Strategically Important Features of the Influence of Sodium Hypochlorite on the Mechanical Properties of Dentin: A Systematic Review

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Abstract

Sodium hypochlorite is the most popular irrigant due to its proteolytic properties, but it affects not only the necrotized remnants of pulp tissue, the lubricated layer and microbial biofilm, but also the collagen fibers of the organic dentin matrix. This adversely affects the strength of dentin and increases the risks of complications of endodontic treatment with chewing load. Determining the effect of sodium hypochlorite and the temperature regime of its irrigation on the structural components of dentin will help to balance the risks and benefits of using this irrigant in endodontic practice.

The aim of this review article is to systematic assessment of scientific data on the effect of sodium hypochlorite and the temperature regime of its irrigation on the hard tissues of the tooth, in particular on the mechanical properties of dentin.

Electronic search of articles was carried out using search engines and databases Google Scholar, Pub Med. The articles are included, the content of which concerns the topics of practical application of sodium hypochlorite solution, as well as the influence of the temperature of this solution on the properties of hard tooth tissues. The publication date criterion has been selected since July 2011

69 articles were reviewed during the review process. After analyzing the literature according to the inclusion criteria, the total number was 14 publications.

Prolonged exposure to the irritant, irreversible changes in dentin occur due to the dissolution of collagen, which leads to irreversible changes in the physical and mechanical properties of dentin.

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Keywords: dentin, dentin elasticity, sodium hypochlorite, irrigation, drug treatment, modulus of elasticity, exposure of NaOCl, dentin elastic modulus, dentin organic components, irrigant.

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Introduction

Sodium hypochlorite (NaClO) is a chemical substance commonly used as a root canal irrigant in endodontic practice due to its antimicrobial effect.[1, 2]

In water, sodium hypochlorite dissociates into a sodium ion and a hypochlorite ion, resulting in the formation of free chlorine, which dissolves the organic substances of the lubricated layer, pulp residues and microbial film.[3,4]

This irrigant is often used in dental practice, as it is the most effective. However, removing the smeared layer can create additional problems during the treatment process.[3, 5, 6]

Dentin is the main component of the tooth, it is on its strength that the further outcome of endodontic treatment depends.[7] It contains 70 % minerals, 17 % organic substances and 13% water.[8,9] The deepest layer of dentin is a non-mineralized organic matrix of collagen proteins.[10,11]

As a result of the effect of sodium hypochlorite on dentin, collagen dissolves and

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dentin elasticity decreases, which leads to irreversible changes in the physical and mechanical properties of dentin.[12, 13, 14] It is also known that when the temperature increases, the antimicrobial and lytic effects of the solution increase, so it is necessary to determine the effect of the temperature regime on the ability to dissolve collagen and change the structure of dentin.[15,16]

The aim of this review article is to systematic assessment of scientific data on the effect of sodium hypochlorite and the temperature regime of its irrigation on the hard tissues of the tooth, in particular on the mechanical properties of dentin

Materials and methods

Electronic search of articles was carried out using search engines and databases Google Scholar, Pub Med. The articles are included, the content of which concerns the topics of practical application of sodium hypochlorite solution, as well as its effect on the properties of hard tooth tissues. The publication date criterion has been selected since July 2011

Search terms included "sodium hypochlorite", "dentin organic structure", "irrigation in dentistry", "antimicrobial effect of NaOCl", "the use of irrigation", "exposure of NaOCl", "dentin elastic modulus"

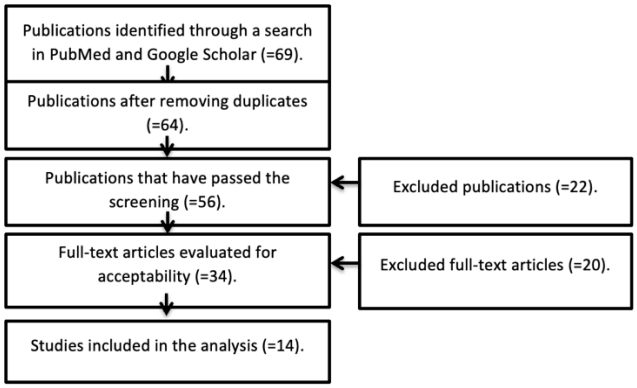

Table 1. Article selection process.

The studies were filtered and selected in several stages. Firstly, they were evaluated by titles. Secondly, individual documents at the first stage were additionally assessed by reading the abstracts and full-text articles. The difference in the choice was resolved through discussion among the readers.

The selection of publications was also carried out according to the following inclusion criteria – the date of publication of the article is not earlier than July 2011, the topics of the use of sodium hypochlorite in the medical treatment of root canals during endodontic treatment, studies containing data on the proteolytic activity of sodium hypochlorite in relation to the organic matrix of dentin, the temperature regimes and exposures of the presented solution and their effects on the structural components of dentin.

The first exclusion criterion was the selection of publications dated earlier than 2011. Further, the review did not include works whose title and summary did not meet at least one of the submitted inclusion criteria. At the last stage, the content of the full-text versions of the selected articles was studied.

During the processing of all the selected information, the possibility of a systematic error was considered. The Cochrane Collaboration system was used to determine the risk of the possibility of a systematic error during the study of the selected information. [17]

The levels of systematic error were systematized as follows: low risk if all the criteria were met; moderate risk when only one criterion was missing; high risk if two or more criteria were missing; and unclear risk if there were too few details to make a decision about a certain risk assessment.

Summarizing the risk of bias for each study, most of the studies were classified as an unclear risk. A number of studies were considered as having a low risk of bias. There were several limitations present in the current review, including studies written in English only, which could introduce a publication bias. There were various degrees of heterogeneity in each study design, materials and methods and treatment provided among the studies.

Results

69 articles were considered, 49 of which were on the PubMed database, 20 - Google Scholar. Having made the selection according to the exclusion criteria, the total number of works was 14 (Table 1). In the selected articles, current data on the influence of sodium hypochlorite and the temperature regime of its irrigation on the structural components of dentin were analyzed.

Author	year of publication	brief conclusion
S Amadori, E Bonetti, E G Campari, I Cappelloni, R Montanari **[27]**	2013	The inelastic behavior of human dentin at a temperature above room temperature can be divided into reversible and irreversible. Irreversible transformation is carried out due to the loss of water in the spaces between the fibrils, which causes the destruction of the spiral structure of the collagen molecule, which leads to the fragmentation of the peptide chain and, finally, to the burning of collagen.
Eda E. Aslantas, Hatice Dogan Buzoglu, Emre Altundasar, Ahmet Serper **[20]**	2014	EDTA, REDTA, NaOCl, and Chlor-XTRA significantly decreased the microhardness of root dentin compared with intact controls ($P < .05$). The addition of surface modifiers to the irrigants did not affect the microhardness of the samples.
Eltit F, Ebacher V, Wang R. **[31]**	2013	Human root dentin has a higher bending strength and a more significant inelastic deformation than coronal dentin. Deformation in the dentin occurs due to microcracks. Dentine tubules directly contributed to both the occurrence and spread of microcracks. Other structural elements in the dentin, such as peritubular dentin and incremental lines, also contributed to the degree and orientation of microcracks.
Forien J-B, Zizak I, Fleck C, et al. **[29]**	2016	The water/collagen/mineral interactions coupled with the tiny sizes of the cHAP crystallites directly contribute to the evolutionary optimization of tooth dentin to reliably resist the loads to which it is exposed. Mineral particles of dentin deform significantly due to osmotic pressure following dehydration and can sustain stresses spanning ~300 MPa when dentin is dehydrated at 125 °C.
Kafantari N, Gulabivala K, Georgiou G, Knowles J, Ng YL **[25]**	2019	NaOCl at 60°C or 80°C significantly reduced the elastic behavior but increased the hysteresis of dentin under cyclic loading.
Gonçalves LS, Rodrigues RC, Andrade Junior CV, Soares RG, Vettore MV **[19]**	2016	Additional randomized clinical trials using clinical outcomes to compare the use of sodium hypochlorite and chlorhexidine during root canal therapy are needed.
Li-sha Gu, Xue-qing Huang, Brandon Griffin, Brian R. Bergeron, David H. Pashley, Li-na Niu, Franklin R. Tay **[21]**	2017	Understanding the deleterious effects of NaOCl on mineralized dentin enables one to balance the risks and benefits in using high NaOCl concentrations for lengthy periods in root canal debridement.
Gazzaneo I, Vieira GCS, Pérez AR, Alves FRF, Gonçalves LS, Mdala I, Siqueira JF Jr, Rôças IN **[18]**	2019	The concerted effects of multiple instruments, the high volume of irrigation, and the long retention time of NaOCl irrigant had a positive influence on intracanal disinfection during chemomechanical preparation.

McGee MP, Morykwas M, Shelton J, Argenta L **[26]**	2012	Collagen unfolding in the interstitial matrix of the dermis determines local increases in interfacial energy. The resulting higher hydration potential and accelerated fluid influx can be explained by emerging surface-tension gradients and decreased resistance to local flow, both consistent with a higher density of hydrophobic residues on solventaccessible surfaces.
Mohammadi, Zahed, and Sousan Shalavi. **[22]**	2013	Sodium hypochlorite (NaOCl), the most common irrigant, is an excellent nonspecific proteolytic and antimicrobial agent.
Ng YL, Reddington LP, Berman A, Knowles JC, Nazhat SN, Gulabivala K. **[30]**	2020	This study demonstrated that accumulative damage of dentine could be facilitated by alternated exposure to NaOCl and EDTA. The effect of dentin on Ca (OH)2 (p H 12.6) reduced the viscosity for 7 days, which led to an increase in the potential for fatigue failure.
Ramirez-Bommer C, Gulabivala K, Ng YL, Young A **[23]**	2018	Data revealed the sequential depletion of collagen by NaOCl and apatite by EDTA in dentine, simultaneously exposing the other moieties. Alternate exposure to NaOCl and EDTA therefore enhances the depth of erosion.
Ryou H, Amin N, Ross A, et al **[28]**	2011	Weibull analyses suggest that deep dentin possesses a larger distribution of intrinsic flaw sizes that contributes to the location dependence in strength.
TARTARI, Talita, BACHMANN, Luciano, MALIZA, Amanda Garcia Alves, ANDRADE, Flaviana Bombarda, DUARTE, Marco Antonio Hungaro, & BRAMANTE, Clovis Monteiro **[24]**	2016	The increase in the exposure time and in the concentration of NaOCl solution lead to an increase in the tissue dissolution and dentin collagen deproteination. Furthermore, some carbonate ions are removed from the dentin inorganic phase by the NaOCl.

Discussion

Sodium hypochlorite is one of the most widely used irrigation solutions in endodontic practice due to its ability to form sodium ion and hypochloric acid during dissociation in water, which causes hydrolytic, antiseptic effects on the root canal biofilm and its components, pulp residues and the lubricated layer. Hypochloric acid is a rather unstable substance that decays over a short period of time into final products-chlorine and oxygen.[18]

Heating the sodium hypochlorite solution significantly enhances the solvent activity of the irrigant. [19] It is important that the stability of a solution of sodium hypochlorite heated to 37°C with an unchanged amount of chlorine is maintained for 4 hours, and when heated to 45 60°C — for an hour.25 Thus, when heating a fresh solution, it should be applied for 1 1.5 hours.

Activation also affects the solubility of sodium hypochlorite. An aqueous solution of sodium hypochlorite is a dynamic equilibrium of sodium hydroxide and hypochlorous acid. When sodium hypochlorite comes into contact with organic tissue, sodium hydroxide reacts with fatty acids to form soap and glycerol, which is known as the saponification reaction. It also reacts with amino acids to form salt and water (neutralization). Also, hypochlorous acid reacts with amino acids to form chloramine and water. These reactions, which occur mainly on the surface, lead to the liquefaction of organic tissue. At the same time, when reacting, sodium hypochlorite molecules are inactivated, which leads to a decrease in local activity. Therefore, to remove the remnants of undissolved tissues, it is necessary to replace the solution with an active one more often.

As is known, heating increases the reaction rate. On the one hand, an increase in the lytic and antiseptic effect when heating sodium hypochlorite will contribute to a more thorough antiseptic treatment of root canals during endodontic treatment, but on the other hand, negative consequences are possible when the organic dentin matrix is dissolved.

Many modern authors suggest a possible negative effect of sodium hypochlorite on the structure and mechanical properties of parietal intracanal dentin. This solution, showing proteolytic properties, affects not only the necrotic remains of the pulp tissue, the lubricated layer and the microbial biofilm, but also the collagen fibers of the organic dentin matrix.

Studies describing the possible negative effects of the products of the NaOCl decomposition reaction on dentin were based on data from scanning electron microscopy, confocal laser microscopy, microradiography, secondary ion mass spectroscopy, energy dispersion spectroscopy, Fourier spectroscopy and other methods.

The physical and mechanical characteristics of dentin are not constant and vary depending on the localization. The strength of the dentin directly depends on the number of tubules, which is explained by the smaller area of the inter-tubular dentin. Also, the decrease in the strength of dentin may be due to the uneven distribution of hydroxyapatite crystals and other elements of the mineral phase of dentin.

Elasticity and strength depend on each other and are one of the most significant characteristics, because it is the ability of dentin, as the main tooth tissue, to withstand mechanical load that determines the stability of the tooth in the oral cavity.

After endodontic treatment, it is recommended to cover the stump of the tooth with a crown. This is necessary to increase the service life of the depulpated tooth, the walls of which become more fragile.

The organic matrix of dentin is represented by type 1 collagen and proteoglycans, the main role of which is to create an oriented fibrillar matrix for further deposition of hydroxyapatite and other inorganic components on it, glycosaminoglycans are components of the regulation of the permeability and water filling of dentin. The collagen fibers in the dentin thickness are encapsulated with hydroxyapatite, so it can be assumed that the proteolytic effect of sodium hypochlorite on dentin is short and insignificant, and the presented solution is not capable of leading to adverse reactions from the physico-mechanical properties of dentin. However, studies have shown changes in the chemical and structural composition of dentin when exposed to various NaOCl irrigation regimes during root canal system therapy. [20, 21]

A solution of sodium hypochlorite reduces the flexural strength and elastic modulus of dentin [22] and the surface deformation of the tooth. Changes in the mechanical properties of dentin are explained by the depletion of dentin collagen. [23]

Type I collagen makes up 22% of the organic material by weight and makes a significant contribution to the mechanical properties of dentin. The effect of NaOCl dissolution on the pulp collagen increases with increasing temperature due to an increase in the reaction rate, which encourages the use of heated solutions in dental practice. Collagen, consisting of 3 helical polypeptide chains connected together by hydrogen and covalent bonds, undergoes various changes depending on temperature and time [24]. The collagen structure changes to different degrees at different temperatures (20-200 ° C) and depends on the levels of hydration and physical retention in mineralized tissues.

Nikoletta Kafantari and al. [25] conducted a study in which they determined the effect of a heated solution of sodium hypochlorite on the viscoelastic properties of dentin. It used standardized dentin rods, which were randomly divided into 6 groups, and immersed in saline solution at 26 degrees, 60 and 80 degrees, sodium hypochlorite 5% at 26, 60 and 80 degrees. The rods were individually tested using dynamic mechanical analysis at the initial level and after every 10 minutes of immersion in the test environment, up to 40 minutes.

The influence of the medium, temperature, exposure time and the ratio of the sides of the rods was studied using generalized estimation equations. As a result, the elastic modulus of the samples immersed in hypochlorite heated to 60 and 80 degrees significantly decreased, and the rest of the rods changed slightly. It was concluded that a solution of sodium hypochlorite at a temperature of 60 and 80 degrees significantly reduces the elasticity of dentin, but

the fragility of dentin increases and its resistance to load decreases.

Heating is not the main factor contributing to the change in the elasticity of the bone. The observed increase may reflect an increase in the density of the collagen network with an increase in temperature and an increase in water absorption, starting from 60 ° C to about 80 ° C, and possibly enhanced by changes in the conformation of collagen [26, 27]

However, dentine rods immersed in NaOCl at 60 ° C and 80 ° C showed a significant decrease in the elastic modulus. These changes in the properties of dentin in heated NaClO groups can be explained by the effect of heated sodium hypochlorite on collagen. There is a depletion of dentin and a deeper denaturation of collagen inside the dentin[28]. This is manifested in the form of changes in the chemical structure of collagen. Denaturation of collagen under the influence of heat occurs due to the indirect deployment of its triple helices due to the rupture of hydrogen bonds between polypeptide chains; individual spirals can then unfold into random turns due to the violation of hydrogen bonds. Such unfolding can enhance the water flow and hydration of the open collagen matrix, increasing the elastic properties. [26, 29] A decrease in the elastic modulus also signals some effect on the mineral matrix or interaction with mineral collagen. [16]

Yuen-Ling Ng and al. [31] conducted a study in which they compared the viscoelastic and chemical properties of human dentin after different exposure times to sodium hypochlorite, ethylenediaminetetraacetic acid and calcium hydroxide. Immersion in 5.25% NaOCl significantly increased tand (viscous behavior) (P = 0.004). The change was noted after the first 10 minutes of immersion without further increase.

Although minerals can be lost from dentin when immersed in saline or NaOCl, this is hardly an active mechanism. It is more likely that the heated NaOCl has a direct effect on the interface between minerals and collagen.

This is consistent with the effect of saline solution at 80 ° C, where there may be a moderate effect on the collagen-mineral bonds due to an increase in the average length of the chain segments. Collagen shrinks when heated at 70 ° C in saline solution, but breaks down at temperatures above 80 ° C. In the presence of NaOCl, the effect is probably enhanced due to a deeper penetration of NaOCl into the dentin and, consequently, probable damage to the protein and mineral structure. The potential clinical significance of these two phenomena is that increased viscosity will cause greater stress, while loss of elasticity or inelastic behavior may delay recovery. This can cause or maintain microcracks and subsequent destruction of the structure under prolonged load. [32]

Conclusions

Sodium hypochlorite or sodium salt of hypochlorous acid has a high bactericidal activity and oxidizing effect. The use of hypochlorite in endodontics always gives better results than the action of other disinfectants. While other antimicrobial agents damage cell membranes or only coagulate proteins, causing the loss of metabolic functions by bacterial cells, hypochlorite quickly disintegrates when it comes into contact with tissue proteins, releasing atomic chlorine, which, combining with amino groups, forms chloramine, a well-known disinfectant. As a result of chemical reactions occurring with proteins, peptide bonds are broken, proteins are dissolved, and not coagulated. From this it can be seen that hypochlorite has, in addition to the usual disinfectant, a unique property of dissolving the organic contents of root canals: necrotic tissues, pus, decay products or scraps of extirpated pulp.

However, it is necessary to understand that these processes require time, which is always not enough at the dentist's appointment. To accelerate the reaction rate, various methods are used, one of which is heating.

An increase in the temperature of the solution leads to proteolysis of the organic matrix of dentin and the combined loss of mineral components, which adversely affects the physical and mechanical characteristics of dentin. Because of this, the risks of failure of endodontic treatment, complications in the form of vertical fractures under mechanical load significantly increase.

Understanding the adverse effects of NaOCl on dentin components allows you to balance the risks and benefits of using sodium hypochlorite and determine the most appropriate mode of operation. It is optimal to heat sodium hypochlorite to 60 °C for no more than 10 minutes. During this time, the maximum

bactericidal effect will be achieved, and due to rehydration, it is possible to restore the elasticity of hard tissues.

As a result of prolonged exposure to the irritant, irreversible changes in dentin occur due to the dissolution of collagen, which leads to irreversible changes in the physical and mechanical properties of dentin.

Declaration of Interest

The authors report no conflict of interest.

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