Majalah Kedokteran Gigi Indonesia
Vol 10 No 1 – April 2024
ISSN 2460-0164 (print), ISSN 2442-2576 (online)
Available online at https://jurnal.ugm.ac.id/mkgi
DOI: http://doi.org/10.22146/majkedgiind.85125

RESEARCH ARTICLE

Effect of sodium thiosulfate irrigation on push-out bond strength of root canal obturation material

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Submitted: 2nd June 2023; Revised: 18th April 2024; Accepted: 28th April 2024

ABSTRACT

Sodium hypochlorite is used as irrigation solution during root canal preparation because of its antibacterial effect. However, it degrades dentinal collagen and generates oxygen free layer on dentin surfaces that might prevent penetration of sealer. Sodium thiosulfate is an antioxidant and has been reported to neutralize that side effect. The objective of this study was to determine the effect of concentration and application time of sodium thiosulfate irrigation on push-out bond strength of root canal obturation material. This study used extracted human mandibular premolars single root post extraction. The root canals were prepared using crown down technique up to file F3. The samples were divided into four groups. Groups IA and IB were irrigated with sodium thiosulfate 5% for 3 and 5 minutes, while Groups IIA and IIB were irrigated with sodium thiosulfate 10% for 3 and 5 minutes. The control group was irrigated with saline for 3 and 5 minutes. The root canals were obturated with epoxy resin sealer and gutta percha, and were incubated for 7 days. Samples were horizontally sectioned into 2 mm thickness in apical third and were tested with push-out technique using universal testing machine. The adherence failure of samples was observed using stereo microscope. Data were analyzed with two-way ANOVA. There was a significant effect between concentration of sodium thiosulfate on push-out bond strength ($p < 0.05$), but application time showed the same effect ($p > 0.05$). The application of antioxidant resulted in an increase in the push-out bond strength of root canal obturation material, with 10% sodium thiosulfate demonstrating the highest push-out bond strength.

Keywords: application time; concentration; push-out bond strength; sodium thiosulfate

INTRODUCTION

The objective of root canal treatment is to remove intracanal infection by eliminating the microorganisms present in the root canal system, create a suitable environment for the healing process, maintain the health of the periradicular tissues, and prevent the canal from reinfection. A successful root canal treatment depends on the endodontic triad which includes biomechanical preparation (cleaning and shaping), cleaning of the root canals using irrigation solutions and intracanal medicaments (disinfection), and filling or obturation.[1] The use of irrigant assists the debridement stage of the root canals during biomechanical preparation by removing organic and inorganic materials.[1] Irrigation solutions with low surface tension are expected to penetrate the dentinal tubules and assist in the cleaning process of the root canal system.[2] Sodium hypochlorite (NaOCl) with 0.5-5.25% concentration is considered a gold standard as irrigation because it has broad antibacterial properties and the ability to dissolve organic tissue.[3] Sodium hypochlorite with 2.5% concentration is recommended as a root irrigation solution because this concentration helps minimize the toxicity effect.[4]

Obturation of the root canal is carried out to seal the entire root canal system, preventing fluids and bacteria from entering the root canal.[1] Gutta percha as the obturation core material is not able to produce a tight filling of the root canal walls if it is not supported by the use of a sealer.[5] Epoxy resin based sealer is used because of its good physical and biological properties, its ability to form micro retention in root canal dentine, low solubility, small shrinkage, and low toxicity.[6,7] Adhesion of the root canal obturation material occurs due to good contact and adaptation between the obturation material and the root canal walls through penetration into the dentinal tubules. The use of irrigation solutions can influence the bond strength of the dentine and filling material.[8]

Sodium hypochlorite irrigation can affect the polymerization of the resin sealer.[9] This is due to the presence of free radicals after sodium hypochlorite irrigation in the dentinal walls and dentinal tubules, causing failure of adhesion at dentin-resin interface area and root canal obturation failure. Another negative effect is that it can cause dentin degeneration due to the breakdown of collagen, which weakens the bond between dentin and resin sealer.[10,11] The push-out bond strength of an epoxy resin sealer on dentine exposed to sodium hypochlorite decreases, with the smallest adhesive strength occurring in the apical third of the root canal dentin.[12]

The oxidizing effect of sodium hypochlorite can be reduced by using antioxidants because they neutralize free radicals.[13] Sodium thiosulfate has been used as an antioxidant that can remove sodium hypochlorite residues with a redox reaction (oxidation-reduction). Previous studies have shown that the use of sodium thiosulfate with a concentration of 5% with an application time of 1 minute, 5 minutes, and 10 minutes functions as an antioxidant that can increase the adhesion of the resin to dentine by neutralizing free radicals in dentine exposed to sodium hypochlorite.[14] The use of sodium thiosulfate with a concentration of 5% with an application time of 3 minutes, 5 minutes, and 10 minutes can restore the adhesive strength of the resin to dentine exposed to sodium hypochlorite.[15] The use of 10% sodium thiosulfate for 10 minutes increases the penetration of epoxy resin sealer in the coronal third, the middle third, and the apical third that are exposed to sodium hypochlorite.[16] No previous study has investigated the effect of concentration and application time of sodium thiosulfate on the adhesion of epoxy resin sealer and gutta percha as obturation materials.

This study was performed to analyze the effect of sodium thiosulfate irrigation with concentrations of 5% and 10% with an application time of 3 minutes and 5 minutes on the push-out bond strength of root canal obturation materials. The push-out test is one of the most accurate, effective, and simple methods to measure the bond strength value between the sealer, dentin, and the core material. A push-out test can be performed to evaluate the bond strength down to low values at various root canal dentin depths.[5]

MATERIALS AND METHODS

This research was performed after obtaining an ethical clearance from the Ethics and Advocacy Unit of the Faculty of Dentistry, Universitas Gadjah Mada (project number 0045/KKEP/FKG-UGM/EC/2022). The samples were premolar mandibular teeth extracted for orthodontic treatment with the following inclusion criteria: straight and perfectly formed apex, no caries, no resorption, no calcification, and no root fractures. Root canal anatomy was confirmed by taking preoperative radiographs using occlusal film (Ultra-speed®, Carestream Dental) in buccolingual and mesiodistal directions. Teeth that met the criteria were stored in PBS solution in a closed tube to obtain 100% humidity, thus preventing dehydration until the time of the study.[17] Sodium thiosulfate with 5% concentration solution was prepared by weighing 5 grams of sodium thiosulfate crystals, then dissolved in 100 ml of distilled water. Sodium thiosulfate with 10% concentration solution was prepared from 10 grams of sodium thiosulfate crystals, then dissolved in 100 ml of distilled water.

The teeth were decoronated at cemento-enamel junction (CEJ) with a double-sided diamond bur (Horico) to leave 14 mm root section (with a working length of 13 mm) which was measured using a caliper from the tip of the root to the cervical of the tooth.[18] Preparation of root canal was performed by a crown down technique with a ProTaper Gold file (Dentsply Maillefer) and an endo motor device (E Connect S, Eighteeth). Preparation was initiated by using K file #10

Majalah Kedokteran Gigi Indonesia. April 2024; 10(1): 8-16
ISSN 2460-0164 (print)
ISSN 2442-2576 (online)

according to the working length. The preparation was started using files SX, S1, and S2 at 2/3 coronal (8.5 mm) for widening 2/3 coronal portion. Apical preparation was carried out with S1, S2, F1, F2, and F3 files with a working length of 13 mm. Each use file was lubricated with 15% EDTA gel. All of the root canals were irrigated with 2.5% NaOCl for 1 minute between each instrument change using a side-vented 30 gauge irrigation needle in manual irrigating technique, then rinsed with saline. Subsequently, a paper point was inserted to dry the root canal. Tooth samples were randomly divided into 2 main groups: group I consisted of 14 teeth using 5% sodium thiosulfate irrigation solution, and group II consisted of 14 teeth using 10% sodium thiosulfate irrigation solution. The two main groups were further divided into 4 subgroups.

Group IA was subjected to final irrigation using 2 ml of 2.5% NaOCl solution for 2 minutes, continued with 2 ml of 5% sodium thiosulfate irrigation for 3 minutes. Group IB was subjected to final irrigation using 2 ml of 2.5% NaOCl solution for 2 minutes, continued with 2 ml of 5% sodium thiosulfate irrigation for 5 minutes. Group IIA was subjected to final irrigation using 2 ml of 2.5% NaOCl solution for 2 minutes, continued with 2 ml of 10% sodium thiosulfate irrigation for 3 minutes. Group IIB was subjected to final irrigation using 2 ml of 2.5% NaOCl solution for 2 minutes, continued with 2 ml of 10% sodium thiosulfate irrigation for 5 minutes. The control group was subjected to final irrigation using 2 ml of 2.5% NaOCl solution for 2 minutes, continued with saline irrigation for 3 minutes and 5 minutes.

Root canal obturation was performed using a single cone technique with a gutta percha mastercone #F3 marked with a rubber stop according to the working length with AH Plus epoxy resin sealer. The remaining gutta percha was cut and compacted using a heated plugger 1 mm in the apical direction. The orifice was closed with glass ionomer cement. Confirmation of the results of root canal obturation was carried out by taking preoperative radiographs using occlusal film (Ultra-speed®, Carestream Dental) from the

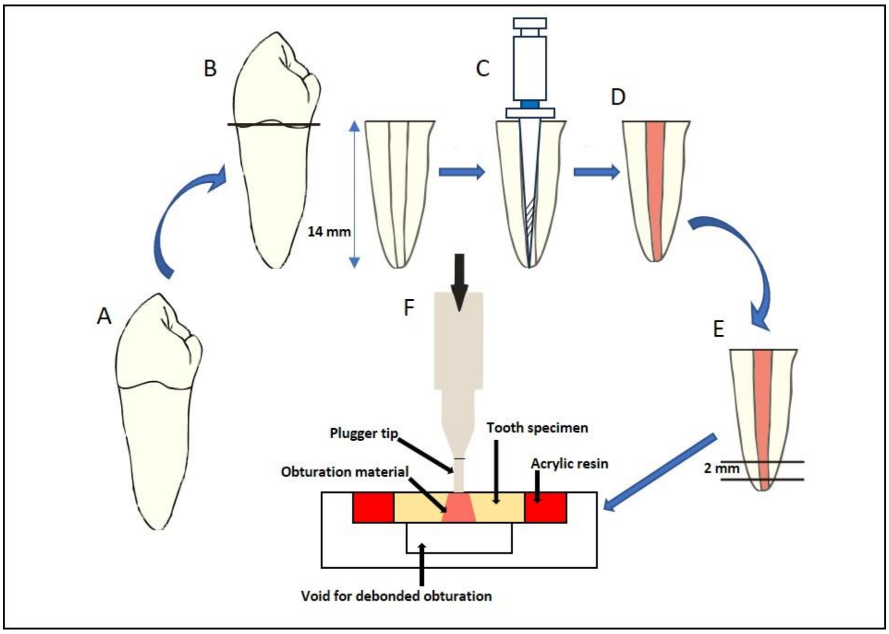


Figure 1. Diagram of sample preparation and push-out test. (A) Mandibular premolar teeth. (B) Mandibular premolar teeth were decoronated at CEJ to leave 14 mm root section. (C) Preparation of root canal up to F3 ProTaper gold rotary file. (D) Obturated root canal using F3 mastercone gutta percha and epoxy resin sealer. (E) Apical portion of root sectioned to obtain 2 mm thick slice. (F). Push-out bond test using universal testing machine.

buccolingual and mesiodistal directions. Samples were stored by placing them on wet gauze and placed in plastic containers. Samples were stored in an incubator at 37 °C with 100% humidity for 7 days to maximize the hardening of the epoxy resin sealer.[18]

Samples were cut 2 mm from the apex, and continued to cut the apical third of the tooth pependicular to the tooth axis with a thickness of 2 mm and measured with an electronic digital calipper (Mitutoyo kawasaki, Japan). The coronal surface of each sample was marked and coded for each group. The sample was positioned on the surface of a custom made, square resin mold with a side length of 20 mm and a height of 2 mm. The push-out bond strength test was carried out by pushing the root canal obturation material using a plugger tip with a cylindrical diameter of 0.3 mm attached to a universal testing machine.[19] The tip of the plugger moved from top to bottom and pushed the root canal obturation material from the apical to the coronal direction at a speed of 1 mm/min. The result of the push-out force was considered as maximum load until obturation material detached from the root canal and was displayed at universal testing machine (Newton). The push-out bond strength was calculated using the following formula:

$$PBS = F/A$$

where PBS is push out bond strength (MPa), F is maximum load (Newton), and A is adhesion area of root canal obturation material (mm^2).[21] Adhesion area of root canal obturation material was calculated using the formula:

$$A = \pi(r1 + r2)\sqrt{(r1 - r2)2 + h^2}$$

where π is 3.14, r1 is coronal radius, r2 is apical radius, and h is sample thickness.[20]

Observation of the type of bond failure of the root canal obturation material was carried out after the push-out test by examining it under stereo microscope (Olympus, Japan) at 40X magnification.[18] The main outcome in this study was the push-out bond strength (MPa). Saphiro-Wilk and Levene's tests were carried out for normality and homogeneity tests. Since the data were normally distributed, parametric statistical tests were applied with two-way ANOVA. Furthermore, the data was tested with LSD Post-hoc to determine the value of comparison between groups. The significance was set at $p < 0.05$. The data were processed using IBM SPSS Statistics for Windows version 22.0 (IBM, USA).

RESULTS

The mean and standard deviation are presented in Table 1. The results showed that the highest mean push-out bond strength was seen in Group IIB (the root canal irrigation group using 10% sodium thiosulfate concentration for 5 minutes), while the lowest mean push-out bond strength was seen in the control group. The normality test was conducted using the Shapiro Wilk test, and the homogeneity test using the Levene's test. The results of the normality test showed that

Table 1. The mean and standard deviation of the push-out ond strength (MPa) resulted form the influence of the concentration of 5% and 10% sodium thiosulfate irrigation solutions for 3 minutes and 5 minutes application time

Treatment group	Mean ± standard deviation
Group IA	3.93 ± 0.23
Group IB	4.19 ± 0.28
Control	3.16 ± 0.08
Group IIA	4.49 ± 0.24
Group IIB	4.60 ± 0.29
Control	3.24 ± 0.52

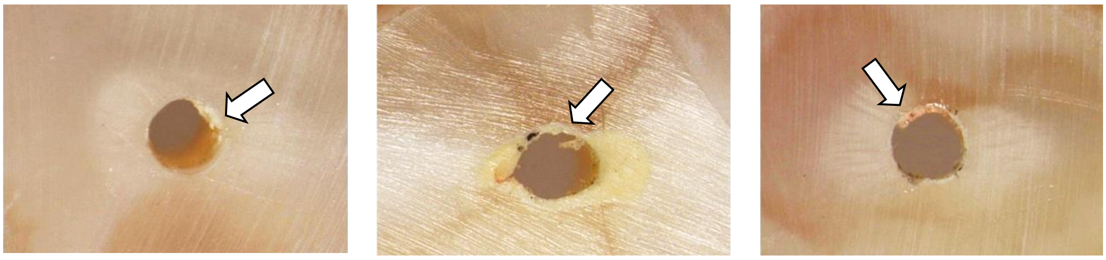
Table 2. The results of two-way ANOVA test on the push-out bond strength resulted form the influence of the concentration of 5% and 10% sodium thiosulfate irrigation solutions for 3 minutes and 5 minutes application time

Source variation	p
Concentration	0.000*
Application time	0.079
Concentration* Application time	0.627

Description : * = p value < 0.05 Significant

Table 4. Percentage of failure types on push-out bond strength resulting from the influence of 5% and 10% sodium thiosulphate irrigation solution for 3 minutes and 5 minutes application time.

Group	Type I (Adhesive)	Failure type Type II (Cohesive)	Type III(Mixed)
Group IA	1	2	4
Group IB	0	3	4
Group IIA	0	2	5
Group IIB	1	2	4
Control	1	3	4
Total	3 (8.3%)	12 (33.3%)	21 (58.3%)



(A) (B) (C)

Figure 2. Results of stereo microscope examination with 40X magnification on the sample. (A) Type I failure or adhesive failure: the root canal walls appear clean from the sealer. (B) Type II failure or cohesive failure: the root canal walls appear to be coated with sealer. (C) Type III failure or combined failure: it appears that part of the root canal walls are coated with sealer

the research data in all treatment groups were normally distributed ($p > 0.05$). The results of the homogeneity test using Levene's test showed that the variance of the data in all treatment groups was homogeneous ($p > 0.05$).

The results of the two-way ANOVA test showed that there was a significant difference in the concentration of sodium thiosulfate solution on the push-out bond strength with $p = 0.000$ ($p < 0.05$). The results of the application time analysis of sodium thiosulfate solution on the push-put bond strength had a value of $p = 0.079$. This indicates that the application time of sodium thiosulfate solution has the same effect on the push-out bond strength ($p > 0.05$). There was no interaction between the concentration and application time of sodium thiosulfate on the push-out bond strength with $p > 0.05$ ($p = 0.627$).

Based on the results of the LSD Post-hoc test, there was a significant difference between the 5% sodium thiosulfate concentration group and the 10% sodium thiosulfate concentration group, a significant difference between the 5% sodium thiosulfate concentration group and the control group, and significant difference between the 10% sodium thiosulfate group and the control group.

Table 4 shows the distribution of the percentage of the mode of push-out bond strength failure analysis. The highest failure percentage was type III (mixed failure), and the lowest failure percentage was type I failure (adhesive failure). Specimen sample of every type push-out bond strength failure was analyzed by stereo microscope as shown in Figure 2.

DISCUSSION

Adhesin of root canal obturation material to dentinal wall is desirable physical property. It prevents coronal and apical leakage, minimizes the risk of filling detachment from dentin during restorative procedures or masticatory functions, and improves the health of periapical tissues.[21,22] Bond strength tests are used to evaluate adhesion between root canal obturaton material and dentinal wall.[7] The bond strength of root canal obturation materials is related to the ability of sealer to penetrate on the root canal walls and dentinal tubules which can be affected by the root canal irrigation material used.[7,23]

The use of sodium hypochlorite as an irrigation solution has the side effect of producing free radicals on the dentin surface. When sodium hypochlorite dissolves in water, it produces hypochlorous acid and hypochlorite ions. This hypochlorite ion is called free chlorine. Not all free chlorine will react, and the remaining chlorine will be called residual chlorine. The remaining oxidation products in the form of chlorine and oxygen rich layers can interfere the polymerization of the resin sealer and the penetration of the resin sealer in the dentinal tubules, thereby reducing the adhesive strength of the resin sealer.[12,13]

Sodium thiosulfate as an antioxidant neutralizes sodium hypochlorite free radicals through two mechanism: chemical reaction mechanism and physical mechanism through flushing. Sodium thiosulfate reacts by neutralizing unpaired electrons in oxidants and forming stable molecules.[14,23] The reaction between sodium thiosulfate and sodium hypochlorite will lower the pH. This leads to the production of bisulfite ions from thiosulfate, which will react with chlorate ions and cause a decrease in chlorate in sodium hypochlorite solution. The reaction will form sodium hydrogen sulfate or sodium bisulfate, which is an inactive salt.[24] The reaction between sodium thiosulfate and sodium hypochlorite makes unpaired chlorine more stable, thereby reducing the side effects of chlorine and free radicals. The reaction that occurs will cause an alkaline pH and will reduce free chlorine. Reducing free chlorine will increase effectiveness, better biocompatibility, and reduce toxicity to tissues. Our findings showed that the reaction between sodium hypochlorite and sodium thiosulfate at concentrations of 5% and 10% did not cause precipitate at root canal walls. Therefore, irrigation of sodium thiosulfate in the root canals did not interfere the penetration of the sealer into the dentinal tubules. This improved the ability of the resin sealer to adhere to the root canal dentin walls.

The use of sodium hypochlorite as an irrigation solution has an effect on the dentine collagen matrix. Collagen in intertubular and intratubular dentin will dissolve due to the deproteinizing effect of sodium hypochlorite which converts insoluble proteins into soluble polypeptides and amino acids. This produces a less receptive dentin surface. This is important because epoxy resin sealers have a micromechanical and chemical attachment mechanism, with micromechanical attachment beginning with the penetration of the sealer into the dentinal tubules and the exposed collagen matrix. The interaction between the resin sealer and the collagen matrix is reduced due to dissolution of collagen, thereby weakening the bond between the dentin and the siler resin.[11,15] Sodium thiosulfate, with a mechanism of action as a secondary antioxidant, will react with free radicals after sodium hypochlorite irrigation. This interaction leads to the development of a stable molecule, which can prevent the damaging effects of dentine collagen and restore adhesive strength of the resin sealer.[25]

The results of this study showed that the push-out bond strength in the control group was lower compared to the 5% and 10% sodium thiosulfate irrigation groups. The saline irrigation after sodium hypochlorite irrigation was only able to give a rinsing effect, but could not neutralize free radical residues due to sodium hypochlorite irrigation. This is in accordance with the research of Correa et al., which found that saline irrigation cannot restore the adhesive strength of the resin material to dentine.[14]

The effectiveness of irrigation solution can be improved by increasing its concentration. Increasing the concentration of sodium thiosulfate may lead to more sodium hypochlorite neutralization reactions. The neutralization reaction that occurs chemically is in the form of an oxidation-reduction reaction that binds free radicals after sodium hypochlorite irrigation. A higher concentration of sodium thiosulfate allows more thiosulfate ions to react to form more stable molecules. The results of this study are in accordance with previous studies which found that higher concentrations of sodium thiosulfate can neutralize sodium hypochlorite faster at the same concentration.[14,15] Research from Correa et al. showed that higher concentrations of sodium thiosulphate exhibited a better effect on the bond strength of the resin material to dentine.[14] The more free radicals that can be neutralized by sodium thiosulfate, the more oxygen-rich layers on the dentin surface that can be removed, thereby improving the polymerization of the resin sealer and increasing the adhesive strength of the root canal obturation material.

The effectiveness of sodium thiosulfate solution in neutralizing sodium hypochlorite is related to the surface tension value. Lower surface tension values can increase the flowability and wetting ability of solution and result in better penetration ability of irrigation solutions into the root canal system and dentinal tubules.[2] The concentration of sodium thiosulfate 10% has a lower surface tension value than the concentration of sodium thiosulfate 5%. The surface tension value of sodium thiosulfate with concentrations of 10% and 5% is lower than that of 2.5% sodium hypochlorite (72 dyne/cm).[2] Therefore, a lower surface tension value at 10% sodium thiosulfate concentration can provide a better rinsing effect of sodium hypochlorite than 5% sodium thiosulfate.

The adhesive strength of the resin sealer material can be affected by the penetration of the sealer into the dentinal tubules. This is directly linked to the chelation ability of the irrigating solution to remove the smear layer created during root canal preparation procedures. The chelation ability of sodium thiosulfate which resembles EDTA will bind calcium and form calcium chelate, thereby facilitating the cleansing of the smear layer.[13,26] The absence of smear layer can improve the cleanliness of the root canal walls, will open the dentinal tubules, and increase permeability. This ultimately helps penetration of the sealer into the dentinal tubules. The use of sodium thiosulfate after sodium hypochlorite irrigation results in better penetration of the siler resin into the dentinal tubules than the use of saline after sodium hypochlorite irrigation, thereby helping to increase the adhesive strength of the root canal obturation material.[16]

The results of the ANOVA test showed that there was no significant effect in the application time of sodium thiosulphate on the strength of the push-out bond strength. The reason for this could be due to the amount of free radicals generated following sodium hypochlorite irrigation which were bound by sodium thiosulfate at 3 minutes of exposure, equivalent to a 5-minute exposure. This shows that within 2 minutes, the amount of free radicals neutralized by sodium thiosulfate is the same. The results of this study are in accordance with the results of the research of Philip et al. which showed that the duration of application of sodium thiosulfate for 3 minutes, 5 minutes, and 7 minutes had the same effect on the strength of the microtensil resin in dentin exposed to sodium hypochlorite.[15]

This research did not use the activation of irrigation solution and a higher temperature of irrigation solution. Increasing the temperature and ultrasonic activation of the irrigating solution can reduce the surface tension and increase the flowability of the irrigating solution on the dentin surface and dentinal tubules.[2,27] Further research could determine the effectiveness of sodium thiosulfate with the use of irrigation solution activation and a higher temperature of sodium thiosulfate solution.

Based on the results of the examination with a stereo microscope, the most frequent failures were type III failures (combination failure types). The combined failure type is a combination of adhesive failure between the resin sealer and the root canal dentine wall, and cohesive failure between the resin sealer. This finding might be due to the use of a single-cone obturation technique in this study, which was suitable for root canals without the use of gutta percha accessories and allowed for the use of thin epoxy resin sealers. When using epoxy resin sealers, most of the resin matrix will penetrate the dentinal tubules. As a result, the sealer layer on the surface of the root canal contains more filler material (filler particles) which has a larger diameter than the dentinal tubules. The thin and non-thick layer of resin sealer leaving only a small amount of resin matrix on the dentin surface of the root canal will result in a weak bond to the sealer and lead to failure in maintaining cohesion on the sealer resin.[28]

CONCLUSION

This study has shown that irrigation of sodium hypochlorite followed by irrigation of 10% sodium thiosulfate resulted in higher push-out bond strength values than irrigation with sodium hypochlorite followed by irrigation of 5% sodium thiosulfate. There was no effect of the application time of sodium thiosulfate irrigation on push-out bond strength values.

CONFLICT OF INTEREST

The authors declare no conflict of interest with the data contained in the manuscript.

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