

Analysis of dentin changes induced by sodium hypochlorite and their impact on the microstructure and mechanical properties of teeth

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ABSTRACT

Endodontic treatment is based on two complementary principles: mechanical and chemical preparation of the root canal system. Studies have demonstrated that endodontic instruments are capable of preparing only approximately 65–80% of the root canal wall surface, with the remaining substantial portion of the canal system insufficiently cleaned. Chemical canal preparation involves irrigation with specific solutions, such as sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), and chlorhexidine, which facilitate the dissolution of organic debris, eliminate microorganisms, and remove the smear layer. The aim of the study was to evaluate the effect of sodium hypochlorite on the mechanical properties of teeth subjected to root canal irrigation with 5.25% NaOCl, and to analyze microstructural and chemical changes- specifically shifts in the elemental composition of root dentin exposed to sodium hypochlorite. Human teeth extracted for orthodontic reasons, including canines and first premolars with single root canals, were used as the study material. Five premolars and five canines were used as control groups, and five premolars and five canines were used in the study groups. Teeth with similar root and crown dimensions were selected. The specimens were randomly assigned to two groups: a control group consisting of teeth not exposed to 5.25% NaOCl and an experimental group comprising teeth irrigated with 10 ml of sodium hypochlorite in three cycles, each lasting four minutes. The samples were subsequently subjected to failure load testing, microstructural analysis, and elemental composition assessment using energy-dispersive X-ray spectroscopy (EDS). In addition, statistical analysis was performed using the Shapiro-Wilk test. Based on the results obtained in the present study, the following conclusions can be drawn that the strength properties of teeth subjected to root canal irrigation with 5.25% NaOCl were lower in both test groups compared to the control groups, in which physiological saline was used as the irrigant. Additionally, EDS analysis of changes in the elemental composition of root dentin treated with 5.25% NaOCl revealed alterations in calcium and phosphorus content following exposure, accompanied by a reduction in the force required to fracture the teeth. Above the authors highlight the need for further research using EDS spectroscopy to determine the cause-and-effect mechanism linking failure load to elemental changes in root canals irrigated with 5.25% NaOCl.

Keywords: root canal therapy, sodium hypochlorite, failure load testing, energy-dispersive X-ray spectroscopy, dental tissue microstructure.

INTRODUCTION

Endodontic treatment, commonly referred to as root canal therapy, plays a pivotal role in contemporary dental practice. Although the lack

of comprehensive epidemiological data makes it difficult to accurately determine its proportion among all dental procedures performed worldwide, its clinical importance remains indisputable. Despite significant advances in endodontic

techniques and instrumentation, concerns persist regarding the potential effects of treatment procedures on the microstructure and mechanical properties of dental tissues. A growing body of evidence suggests that endodontic therapy may adversely affect several physical and mechanical parameters of dentin, including microhardness, modulus of elasticity, flexural strength, and compressive strength. Such alterations may compromise the structural integrity of the tooth and increase its susceptibility to fracture under functional masticatory loads, representing a significant challenge in clinical practice.

It is repeatedly emphasized in the endodontic literature that the procedures employed during endodontic treatment substantially alter the microstructure of dental tissues, resulting in the loss of part of their original structure and potentially affecting the mechanical strength of the tooth [1].

Premolars, owing to their anatomical position and functional role, are subjected to complex masticatory loads, including compressive, tensile, bending, and torsional forces. The characteristics of these forces and their effects on root structure depend on the extent to which the natural anatomy of the tooth is preserved, as well as on the dental procedures performed. The root of a premolar is exposed primarily to axial forces. However, lateral and torsional forces are also present. Axial forces are transmitted along the long axis of the tooth and are considered the most physiological, whereas horizontal and rotational forces may generate unfavorable overloading.

Canines, due to their considerable length and robust root morphology, are adapted to withstand predominantly axial forces, but also lateral and rotational forces, particularly during mandibular movements. Their role in canine guidance exposes them to complex loading conditions, including bending and torsional forces. Furthermore, loss of the natural crown and dentinal microdamage resulting from root canal preparation may lead to localized overloading. Despite their favorable anatomy, endodontically treated canines require appropriate restoration to minimize the risk of fracture under lateral and rotational loading [2,3].

Owing to the complex and irregular anatomy of the root canal system, its adequate debridement cannot be achieved through mechanical procedures alone. Furthermore, the limited dimensions of endodontic instruments prevent effective access to lateral canals, anastomoses, and narrow ramifications of the root canal system.

Consequently, mechanical preparation should always be supplemented by irrigation, which provides chemical assistance in the cleansing of the canal system. Mechanical root canal irrigation is performed by means of endodontic instruments, either hand-operated or engine-driven. Chemical root canal preparation consists of canal irrigation with dedicated solutions, such as sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), and chlorhexidine, which dissolve organic remnants, eliminate microorganisms, and remove the smear layer.

Although a reduction in dentin microhardness may facilitate canal preparation, it may simultaneously contribute to the structural weakening of the tooth. Therefore, the selection of an appropriate irrigating solution and its concentration should achieve a balance between effective disinfection and preservation of dentin structural integrity. NaOCl is one of the most commonly used irrigants in endodontic treatment because of its potent proteolytic properties. It acts as a nonspecific agent capable of degrading organic components.

The aim of the study was to evaluate the effect of sodium hypochlorite on the mechanical properties of teeth subjected to root canal irrigation with 5.25% NaOCl, and to analyze microstructural and chemical changes- specifically shifts in the elemental composition of root dentin exposed to sodium hypochlorite.

MATERIAL AND METHODS

Human teeth extracted for orthodontic reasons were used in this study, including canines and first premolars with single root canals and fully developed, anatomically mature roots. The selection of teeth was based on predefined study criteria. The average length of a premolar (approximately 21 mm) and the relatively narrow cross-sectional area of the root in the cervical region make these teeth particularly susceptible to fracture following root canal treatment. Teeth with similar root and crown lengths were selected. Twenty human teeth were used for the study and divided into four groups. Five premolars and five canines were used as control groups, and five premolars and five canines were used in the study groups.

The teeth consisted of single-rooted, single-canal upper second premolars with dimensions falling within the average range for this tooth group:

- Total tooth length (height): approx. 20.8 to 21.4 mm
- Crown length: approx. 8.2 to 8.5 mm
- Crown width (mesiodistal dimension): approx. 6.6 to 6.7 mm
- Crown depth/width (buccopalatal dimension): approx. 9.3 to 9.5 mm
- Root length: 12.8 to 13.00 mm

The teeth consisted of single-rooted, single-canal canines with dimensions falling within the average range for this tooth group:

- Total tooth length: approx. 26.3–26.8 mm
- Crown length: approx. 10.1–10.4 mm
- Root length: approx. 16.2–16.3 mm
- Crown width (mesiodistal): approx. 7.5–7.6 mm
- Width (vestibulopalatal): approx. 8.1–8.3 mm

The measurements were performed using a standard caliper.

The study material was obtained in accordance with procedures approved by the Bioethics Committee (approval No. KE-0254/339/2016).

Following extraction, the teeth were stored in physiological saline solution at approximately 37 °C in order to simulate the conditions of the oral environment. The exact age of the teeth was unknown. However, all specimens intended for endodontic treatment were free from caries, cracks, and fillings, as confirmed by stereomicroscopic examination.

The research material was randomly assigned to two groups:

- a control group, comprising teeth irrigated with saline solution,
- an experimental group, comprising teeth irrigated with 5.25% sodium hypochlorite according to the protocol described below.

Initially, a minimally invasive root canal access was created, in accordance with modern standards and principles. Next, the working length of the root canal was determined. The measurement involved advancing a size 10 C-Pilot file (VDW, Germany) to the anatomical terminus, then withdrawing it by 1 mm; the resulting measurement established the working length. Subsequently, chemomechanical canal preparation was carried out using Reciproc Blue instruments and a 5.25% NaOCl irrigant. Reciproc Blue files operate using a reciprocating motion (an oscillating action where the file rotates alternately left and right). This motion

generates significantly less stress within the root compared to the continuous rotation motion traditionally used for mechanical canal preparation.

Reciproc motion reduces the risk of dentinal microcracks. Furthermore, thanks to a special heat treatment process, the Reciproc Blue instrument offers high flexibility and “controlled memory”, allowing it to precisely follow the natural shape and curvature of the canal. This minimizes the risk of canal straightening or excessive dentin removal in a single area, thereby protecting the tooth structure from weakening. Additionally, the file is designed to be inserted into the canal without the need for prior aggressive enlargement using hand instruments. The Reciproc Blue file is a single-instrument system for mechanical root canal preparation, allowing for a more conservative approach to tissue removal compared to systems requiring multiple files of varying sizes and tapers. The Reciproc Blue system offers three main file sizes—R25, R40, and R50. The R25 file (size 25, 0.08 taper, red color code) was used in this study.

Mechanical preparation was performed in an environment of 5.25% NaOCl irrigant. The Reciproc Blue file was operated using a VDW Reciproc Silver endodontic motor (VDW, Germany), programmed with the specific reciprocating motion and parameters (speed and torque) required for this file.

Three cycles (movements) were performed in each canal to reach the working length. Light, smooth reciprocating movements (a “pecking motion”) with an amplitude of 2–3 mm were employed. Each cycle consisted of file withdrawal-> irrigation-> patency verification-> and was repeated until the file reached the full working length.

The file operated continuously within the 5.25% NaOCl environment. Additionally, after each withdrawal of the file from the canal, 5.25% NaOCl irrigant was introduced using a syringe and endodontic needle, followed by manual dynamic activation (MDA) of the NaOCl using a red gutta-percha point (size 25, 0.6 taper). During instrumentation, each canal was irrigated with a total of 10 mL of NaOCl distributed over three irrigation cycles, and each cycle lasted four minutes. The final irrigation was performed using 2 mL of physiological saline solution. Following each irrigation, the total volume per canal was 5.25% NaOCl. Manual activation of the irrigant was carried out using a size 20 gutta-percha point with a 0.6 mm taper.

Teeth assigned to the control group underwent the same endodontic procedures—including preparation, irrigation, and activation—as those in the study group, with the difference being the use of 0.9% saline solution as the root canal irrigant. In the study group, a minimally invasive endodontic access cavity was also prepared, and the canals were instrumented using the same Reciproc Blue system (size 25) following the determination of working length according to the previously described protocol.

Teeth assigned to the control group were irrigated exclusively with physiological saline solution, using 10 mL per canal. The prepared specimens were subsequently transferred to the laboratory for microstructural analyses and mechanical testing.

Failure load testing was performed at room temperature (22 ± 1 °C) using a Shimadzu universal testing machine (Japan) with a maximum load capacity of 20 kN. A special holder for squeezing teeth, patented by the authors, was used for dental examinations [4]. The measurement accuracy was within $\pm 1\%$ of the recorded value. All tests were conducted at a crosshead speed of 1 mm/min. Figure 1 shows the fixture used for failure load testing of the teeth [4]. The tooth is positioned vertically, and a rounded loading pin acts on the tooth crown from above, through which the load is applied. Tooth fracture occurring under the applied load was used as the failure criterion.

To evaluate the effects of 5.25% NaOCl used for root canal irrigation on the structure of dental hard tissues, integrated microstructural analyses were performed using two complementary characterization techniques: scanning electron microscopy (SEM) and energy-dispersive X-ray

spectroscopy (EDS). Surface morphology was examined using a Nova NanoSEM 450 scanning electron microscope (FEI, Thermo Fisher Scientific, Netherlands).

The chemical characterization of the samples was performed using an EDS (EDAX detector), which enabled the identification of the local elemental composition of the examined dental tissues.

As in other studies, EDS examinations and elemental analyses were performed by researchers who were blinded to the group assignments of the samples. Furthermore, all spectroscopic measurements and integration ranges were standardized and automated using software parameters, thereby eliminating the influence of researcher subjectivity on the data acquisition process.

A total of 20 dentin sections were allocated into four groups using a tooth-balanced allocation ($n = 5$ per group). Acquisition parameters were set at a working distance of 10 mm, an accelerating voltage of 15 kV, and an acquisition time of 100 s. The low-vacuum operating mode eliminated the need for conductive metal coating of the non-conductive specimens while maintaining high image quality. This represented a significant advantage over conventional high-vacuum methods. The atomic weight percentage (%) of the main inorganic elements present in dentin was determined, including calcium (Ca), phosphorus (P), sodium (Na), magnesium (Mg), fluorine (F), potassium (K), and sulfur (S).

Due to the exploratory nature of the study and the technical complexity associated with specimen preparation and EDS analyses, five specimens were included in each group. The untreated control group served as the baseline of reference for spectral and elemental characterization of dentin. All groups were analyzed under identical conditions. Accordingly, the experimental design was primarily focused on detecting treatment-related trends and chemical alterations among the experimental groups.

RESULTS

The results of the test performed on the selected teeth are presented in Table 1, followed by a statistical analysis.

An independent two-tailed Student's *t*-test for independent samples ($n_1 = n_2 = 5$) was performed.

The Shapiro-Wilk test indicated a normal distribution for all examined groups ($p > 0.05$),

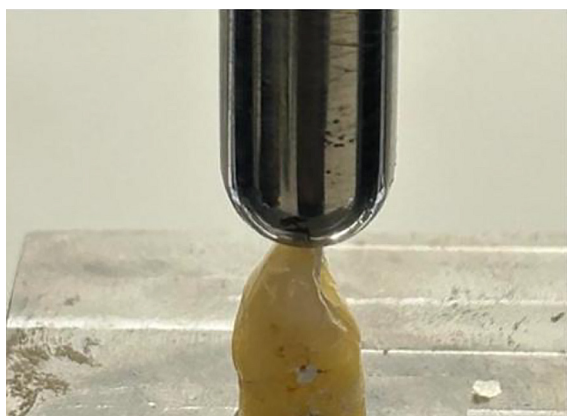


Figure 1. Failure load test – tooth positioned in the compression fixture

Table 1. Failure load of the examined teeth

Tooth group	Control group "Failure load" [N]	Experimental group "Failure load" [N]
Premolars	502 ± 6.43	396 ± 4.97
Canines	872 ± 17.72	756 ± 22.10

providing no basis for rejecting the assumption of normality of distribution. Subsequently, an independent-samples Student's- test was performed to compare the control and experimental groups for both tooth types. No evidence against normality and homogeneity of variances was found, as assessed using the F-test/Levene's test Premolar group: $F(4,4) = 1.67$, $p = .631$; Canine group: $F(4,4) = 1.56$, $p = .679$). These results justify the use of the standard (pooled-variance) Student's t -test rather than the Welch correction. The statistical analysis revealed significant differences between the control and experimental groups in both cases. For both tooth categories, the obtained p -values were below 0.05, confirming the statistical significance of the observed differences. For premolars, the analysis yielded a p -value of 2.03×10^{-9} and a t -value of 9.16, whereas for canines the corresponding values were 1.63×10^{-5} and 29.23, respectively. These findings indicate a particularly pronounced effect of NaOCl exposure concerning the premolars.

The apparently large t -values are a direct mathematical consequence of the very low within-group variability (SD on the order of a few

percent of the mean) combined with a large and consistent between-group difference, i.e., $t = (M_1 - M_2) / SE(\text{diff})$.

The confidence intervals and effect sizes are shown in Table 2.

MICROSTRUCTURAL ANALYSIS

Figures 2a and 2b present the microstructure of the root canal wall of a premolar from the control group subjected to a failure load but not exposed to NaOCl.

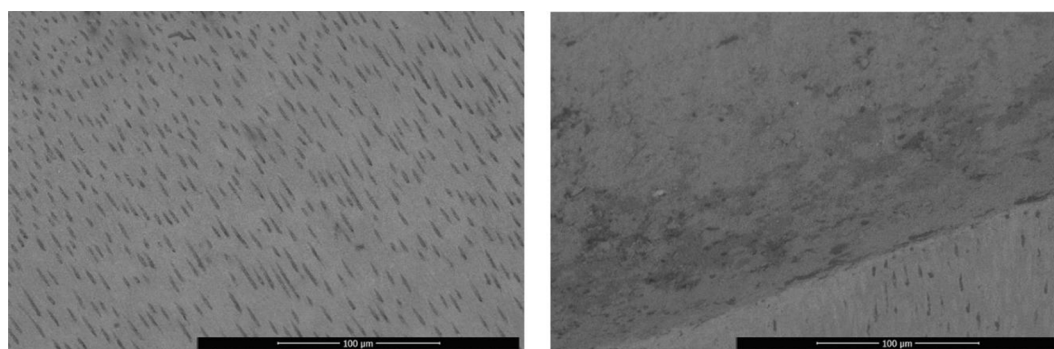
Dentinal tubules are clearly visible in Figure 2a, while Figure 2b shows the dentin-cementum interface and a homogeneous root canal wall structure. No cracks or structural defects were observed within the root canal wall (b).

Figure 3 illustrates the microstructure of the root canal wall of a premolar irrigated with NaOCl and subsequently subjected to a failure load.

Visible cracks were observed within the root structure (Figure 3a). In addition, exposed dentinal tubules were evident in Figure 3b. Figure 4 presents the microstructure of the root canal wall

Table 2. The result of statistical analysis for every group of teeth

Premolar group (control vs. tested):	Canine group (control vs. tested):
$M_{\text{control}} = 502.40 \text{ N}$ ($SD = 6.43$), $M_{\text{tested}} = 396.20 \text{ N}$ ($SD = 4.97$)	$M_{\text{control}} = 872.00 \text{ N}$ ($SD = 17.72$), $M_{\text{tested}} = 756.00 \text{ N}$ ($SD = 22.10$)
Mean difference = 106.20 N, 95% CI [97.82, 114.58]	Mean difference = 116.00 N, 95% CI [86.79, 145.21]
$t(8) = 9.16$, $p = 0.000016$ (1.63×10^{-5})	$t(8) = 29.23$, $p = 0.000000$ (2.03×10^{-9})
Hedges' $g = 16.70$ (very large effect)	Hedges' $g = 5.23$ (very large effect)


Figure 2. SEM micrographs of the root canal wall of a premolar from the control group following failure load: (a); (b)

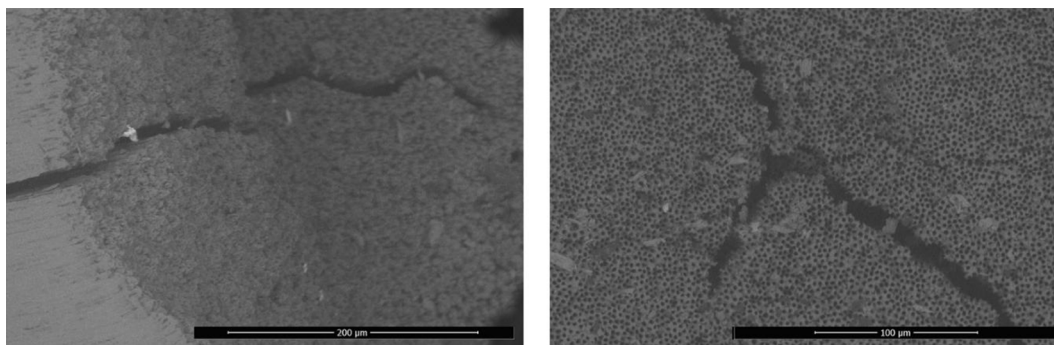


Figure 3. SEM micrographs of the root canal wall of a premolar following NaOCl irrigation and failure load: (a); (b)

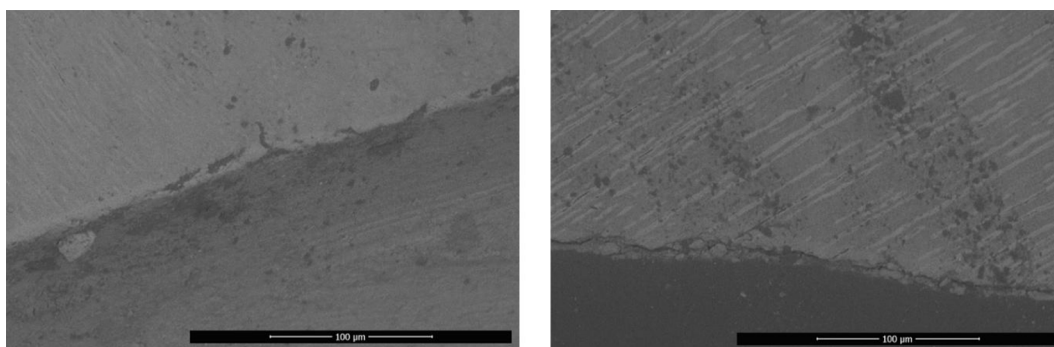


Figure 4. SEM micrographs of the root canal wall of a canine from the control group following failure load: (a); (b)

of a canine from the control group that was subjected to a failure load without prior exposure to sodium hypochlorite.

Dentinal tubules are visible in Figure 4a, whereas Figure 4b shows the dentin-cementum interface. No cracks were detected within the root canal wall structure.

In contrast, Figures 5a and 5b present the microstructure of the root canal wall of a canine irrigated with NaOCl. Visible cracks can be observed within the root structure.

Statistical comparisons between groups were performed using the Mann-Whitney U test. A decrease in the percentage (atomic) content of

calcium and phosphorus was observed in the NaOCl group compared to the control group ($p < 0.05$). Lower sodium values were found in the group of teeth treated with NaOCl. The dominant elements detected in all study groups were calcium and phosphorus, whereas magnesium and fluorine were present in lower (atomic) percentages. Fluorine and sodium contents in all groups were below the limit of detection (Table 3).

The predominant elements detected in all experimental groups were calcium and phosphorus, while sodium, magnesium, and fluorine presented lower numerical atomic percentages. Chlorine was below the detection limit in all groups.

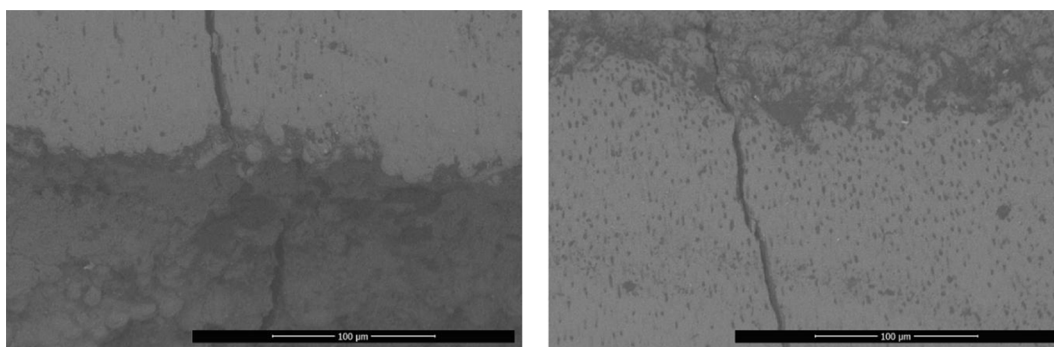


Figure 5. SEM micrographs of the root canal wall of a canine following NaOCl irrigation and failure load: (a); (b)

EDS analysis confirmed a critical and significant reduction in calcium and phosphate levels in the NaOCl group, indicating severe demineralization. This could be taken into account that it establishes a chemical substrate highly susceptible to biomechanical impairment more than any individual treatment.

Additionally it was checked the statistical analysis based on EDS and failure load (Figures 6–9).

The value between breaking strength (F, in N) and mineral content (P and Ca, in wt%) was determined at three independent levels of data aggregation to assess the stability and reliability of this relationship:

1. Individual sample level, within subgroups (n=5). For each of the four subgroups (test canines, control canines, test premolars, control premolars), the Pearson coefficient (r) was calculated between the measured breaking strength and the corresponding content of P (and separately Ca) for the same verified sample. Statistical significance (p) was not calculated here due to the small sample size (n=5); with such a small N, a significance test has negligible power and the result would be unreliable—at this level, r is treated solely as an indicator of the direction and strength of the relationship.

2. Samples from the test and control groups were combined into a single dataset, and the Pearson was calculated along with the p-value (significance test for the coefficient, $H_0: r=0$). This level offers greater statistical power than the within-subgroup analysis because it encompasses a wider range of values for both strength and mineralization.

3. Global level, combining both tooth types (n=20). For verification, was also calculated across all 20 paired observations combined (canines and premolars together) to determine whether the relationship persists regardless of tissue type or is specific to a particular type of tooth.

Method selection. Pearson (not Spearman) was used because the data are continuous and the relationship between the variables is approximately linear (increasing mineralization increasing strength). The direction of the relationship is fully consistent at the subgroup level. In all four subgroups, the relationship between strength and P (phosphorus) and between strength and Ca (calcium) is positive and strong (r ranging from 0.58 to 1.00)—meaning that the higher the mineral content, the higher the breaking strength. No instances of a negative relationship were observed

Table 3. Impact of the chemical elements identified by EDS analysis on the microstructure of dental tissues before and after sodium hypochlorite treatment the average results

Chemical element (symbol)	Canine – Experimental group / Weight Conc. [%]	Canine – Control group / Weight Conc. [%]	Premolar – Experimental group / Weight Conc. [%]	Premolar – Control group / Weight Conc. [%]
Phosphorus (P)	Biofilm/possibility of phosphate residues / 6.63	Mineral balance/ 19.65	Indicates disruption of the mineral structure / 16.49	Disturbance of mineral balance / 23.9
Calcium (Ca)	Mineral depletion / 11.61	Presence of secondary calcium deposits or differences in mineralization / 30.13	Calcium loss / 8.16	Presence of secondary calcium deposits or differences in mineralization / 13.47
Magnesium (Mg)	Presence of small amounts of organic residues and dentin-specific ions / 1.17	No significant effect of instrumentation / 1.51	Loss of accompanying mineral components / 1.24	Slight mineral loss / 1.54
Potassium (K)	Removal of potassium ions due to irrigation / 0.96	Stable elemental content / 0.75	Leaching of ions from dentin / 1.07	Virtually no changes / 0.70
Chlorine (Cl)	Intensive contact with NaOCl / 2.68	Elemental content/ 0.64	Confirms the presence of NaOCl residues in root canal dentin / 0.96	Possible contamination or residues from instrumentation / 1.28
Sulfur (S)	Presence of organic residues or contamination / 0.37	Presence of organic substances or contamination / 1.08	Possible loss of sulfur-containing compounds (e.g., amino acids) / 0.04	Trace amounts of sulfur-containing proteins / 0.24
Fluorine (F)	Effect of NaOCl on dental tissues / 0.03	Possible leaching or level below the detection limit / 0.03	Effect of NaOCl on dental tissues / 0.04	Possible leaching or level below the detection limit / 0.03
Sodium (Na)	Very low / at the limit of detection/ 0.03	Local differences in mineralization / 0.26	Very low / at the limit of detection/ 0.06	Very low / at the limit of detection/ 0.21

after verifying sample classification. The relationship is statistically significant within the same tooth type ($n=5$). For canines, both (P and Ca) are highly statistically significant ($p=0.015$ and

$p=0.0001$). For premolars, the with phosphorus is significant ($p=0.0017$), while the with calcium borders on significance ($p=0.064$)—suggesting a genuine effect that would require a larger sample

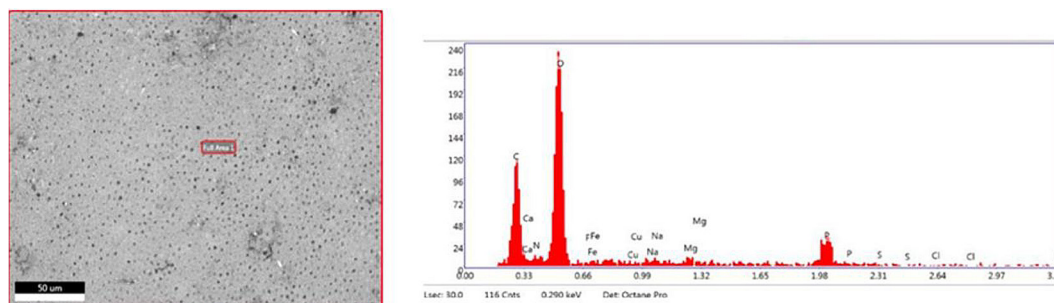


Figure 6. Root dentin area selected for EDS analysis and the corresponding spectrum obtained from a premolar of the control group in the region adjacent to the root canal

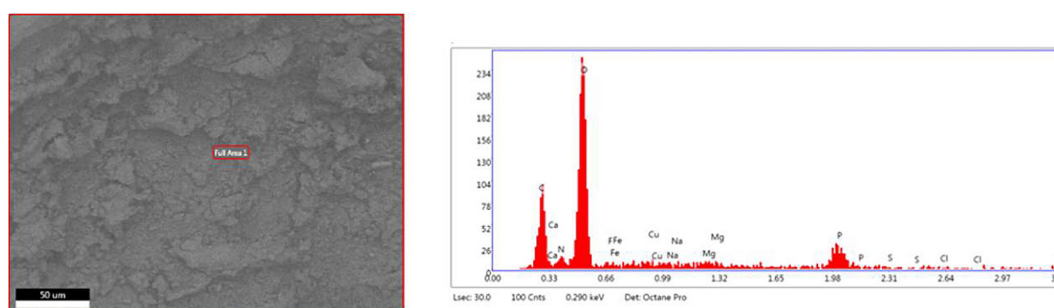


Figure 7. Root dentin area selected for EDS analysis and the corresponding spectrum obtained from a premolar of the experimental group in the region adjacent to the root canal

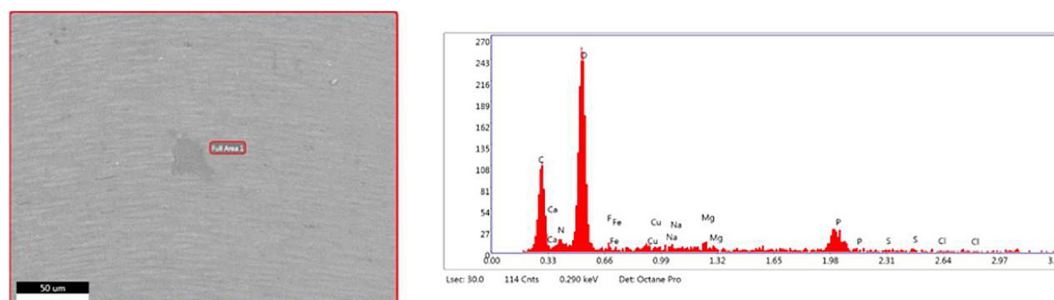


Figure 8. Root dentin area selected for EDS analysis and the corresponding spectrum obtained from a canine of the experimental group in the region adjacent to the root canal

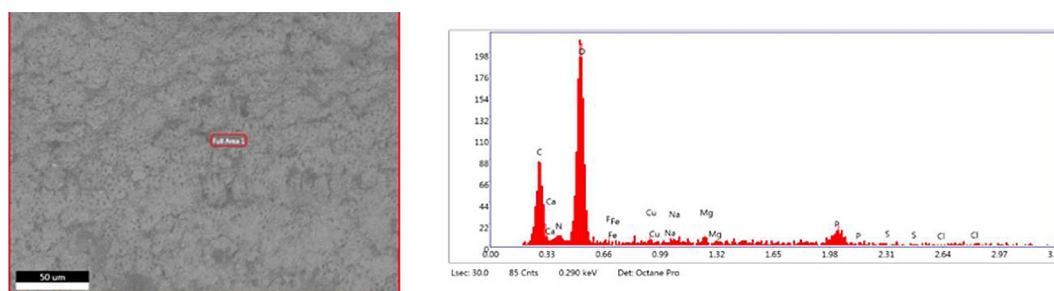


Figure 9. Root dentin area selected for EDS analysis and the corresponding spectrum obtained from a canine of the experimental group in the region adjacent to the root canal

size for full confirmation. The relationship disappears when both tooth types are combined in a single analysis. At the aggregate level ($n=20$), the virtually vanishes (r close to zero, lack of significance). This indicates that tooth type is a variable that differentiates the baseline strength level independently of mineralization; canines are inherently much stronger than premolars, regardless of the degree of mineralization. Therefore, between strength and mineral composition should be reported and interpreted only within the same tissue type, never by combining different tooth types—doing so obscures and invalidates the actual relationship. C

The mineralization of dental tissue (Ca and P content) is a significant, positively correlated predictor of its mechanical strength, provided the analysis is conducted within a homogeneous tooth type. The effect size is greatest for calcium in canines and for phosphorus in both tooth types.

An analysis of EDS data (elemental composition—calcium and phosphorus) combined with failure load results reveals a consistent pattern across the tooth groups studied. For both canines and premolars, the control group exhibited higher calcium and phosphorus content, which could be concluded that greater failure load compared to the study group.

This trend was identical for both tooth types, suggesting that the reduced mineralization (loss of calcium and phosphorus) observed in the study group may be linked to the teeth's reduced failure load. This is further supported by the qualitative EDS findings: samples from the study group showed calcium loss and disrupted mineral structure, whereas control samples displayed characteristics of a proper mineral balance.

DISCUSSION

There is considerable controversy in contemporary literature regarding the weakening of hard tooth tissues associated with endodontic treatment.

According to Becciani and Castelucci [10] endodontic treatment results in the loss of mineralized tooth tissue and alterations in physico-chemical properties; furthermore, the use of root canal irrigants can compromise the mechanical properties of dentin.

The use of sodium hypochlorite as an irrigant during endodontic treatment is essential and mandated by endodontic society protocols. Sodium

hypochlorite is the primary and most important irrigant used in endodontics. Thanks to its lytic and antimicrobial properties, it effectively dissolves both vital and necrotic pulp tissue as well as the organic components of the smear layer. It effectively penetrates and cleans areas inaccessible to endodontic instruments. Despite its many advantages, however, this agent can weaken the dentin structure itself and negatively affect its physical properties, leading to increased tooth brittleness.

Based on the authors' own research and the analysis of destructive loads, a decline in strength parameters was observed in both tooth groups—canines and premolars—subjected to root canal irrigation with 5.25% NaOCl. The differences in strength between canines and premolars can be attributed to their morphology; the canine, possessing a more massive and highly mineralized structure, exhibits greater resistance to the effects of chemical agents. Due to thinner walls and a dentin structure more susceptible to penetration, premolars may be more prone to rapid chemical and mechanical damage.

Sim et al. [5] demonstrated that immersing dentin in a 5.25% NaOCl solution drastically reduces mechanical strength and the elastic modulus compared to a control group rinsed with saline.

Similar conclusions were reported by Grigoratos et al. [6], who investigated the effect of using NaOCl (3% and 5%) on the strength parameters of dentin; the negative impact of the substance on the elasticity and mechanical resistance of tooth structures was confirmed. Zou et al. noted that the degradation of canal walls and the intracanal surface progresses with increasing NaOCl concentration. Dentin exposed to NaOCl undergoes demineralization more readily, which directly reduces the mechanical strength of the root. The authors suggest a minimally invasive approach to protect the tooth against fracture. Microstructural analysis revealed a clearly defined boundary between the enamel and the dentin.

Microscopic imaging disclosed characteristic morphological differences between these tissues: the homogeneous, smooth structure of the enamel contrasted with the more porous and irregular surface of the dentin.

A crack was observed along the enamel-dentin junction, suggesting that this zone may have served as an initiation or propagation site for damage under the influence of failure loads in teeth subjected to root canal irrigation with 5.25% NaOCl. This phenomenon aligns with literature

reports indicating the biomechanical sensitivity of this interface, which stems from the differing mechanical properties of the adjacent tissues: enamel—a hard, brittle material—and dentin, which exhibits greater elasticity and capacity for elastic deformation. The presence of a crack suggests that the dentino-enamel junction (DEJ) not only failed to arrest crack propagation but actually served as a natural line of structural weakness.

In summary, the results highlight the need for caution when using 5.25% sodium hypochlorite during endodontic procedures. Excessive tissue exposure to this agent can significantly weaken the dentin structure and increase the risk of tooth fracture. Therefore, the selection of irrigants should take into account not only their antimicrobial efficacy but also their impact on the biomechanical and chemical properties of dentin—factors directly relevant to the durability and success of endodontic treatment.

Statistical analysis demonstrated between mineral loss in the tooth tissues and the magnitude of the failure load. Changes in structure and mineral composition observed in the group treated with NaOCl indicate a significant chemical synergy that clinicians should take into account.

As demonstrated by Ruiz et al. [7], irrigation with NaOCl does not favor tissue preservation. Instead, it is associated with a simultaneous destructive process in which NaOCl causes collagen degradation. NaOCl removes the protective collagen sheath, completely exposing the underlying crystals beneath it, and induces structural demineralization characterized by a loss of calcium and phosphorus, confirming the depletion of the original mineral components.

Zhang's et al. [11] study analyze how exposure time and NaOCl concentration affect the microstructure and mechanical properties of dentin, demonstrating between the degradation of tissue components and the loss of the tooth's mechanical stability.

Moorer et al. [12] describe why intensive irrigation and activation of NaOCl are so effective at destroying organic tissue. Regarding the lytic mechanism of sodium hypochlorite on organic tooth tissue: since dentin consists of a collagen network (organic) and hydroxyapatite crystals (inorganic, rich in calcium and phosphorus), the aggressive dissolution of collagen—following Moorer's mechanism—exposes the tooth's minerals.

When the collagen matrix is destroyed by activated NaOCl, calcium and phosphorus ions

lose their organic “scaffolding” and become susceptible to leaching, which directly leads to a reduction in microhardness and the tooth's fracture resistance.

CONCLUSIONS

Based on the results obtained in the present study, the following conclusions can be drawn:

- The strength properties of teeth subjected to root canal irrigation with 5.25% NaOCl were lower in both test groups compared to the control groups, in which physiological saline was used as the irrigant.
- EDS analysis of changes in the elemental composition of root dentin treated with 5.25% NaOCl revealed alterations in calcium and phosphorus content following exposure, which could be accompanied by a reduction in the force required to fracture the teeth.
- The authors highlight the need for further research using EDS spectroscopy to determine the cause-and-effect mechanism linking failure load to elemental changes in root canals irrigated with 5.25% NaOCl.

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