30°C, 40°C, 50°C and 60°C) were obtained using Mohr balance and Ostwald viscometer. The Shapiro-Wilk test and Mann-Whitney U-tests were used for the statistical analysis. (α = 0.05).

Results: No significant differences were recorded at each temperature among 3% hydrogen peroxide, 0.9% sodium chloride and aqueous solution of 0.2% CHX and 0.2% cetrimide. 5% NaOCl and 17% EDTA showed the higher values. Viscosity statistically decreased with increasing temperature.

Conclusion: Within the limitations of this study, 5% NaOCl and 17% EDTA are significantly viscous at room temperature and their viscosity reduces with elevating temperature.

Key Words: Root canal irrigants, temperature, viscosity

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Address for correspondence:
Dr. Claudio Poggio, Department of Clinical, Surgical, Diagnostic and Pediatric Sciences, Section of Dentistry, Piazzale Golgi 3, 27100 Pavia, Italy.
E-mail: claudio.poggio@unipv.it

INTRODUCTION

The ultimate goal of endodontic treatment is the complete eradication of microorganism from the root canal space, or at least their reduction to levels compatible with periradicular tissue health.[1] Although, after chemo mechanical treatment of root canals the population of microorganisms is significantly decreased, all the microorganisms are not eliminated.[2] Due to the complexity of endodontic space, mechanical instrumentations alone cannot achieve this outcome.[3] Endodontic irrigants can remove debris and microorganisms from the areas that cannot be mechanically approached.[4] Several conditions affect how these irrigants spread onto the root canal system and reach the noninstrumental areas.[5]

Two of the most essential parameters related to fluid flow are its surface tension and its viscosity.[5] Fluid surface tension and viscosity largely influences the ability of an irrigant to penetrate into dentine and its spreading property on dentin surfaces.[6] It has been demonstrated that high viscosity and high surface tension reduce the ability of sodium hypochlorite (NaOCl) to penetrate into dentine and its antibacterial effectiveness within dentinal tubules.[7] To obtain a suitable contact time of irrigants with root canal dentinal walls, a major role

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is played by the wettability. Wettability is correlated with surface tension[8] on ideal surfaces (chemically homogeneous, flat, nonreactive, undeformable, and not swollen by the wetting liquid) and then with the surface properties of dentine.[9] Surface tension is a condition of intramolecular attraction, and it is decreased when this condition is destroyed. This may be accomplished by the use of heat or the addition of surfactant.[10] Adding surfactants to irrigants, the surface tension decreases until reaching the critical micellar concentration (CMC). Above the CMC, the addition of surfactant provokes formation of micelles in the liquid, keeping constant the surface tension. The best wetting properties of the irrigants are obtained at this concentration.[6]

Viscosity can be described as the internal resistance to root canal irrigant flow deformed by either shear or tensile stress.[11] Viscosity is a property arising from collisions between neighboring particles in a fluid that are moving at different velocities. When the fluid is forced through a tube, the particles which comprise the fluid generally move faster near the tube's axis and more slowly near its walls; therefore, some stress (such as a pressure difference between the two ends of the tube) is needed to overcome the friction between particle layers and keep the fluid moving. For the same velocity pattern, the stress required is proportional to the fluid's viscosity.[11] The coefficient of viscosity (η), or dynamic coefficient of internal friction (which characterizes the magnitude of the friction forces), is a characteristic parameter of the liquid itself and depends on the nature of the fluid and its temperature. This parameter describes the internal friction forces that are exercised between the several layers of liquid in conditions of laminar flow.[12] The flow is considered laminar when the fluid flows in parallel layers, with no disruption between the layers. This condition occurs when a liquid flowing in a conduit of small dimensions with a not excessive speed, such as to not creating vortices within the liquid itself. In these cases, the Poiseuille equation [Figure 1] establishes a relationship of proportionality between the flow conduit for the liquid and the forces that move it. The Poiseuille equation [Figure 1] can be used to experimentally determine the coefficient of viscosity of a liquid. However, it is much simpler to determine η with a liquid, for example, water, for which the coefficient of viscosity is known. In this case, it is enough to flow through the capillary the same amount of water and of the

$$V = \frac{\pi \, \Delta p \, r^4 \, t}{8 \, \eta \, L}$$

V: *volume of the liquid*
r: *radius of vessel*
t: *time*
η: *coefficient of viscosity*
Δp: *change of pressure*
L: *vessel lenght*

Figure 1: Poiseuille equation.

liquid tested and subsequently compare the timing of runoff in the two cases.[12] The role of viscosity is critical in irrigant dynamics. The reduction in viscosity in fact facilitates the progression and spread of a liquid in a long and tight tube. Therefore, it has been demonstrated that the reduction in viscosity improve the flow of the endodontic irrigant into root canal intricacies.[5] Temperature is one of the primary influencing variables affecting fluid viscosity.[11] Various studies have evaluated the effect of temperature on NaOCl in terms of antibacterial activity and not in terms of dynamic viscosity.[13] However, recent studies have reconsidered the dynamic viscosity of NaOCl, taking into consideration the role of its concentration at room temperature and body temperature.[5]

The purpose of this study was to assess the influence of temperature on the viscosity of different endodontic irrigants, by measuring and comparing the η of the tested solutions at different temperatures (22°C, 30°C, 40°C, 50°C and 60°C).

MATERIALS AND METHODS

The formula given in Figure 2 has been applied to calculate the η of the irrigants at different temperatures (22°C, 30°C, 40°C, 50°C and 60°C). The coefficient of viscosity of the water (η_W) is known. The density of water (d_W) and the density of irrigants tested (d_Y) were determined by Mohr balance (PHYWE Systeme GmbH & Co., KG, Göttingen, Germany), which allows determining the relative density of a liquid by comparing the buoyancy impressed by the water and by the liquid tested to the same object.

For the measurements at different temperatures, the container with the root canal irrigant was immersed in a thermostat (with digital temperature setting with maximum displacements of ± 0.01°C) containing silicone oil.

The timing of runoff of the water (t_W) and of the irrigating solutions tested (t_Y) were calculated using an Ostwald viscometer (Sigma-Aldrich Corporation, St. Louis, MO, USA). The Ostwald viscometer is constituted of a glass tube folded into a U. It was immersed vertically in a thermostat containing silicone oil, leaving the two ends emerging. There are two arms of the viscometer. One is the wider arm and the other one is the narrow arm. The narrower arm is known as the capillary. There are two bulbs on the U shaped tube. The bulbs are located on the upper side at the capillary arm and on the lower side at the wider arm. The method in which the viscosity is measured includes the measurement of time of runoff that the liquid takes to flow from one point to another point. The two points are placed on the upper side and on the lower side of the bulb which is located at the capillary arm. We have named these markings as point A and point B. The mark above the bulb is point A and below the bulb is point B [Figure 3]. The time that it takes for the liquid to flow from point A to point B was measured. The rate of flow of the liquid was measured and it was done through the suction of the liquid. The liquid was pumped up above the mark A. When the liquid was reached above the mark A, it was released and it was allowed to flow from point A to point B. The time was then noted. The time measured was then substituted in the formula given in Figure 2 to get the viscosity of the liquid. The density and timing of runoff of the water and of the irrigating solutions were tested at different temperatures (22°C, 30°C, 40°C, 50°C and 60°C) for at least three times. The arithmetic mean of the values was calculated.

The following irrigating solutions were tested:

Group 1: Hydrogen peroxide 12 Vol. (Ogna Laboratori Farmaceutici, Muggiò, MB, Italy), aqueous solution of 3% hydrogen peroxide;

Group 2: 0.9% sodium chloride (Baxter Healthcare Ltd., Compton, Newbury, Berkshire, UK);

Group 3: Cloreximid (Ogna Laboratori Farmaceutici, Muggiò, MB, Italy), aqueous solution of 0.2% chlorhexidine (CHX) and 0.2% cetrimide;

Group 4: Niclor 5 (Ogna Laboratori Farmaceutici, Muggiò, MB, Italy), aqueous solution of 5% NaOCl;

Group 5: Ethylenediaminetetraacetic acid (EDTA) 17% (Ogna Laboratori Farmaceutici, Muggiò, MB, Italy), aqueous solution of 17% EDTA.

Statistical analysis

The statistical analysis was conducted with Stata 12 (StataCorp. 2011. Stata Statistical Software: Release 12. College Station, TX, USA). Viscosity coefficients for each irrigant were assessed to be normal with Shapiro-Wilk test. Mann-Whitney U-test was applied to determine if there were significant differences among them at the different temperatures. Significance was set at $P < 0.05$.

RESULTS

The data shows that the coefficient of viscosity of all irrigants tested decreased with increasing temperature. Table 1 reports both the density of water (d_W) and that of the irrigants (d_Y) as the temperature varies

$$\eta_Y = \eta_W \frac{d_Y\, t_Y}{d_W\, t_W}$$

η_W: *viscosity of water*
η_Y: *viscosity of tested liquid*
d_W: *density of water*
d_Y: *density of tested liquid*
t_W: *timing of runoff of water*
t_Y: *timing of runoff of tested liquid*

Figure 2: Equation for determination of the coefficient of viscosity when liquid viscosity is known.

Figure 3: Schematic image of Ostwald viscometer.

Table 1: Irrigants density in poise (average time in seconds to cross the viscometer) at different temperatures

rrigants	22°C	30°C	40°C	50°C	60°C
H_2O	0.997 (148.50)	0.993 (128.50)	0.988 (106.80)	0.984 (90.80)	0.980 (79.06)
Hydrogen peroxide	1.011 (148.16)	1.008 (128.16)	1.004 (105.46)	1 (90.40)	0.995 (79.16)
Sodium chloride 0.9%	1.006 (151)	1.002 (128)	0.997 (106.30)	0.993 (90.60)	0.989 (79.36)
Cloreximid	0.998 (151.10)	0.995 (130.50)	0.991 (106.60)	0.987 (90.50)	0.983 (79.33)
Niclor 5	1.087 (185.33)	1.084 (160.76)	1.080 (132.50)	1.075 (112.03)	1.071 (97.43)
EDTA 17%	1.120 (253.40)	1.099 (216.75)	1.095 (181)	1.092 (149.80)	1.089 (127.86)

EDTA: Ethylenediaminetetraacetic acid.

and the average time (in s) taken for the water (t_W) and the irrigants (t_Y) to cross the viscometer. Applying the formula shown in Figure 2, it was possible to experimentally determine the values of the coefficients of viscosity of irrigants examined at different temperatures.

The coefficients of viscosity of the different solutions (η) at the various temperatures are reported in Table 2. Different results were obtained for each value of temperature. Shapiro-Wilk test confirmed that the values of viscosity coefficients for each irrigant were not distributed as a bell-shaped Gaussian. Due to this fact, nonparametric inferential statistical methods were performed. Mann-Whitney U-test showed that when irrigants were maintained at 22°C, no significant differences were recorded among hydrogen peroxide, sodium chloride, and cloreximid ($P > 0.05$); 5% NaOCl and 17% EDTA showed higher values confirmed by significant differences ($P < 0.05$). Similar results were obtained when temperature was set at 30°C, 40°C, 50°C and 60°C.

DISCUSSION

The three most important properties for an endodontic irrigant are its ability to facilitate the removal of inorganic debris produced during instrumentation (keeping them in suspension and avoiding overcrowding at the apex), its organic tissue dissolution ability and its antimicrobial activity.[14] Four of the most common endodontic irrigants were compared in this study.

The aqueous solution of 3% hydrogen peroxide is an oxidizing agent used in endodontic. The hydrogen peroxide, in contact with the tissues, forms bubbles of molecular oxygen. The foam production favors the removal of debris (detergent action), while the liberation of oxygen inactivates anaerobic germs (germicidal action).[3] NaOCl is the most recommended endodontic irrigant due to its tissue dissolution ability, which is a function of its concentration, available surface area of the involved tissue, exposure time, variations in temperature, surface tension, and volume of the irrigant.[15,16] EDTA is employed due to its ability to remove the inorganic component of smear layer and is recommended in a concentration of 17%.[17] EDTA reacts with calcium ions in dentin resulting in the formation of calcium chelates.[18] Some *in vitro* studies have shown that CHX has potent antimicrobial ability, especially against E. faecalis,[19] and it is highly effective in reducing endodontic bacteria in teeth with apical periodontitis.[20] However, when CHX -based irrigant solutions are added to NaOCl, they create a precipitate responsible for pigmentation and discoloration of teeth[21] and recently considered as a cytotoxic product.[22]

Nowadays the recommended irrigation protocol consists of a combination of NaOCl and EDTA. EDTA is an effective rinse solution for removing the smear layer in canals irrigated with NaOCl. The smear layer is well removed from the middle and coronal thirds of canal preparations, but EDTA sometimes is less effective in the apical third of the canals.[23] This may be due to the narrowing of endodontic space which inhibits fluids dynamics.

Many studies have evaluated the effect of heating on antimicrobial efficacy[15,24] and tissue dissolution properties of NaOCl.[15,16] There is an inverse relationship between the value of the viscosity of a liquid (root canal irrigant) and temperature, and there is a direct relationship between viscosity and the detergent properties of a liquid. Indeed, a liquid having low viscosity tends to spread with greater ease.[11]

In this study, the coefficient of viscosity of all irrigating solutions examined decreased significantly with increasing temperature. In particular, at 22°C the coefficient of viscosity of the different solutions is not uniform, but changes from the minimum value of 3% peroxide hydrogen to the maximum value of 17% EDTA. Comparing hydrogen peroxide, sodium chloride and cloreximid, no significant differences

Table 2: Median of viscosity coefficients (poise) obtained for each irrigant at different temperature

Irrigants	22°C	30°C	40°C	50°C	60°C
Hydrogen peroxide	0.00961^{a}	0.0082^{e}	0.00662^{i}	0.00505^{n}	0.00355^{t}
Sodium chloride 0.9%	0.00974^{a}	0.00814^{e}	0.00662^{i}	0.00503^{n}	0.00354^{t}
Cloreximid	0.00967^{a}	0.00824^{e}	0.0066^{i}	0.00499^{n}	0.00352^{t}
Niclor 5	0.01292^{b}	0.01106^{f}	0.00895^{j}	0.00673^{o}	0.00471^{u}
EDTA 17% solution	0.01821^{c}	0.01512^{g}	0.00124^{k}	0.00915^{p}	0.00628^{v}

The same superscript letters indicate no significant differences ($P > 0.05$) between the groups. Different superscript letters indicate significant differences ($P < 0.05$) between the groups. EDTA: Ethylenediaminetetraacetic acid.

were recorded at 22°C ($P > 0.05$); NaOCl and 17% EDTA showed higher viscosity ($P < 0.05$). Similar results were obtained at 30°C, 40°C, 50°C, and 60°C. When temperature was increased, the coefficients of viscosity decreased in a similar way for all irrigants. At room temperature the higher viscosity would inhibit fluid dynamics and elevating temperature reduces viscosity and enhances fluid properties. This reduction in viscosity is explained by the thermal agitation of the fluid molecules, which move more easily resulting in an improvement of irrigants dynamic. This improvement in flow characteristics is due to the reduction of viscosity, thereby improving the spreading of the liquid into canal narrowing.[25]

CONCLUSION

The preheating of endodontic irrigants can be considered advantageous. In fact, in this study, increasing temperature has reduced the coefficient of viscosity of all the tested irrigants, thus improving the spreading ability of the solutions. 5% NaOCl and 17% EDTA proved to be the more viscous liquids among those tested. Therefore, in root canal spaces with complex anatomy, which rely primarily on irrigation rather than instrumentation, the preheating of irrigants would prove to be clinically useful. However, the role of viscosity is critical in irrigant dynamics and future studies may be useful to understand how temperature and/or various irrigating methods can influence irrigant solutions spreading abilities.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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