Jordan Journal of Dentistry, Volume **2**, No. **3**, **2025**
DOI: https://doi.org/10.14525/JJD.v2i3.02

Jordan Journal of Dentistry

www.jjd.just.edu.jo

Efficacy of Different Solvents in Re-achieving Apical Patency After Obturation with a Calcium Silicate-based Root Canal Sealer

Aladdin A. Al-Qudah[1], Ziad J. Elmasry[1], Maram Jaradat[1], Layla Y. Hassoneh[1], Ahmad A. Jum'ah[1]

1 Department of Conservative Dentistry, Faculty of Dentistry, Jordan University of Science and Technology, Irbid, Jordan.

ARTICLE INFO

Article History:
Received: 3/12/2024
Accepted: 24/1/2025

Correspondence:
Aladdin Al-Qudah,
Department of Conservative Dentistry, Faculty of Dentistry, Jordan University of Science and Technology, Jordan.
E-mail: aqudah@just.edu.jo

ABSTRACT

Objectives: This study aims to evaluate the efficacy of different solvents in dissolving and retrieving a calcium silicate-based root canal sealer, BioRoot RCS (Septodont, Saint-Maur-des-Fossés, France).

Materials and Methods: 110 mandibular premolars were instrumented and obturated with BioRoot RCS and single cone gutta-percha (GP) placed to the working length (group WL) or 2 mm short of the WL (group WL-2mm). Retreatment of canals was performed using rotary instruments, hand files and one of the following solvents (n=10): chloroform, xylol, eucalyptol, orange oil, endosolv or no solvent (n=5) as a control group. The ability to re-achieve apical patency was evaluated. Next, 60 standardized stainless steel rings were used as molds for BioRoot RCS placement. The sealer molds were divided into 12 groups (n=5) and immersed in 10 ml of each solvent and distilled water as a control group, at 2 immersion periods (3 and 10 minutes). The percentage of sealer's weight loss pre- and post-immersion was calculated. Data were statistically analyzed with the chi-square, Fisher exact, Kruskal-Wallis on ranks, and Wilcoxon tests.

Results: No significant difference was found between all tested solvents and the control group in terms of re-achieving apical patency and the ability to dissolve BioRoot RCS ($p>0.05$).

Conclusions: Re-achieving apical patency after obturation with BioRoot RCS is not a predictable procedure and will mainly rely on the mechanical action of endodontic instruments.

Keywords: Calcium silicate-based sealers, Obturation, Organic solvents, Retreatment, Solubility.

1. Introduction

A high success rate of 97% has been reported for initial endodontic treatment (1); however, cases of post-treatment failure still occur (2). Persistent or secondary intra-radicular infections are the main reason for initial endodontic treatment failure (3,4). Non-surgical root canal retreatment (NSRCR) is considered the treatment of choice in the management of persistent endodontic disease (5). The aim of NSRCR is to remove root canal filling material and re-achieve access to the apical foramen, in order to facilitate cleaning and shaping of the root canal system (6).

One of the prognostic factors affecting the outcome of NSRCR is the achievement of patency at the canal terminus (7,8). The ability to achieve apical patency in NSRCR depends mainly on the retrievability of root canal filling material. Gutta-percha (GP) in conjunction with a root canal sealer form the most common used root canal filling materials (9,10). One of the properties of an ideal root canal sealer is that it should be easily removed from the root canal space if needed (11). Removal techniques involve mechanical instrumentation alone or

with the use of organic solvents (9).

Several types of solvents have been advocated for many years to soften GP and root canal sealers and assist in their removal, such as chloroform, xylol, eucalyptol, and orange oil (9,12). Chloroform has been found to be the most effective solvent for the removal of GP (13,14). However, it is a toxic solvent with limited evidence of carcinogenicity (15). If handled judiciously in NSRCR, chloroform is safe and of no particular risk to the dental team (16). On the other hand, the risk to patients should also be considered and further investigated.

Xylol/Xylene is a less toxic alternative to chloroform and has been investigated for GP removal (17). Some studies reported less efficiency of xylol compared to chloroform (18). However, others found that the application of xylol was more effective in dissolving different root canal sealers compared to chloroform, eucalyptol and orange oil (19).

Essential oils, such as orange oil and eucalyptus oil, are able to dissolve different types of endodontic sealers, and have been reported to be safe and useful for this purpose (20). Some studies found that eucalyptol is less effective compared to chloroform, xylene, Endosolv E, and orange oil (18). On the other hand, a study reported that its dissolving ability may increase if warmed (21).

The use of orange oil in dissolving GP and endodontic sealers has been recommended although its action was slower than that of chloroform (22).

Endosolv (Septodont, Saint- Maur, France) is recommended by the manufacturer for the removal of GP, zinc-oxide eugenol-based and phenolic resin-based root canal sealers from the root canal space. This solvent has been introduced by the company Septodont after the discontinuation of Endosolv E and Endosolv R.

In the last decade, various calcium silicate-based (CS) root canal sealers have been introduced as root canal sealing materials (10). CS sealers have excellent properties, such as antibacterial activity, biocompatibility, osteoconductivity, apical sealing ability as well as excellent physical properties (23-26). BioRoot RCS (Septodont, Saint-Maur-des-Fossés, France) is a CS root canal sealer based on tricalcium silicate materials. The powder contains tricalcium silicate, zirconium oxide as biocompatible radiopacifier and a hydrophilic biocompatible polymer for adhesion to tooth structure. The liquid contains mainly water, calcium chloride as a setting modifier and a water reducing agent. BioRoot RCS is a bioactive sealer that stimulates bone formation and mineralization of the dentinal structure, hence creating a favorable environment for periapical healing (27). It is considered to be a biocompatible material with excellent sealing properties (27,28).

However, the retrievability or removal of CS sealers from the root canal space during NSRCR is still questionable. There is limited information in the literature on the ability to re-achieve apical patency through CS sealers, especially when the obturation has a short GP and the CS sealers are solely filling the remaining apical part of the canal, which is a common clinical scenario in NSRCR cases. It has been reported that the removal of a CS sealer (EndoSequence CS, Brasseler USA, Savannah, GA), resulted in obstruction of the apical foramen and a loss of patency (29). Moreover, some studies reported that the solubility of some CS sealers in chloroform is lower than conventional sealers, such as resin-based sealers (30). Information about the solubility of CS sealers in organic solvents is limited.

Thus, the aims of the current *in-vitro* study were to evaluate the efficacy of different solvents in re-achieving apical patency after obturation with BioRoot RCS and GP in two different obturation levels, and to evaluate the solubility of BioRoot RCS in different solvents.

The null hypothesis was that there is no difference between different types of tested solvents in terms of re-achieving apical patency after obturation using BioRoot RCS and in solubilizing BioRoot RCS.

2. Materials and Methods

The study protocol included two phases; the first phase evaluated the ability to re-achieve apical patency in teeth obturated with BioRoot RCS and GP following the use of different solvents. The second phase evaluated the solubility of BioRoot RCS by measuring its weight loss after immersion in different solvents.

2.1 Re-achieving Apical Patency Test

2.1.1 Selection of Teeth, Sample Preparation and Experimental Groups

One hundred and ten sound human mature mandibular single-rooted premolars extracted as part of an orthodontic treatment plan were included in the current study. All included teeth had a single apical foramen and an apical root curvature less than 20

degrees. Digital radiographs were taken to verify that each tooth has one canal. The apical root canal curvature was measured by drawing a line on the radiographical image parallel to the long axis of the canal. A second line was drawn from the apical foramen to intersect with the first line at the point where the canal began to leave the long axis of the tooth, as shown in (Fig. 1A). The acute angle formed was measured by VixWin Pro ™ imaging software (Gendex Dental Systems, Des Plaines, IL, USA). Teeth were stored in distilled water until preparation and testing.

All included teeth were decoronated using a diamoned wheel saw to standardize the root length to 15mm. A #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted in the canal until it was visible at the apical foramen and the working length (WL) was determined by subtracting 1 mm from this measurement. The root canals were prepared using a combination of manual files and ProTaper Universal Rotary System (Dentsply Maillefer, Ballaigues, Switzerland) to size F3. Irrigation with 2 mL of a 5.25% sodium hypochlorite (NaOCl) solution was performed during mechanical preparation of the canals. Following mechanical preparation, 17% EDTA was applied for 1 min followed by 2 mL of 5.25% NaOCl. A 27-G side-vented needle was used for all irrigation procedures by inserting the needle tip 1mm shorter than the WL. The canals were dried with paper points and apical patency was reconfirmed before obturation by inserting #10 K-file 1mm beyond the WL.

All teeth were obturated using BioRoot RCS and a single GP master cone (#F3, Dentsply Maillefer, Ballaigues, Switzerland). The sealer was mixed according to the manufacturer's recommendations, a full leveled spoon of powder was mixed with 5 drops of liquid, then it was introduced into the canal with a #25 lentulo spiral (Dentsply Maillefer) to the WL until the sealer was extruded from the apical foramen (13).

Next, the specimens were divided into 2 groups (n=55 for each group). In the first group (WL), the master cone was inserted to the WL (Fig. 1B). In the second group (WL-2 mm), the master cone was trimmed by a surgical blade #15 to fit approximately 2 mm short of the WL to ensure that the apical 2 mm was filled with sealer only, to stimulate a "short obturation" and to evaluate the ability of re-achieving patency through BioRoot RCS (Fig. 1B). Following obturation, master cones were cut *via* heated plugger. The access cavities were temporarily sealed with Cavit (ESPE-Premier, Norristown, PA, USA), then the specimens were covered by wet gauze and placed in a container. The container was stored in an incubator (TS 606/2-I, WTW, Germany) (80-90% humidity and 37°C) for 2 weeks to allow sealers to set completely.

After the 2-week incubation period, both groups (WL and WL-2mm) were further sub-divided randomly into the following 5 sub-groups (n=10) based on the tested solvent used in retreatment: group I chloroform; group II xylol (Applichem, Germany); group III eucalyptol (Cerkamed, Poland); group IV orange oil (Dr.Schumacher, Germany); group V Endosolv (Septodont, Saint-Maur, France). Additionally, two control groups (WL and WL-2mm) with no solvent were included as control groups (n=5).

The temporary restorations were removed with a straight fissure carbide bur in a high-speed handpiece. ProTaper Universal Retreatment files D1 and D2 (Dentsply Maillefer, Ballaigues, Switzerland) were used sequentially to remove the coronal root canal filling material at 500 rpm and 4N.cm torque in a crown-down manner, leaving 3 mm of obturation material.

An attempt to re-achieve patency was initiated by placing 3 drops of the tested solvent in the root as far apically as possible delivered by a 27-G side-vented needle, followed by using a new #10 K-file (21mm length) (Dentsply Maillefer, Ballaigues, Switzerland) in a watch winding motion (13). Patency was defined as the visualization of the file from the anatomic apex, achieved by inserting the file 1mm beyond the WL. If patency could not be re-achieved within 3 minutes after placing the solvents, the patency test was terminated.

The ability to re-achieve apical patency was reported for each sample (achieved, or not achieved). All sample preparation, treatment, and evaluation were performed by a single operator to reduce inter-operator variability.

2.2. Solubility of BioRoot RCS Test

2.2.1 Sample Preparation

Sixty standardized stainless steel rings with a thickness of 1.65 mm ± 0.1 mm and an internal diameter of 6.2 mm ± 0.1 mm were fabricated at the engineering workshops of Jordan University of Science and Technology to be used as molds for BioRoot RCS placement. A small peripheral hole was drilled in each ring by a small round carbide high-speed bur. This hole was drilled to hang the rings in the glass test tubes using

stainless steel wires during the immersion process as described below (30,31).

The stainless steel molds were placed on wax sheets over a vibrator device, in which the freshly mixed sealer was injected into the mold using a 3-milliliter (ml) syringe filling the central hole of the ring with slight excess, to prevent air entrapment and void formation (Fig. 1C). All molds were covered by wet gauze and placed inside a container. The container was stored in an incubator (TS 606/2-I, WTW, Germany) for two weeks at 37°C and 80%-90% humidity, to allow the sealer to set completely. Any samples showing void formation were excluded and replaced with new void-free samples.

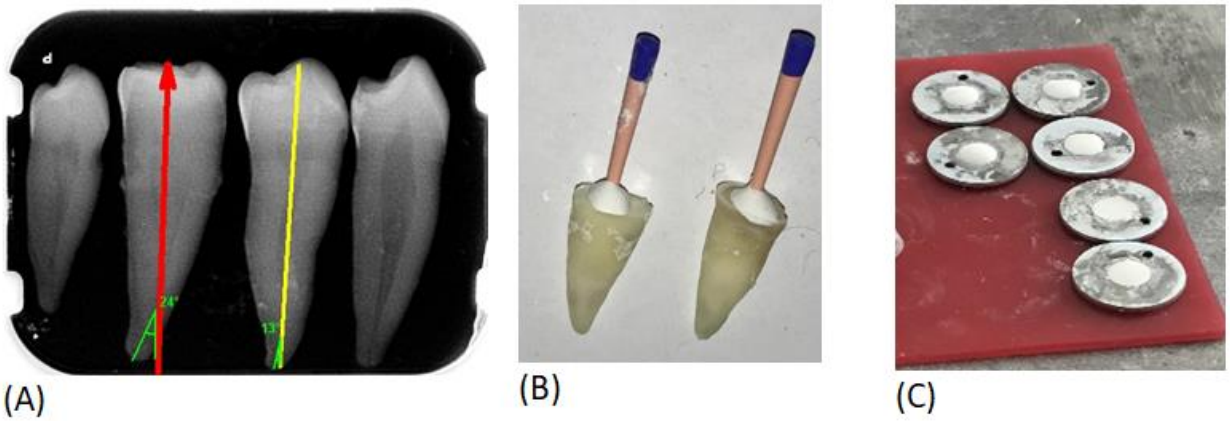

Figure 1: (A) A digital radiograph showing the measurement of root canal curvature angles of two teeth; (B) Decoronated teeth samples obturated with single master cone and Bio-Root RCS; (C) A representative image of filling the central hole of stainless steel molds with sealer using a 3-milliliter syringe with slight excess while turning on the vibrator

Two weeks later, the samples were taken out of the humidifier and excess sealer was trimmed to the level of the mold surface using a composite finishing disc (Finishing disc, Enhance® Finishing system). Next, the samples were randomly divided into 6 groups (n = 10), based on the tested solvent: group chloroform; group xylol (Applichem, Germany); group eucalyptol (Cerkamed, Poland); group orange oil (Dr.Schumacher, Germany); group Endosolv (Septodont, Saint- Maur, France) and group distilled water as a control group. Each group was further divided into two sub-groups (n = 5) based on the immersion period (3-minute and 10-minute immersion periods).

A baseline weight measurement (pre-immersion) for each sample was recorded using a digital scale (Kern type ABJ-NM/ ABS-N, Germany). This was carried out by measuring each sample 3 times and the average reading was recorded to obtain the initial mass. All weight measurements were recorded to three decimal places of a gram (g).

2.2.2 Solubility Testing

Each sample in the sub-groups was immersed in 10 ml of its solvent in a glass test tube for 3 minutes or 10 minutes in a static environment. The molds were hanged by inserting a stainless steel wire in the peripheral hole of the mold to allow its suspension in the solvent. After the specified immersion period, the samples were removed from the solvents and wiped with filter paper. Furthermore, the solvents were allowed to evaporate completely from the samples for 24 hours at 37°C in a dry oven (UL 30, Memmert GmbH, Germany).

A second weight measurement (g) was recorded for each sample (post-immersion) using the same manner as described above (3 times and the average reading was recorded). The percentage of weight loss was calculated to three decimal places based on the difference between pre- and post-immersion readings.

2.3 Statistical Analysis

The experimental data obtained from phases 1 and 2 was analyzed using SPSS, version 23.0 (SPSS, Inc., Chicago, IL). Chi-square test was performed to analyze the ability to re-achieve apical patency and the Fisher exact test was used for one-to-one comparison between sub-groups of each solvent. Regarding the solubility

testing results, the Shapiro-Wilk test indicated that data was not normally distributed. Kruskal-Wallis on ranks test was used for multiple-group comparisons. Wilcoxon test was applied for comparison between 3-minute and 10-minute immersion periods for each solvent. A significance level of $\alpha = 0.05$ was applied to all tests.

3. Results

3.1 Re-achieving Apical Patency

Percentages of samples (%) with re-established apical patency at different solvents and obturation lengths are shown in Table 1. In group WL, apical patency was re-achieved in 50% of the chloroform sub-group, followed by xylol, orange oil and Endosolve sub-groups in which 40% of specimens in each of these groups re-achieved apical patency. 20% of samples showed apical patency in eucalyptol and control sub-groups. No statistically significant difference was found between all sub-groups (P >0.05).

Table 1: Percentage of samples (%) with re-established apical patency at different solvents and obturation lengths (n=10).

Sub-groups	Percentage of samples with re-established patency (%)	
	Full WL	WL-2mm
Chloroform	50	80
Xylol	40	40
Eucalyptol	20	60
Orange oil	40	60
Endosolv	40	60
Control group	20	40

In group WL-2mm, apical patency was re-achieved in 80% of the chloroform sub-group, 60% of eucalyptol, orange oil and Endosolv sub-groups, and in 40% of xylol and the control sub-groups. No statistically significant difference was found among all sub-groups (P >0.05).

Similarly, for each tested solvent, there was no statistically significant difference between WL and WL-2mm sub-groups (P>0.05).

3.2 Solubility of BioRoot RCS

Mean and standard deviation (SD) for the percentage of weight loss of BioRoot RCS for each solvent sub-group at two different immersion periods are shown in Table 2.

In the control group, distilled water did not dissolve the sealer after three minutes of immersion, while in 10-minute immersion, it was dissolved only by 0.001%.

Overall, the percentage of weight loss for all sub-groups showed no statistically significant difference at both immersion periods (p>0.05) (Table 2).

For each tested solvent, the results revealed no significant increase in the percentage of sealer's weight loss with time (3 minutes and 10 minutes) (P>0.05).

Table 2: Mean percentage (%) with standard deviation (SD) of weight loss(gram) for Bio-Root RCS at different solvents and immersion periods (minutes) (n=5)

Sub-groups	Percentage of weight loss (g)			
	3 minutes		10 minutes	
	Mean (%)	SD	Mean (%)	SD
Chloroform	0.006	0.003	0.019	0.025
Xylol	0.005	0.008	0.008	0.017
Eucalyptol	0.002	0.002	0.006	0.002
Orange oil	0.002	0.002	0.005	0.002
Endosolv	0.004	0.004	0.007	0.007
Distilled water	0.000	0.000	0.001	0.002

4. Discussion

Despite the high success rate of initial root canal treatment, NSRCR has become a frequent procedure in modern dentistry (5). Complete removal of the potentially infected root canal filling material during NSRCR and re-achieving apical patency is essential for efficient disinfection of the root canal system (7, 8).

CS sealers, such as BioRoot RCS, are becoming widely used for the obturation of root canal treated teeth due to their superior properties (23-25). One of the concerns associated with the use of CS sealers is their retrievability in cases where NSRCR is indicated (30). This study investigated the efficacy of different solvents in re-achieving apical patency after obturation with BioRoot RCS and their efficiency in dissolving BioRoot RCS. The results of the current study revealed that no significant difference was found between all tested solvents and the control group in terms of re-achieving apical patency and the ability to dissolve BioRoot RCS, thus accepting the null hypothesis.

BioRoot RCS interacts chemically with the dentine along the root canal wall through an intra-tubular diffusion of the calcium silicate minerals in a mineral infiltration zone (32). The bioactivity of this sealer leads to the deposition of apatite crystals in a mineral infiltration zone (32). The bonding of BioRoot RCS is postulated to be micro-mechanical in nature similar to resin sealer tags, as demonstrated in a confocal microscopy study (33). This biomineralization activity as well as its hardness upon setting (34), may impede the complete removal of this sealer from the root canal during NSRCR.

To the best of the authors' knowledge, this is the first study to investigate the efficacy of different solvents in dissolving or retreating cases of BioRoot RCS at different obturation levels. In the first phase of the study, the ability to re-achieve apical patency for two groups (WL and WL-2mm) was tested using a standardized method adopted from previous studies (13,29). The root canal anatomy varies greatly, especially in the diameter of apical third (35). Only mature roots with an apical curvature less than 20 degrees were included in this study in an attempt to standardize the apical third anatomy in terms of diameter and straightness (29). The WL group was filled to the WL, while the WL-2mm group was filled 2 mm short of the WL to mimic a short obturation, which is a frequently met clinical situation during NSRCR (36). This patency study model (WL-2mm group) allowed for testing whether the sealer can be penetrated using a combination of solvents and files in cases where the apical part of the canal is filled solely with the BioRoot RCS material.

The current study showed no difference in achieving patency between all tested solvents and the control group. In the WL group, apical patency was re-achieved in 20%-50% of the samples, while in the WL-2mm group, it was slightly higher to 40%-80%. However, the differences were statistically insignificant. The results indicate that obturation with single GP cone and BioRoot RCS may result in the blockage of the apical foramen and a loss of apical patency at both obturation levels. A study reported that remaining BC sealers were detected in the apical foramen using scanning electron microscopy, preventing the re-achievement of the apical patency during retreatment (29). Moreover, a recent micro-computed tomography study reported that the percentage of CS material (EndoSequence BC) removed in the apical third during retreatment was around 70% (11). These findings may provide a rationale for the current results.

Some previous studies reported that chloroform was significantly more efficient in re-achieving apical patency when compared to other solvents (13, 14). A study found that chloroform was able to re-achieve apical patency in 100% of cases obturated using MTA Fillapex® (Angelus, Londrina, PR, Brazil) in both groups (WL & WL-2mm) (13). Similarly another study re-achieved apical patency in all cases obturated to the WL using EndoSequence BC Sealer with the aid of chloroform (14). In the current study, chloroform did not show significant superior results for BioRoot RCS and was comparable to the control group (no solvent).

A study evaluated the efficiency of Endosolv E and Endosolv R (precursors of Endosolv), in re-achieving apical patency for cases obturated using MTA Fillapex®. Endosolv E showed efficiency in 100% of cases, while Endosolv R reported lower efficiency ranging from 10% to 50% of the cases. Their results also showed higher efficiency of eucalyptol in comparison to the current study (80%-90%, 20%-60%, respectively) (13).

On the other hand, some studies reported that patency can be re-achieved in 80%-100% of the cases obturated using CS sealer to the full WL (EndoSequence BC) without the aid of any solvent (29, 37). However, when testing samples obturated 2mm shorter than WL,

patency was re-achieved only in 30% of the cases (29). This indicates that penetrating through the CS sealer could be more challenging if the apical area is only filled with the sealer material (13,14,29). However, this did not apply for BioRoot RCS, as both groups in the current study (WL and WL-2mm) showed statistically comparable results. Interestingly, a recent study testing samples obturated 2mm short of the WL reported that the retrievability of three calcium silicate–based sealers decreased when solutions were used compared with no solution (36).

Such differences between the current results and previous studies could be attributed to the difference in the experimental protocols, solvents, immersion periods, the type and properties of CS sealers tested. A micro–computed tomographic study showed that BioRoot RCS exhibited a significantly higher percentage of voids than AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany) when the cold lateral condensation technique was employed (33). The presence of voids could be attributed to the properties of BioRoot RCS, as it has a shorter working time and less flow compared to AH Plus (38). Manual mixing of the sealer and difficulty in manipulating standardized amounts of powder and liquid (especially liquid drops) may also contribute to void formation. Presence of voids could affect the ability to penetrate through the material during retreatment.

On the other hand, a study evaluating the amount of remaining sealer in the dentinal tubules following retreatment by confocal laser scanning microscopy showed that the highest penetration depth was measured in BioRoot RCS compared to MTA-Fillapex, and AH26 (Dentsply DeTrey GmbH, Konstanz, Germany) (39). This could make complete removal of the remaining material during NSRCR more challenging. This indicates that thorough investigations of various types of CS sealers are crucial, due to differences in their properties and behaviors.

In the second phase of the study, a standardized protocol was followed to evaluate the solubility of BioRoot RCS in solvents (30, 31). BioRoot RCS was filled in standardized molds in a way that prevented void formation, as described in the "methods" section. The soaked molds were wiped with filter paper following their immersion in different solvents, in an attempt to prevent adherence of sealer and solvent residues to the mold surface. Next, they were placed in an oven for 24 hours at 37°C to ensure complete evaporation of solvents and dryness of the mold surfaces, since the organic solvents are volatile. These steps maximized the accuracy of weight measurement by eliminating extra weight from potentially adhered solvents to the molds.

The current study tested two immersion periods, 3 minutes and 10 minutes. There are no established clinical standards for evaluating the root canal sealer solubility in organic solvents. Previous similar *in-vitro* studies adopted various immersion periods ranging from 30 seconds to 20-minute (19, 30, 31). The 3-minute immersion period applied in the current study is clinically relevant, and supports the validation of the results obtained from phase 1, Furthermore, the 10-minute immersion period was applied to assess the effect of extended exposure time on the dissolution of BioRoot RCS.

The current study showed no significant difference in the weight loss percentage of BioRoot RCS after immersion in different solvents and the control group for both tested periods (3 minutes and 10 minutes). Similarly, no significant differences were found between 3- and 10-minute immersion periods for all tested solvents. In contrast, several previous investigations reported a significant increase in the solubility of CS sealers with longer immersion periods (19, 30, 31, 40). A study reported that chloroform showed a significantly higher dissolving effect compared to eucalyptol in dissolving MTA Fillapex® at different immersion periods (30). Another study reported a higher dissolving ability of Endosolv E compared to eucalyptol, but lower than chloroform for MTA Fillapex®. The differences in results between different studies could be attributed to the different types of CS sealers tested, as well as the different immersion solutions and periods.

In the control group, distilled water did not dissolve BioRoot RCS in the 3-minute group, while it dissolved the minimum insignificant percentage of sealer in the 10-minute group. Similarly, a previous study reported no weight loss of MTA Fillapex® after 10 minutes of immersion in distilled water (30).

This *in-vitro* study presented several limitations. Some clinically relevant parameters, such as the effect of body temperature on solvents, and the dilution or interaction of solvents with biological fluids, could not be tested due to *in-vitro* conditions. The possibility of chemical interaction of the sealer with the solvents

tested in the current study is not clearly understood. If reactions occur, the solubility testing might not provide sufficiently accurate results. Future studies analyzing the amount of sealer leached into the tested solutions could offer further insights into its solubility characteristics. Moreover, the comparison with different types of CS sealers and the use of different NSRCR methods was not conducted and could add more data to the current results. Hence, the need for further investigations is recommended to impose sound clinical recommendations.

5. Conclusions

BioRoot RCS cannot be sufficiently dissolved in various solvents used for re-treatment even after an immersion period of 10 minutes. These findings support the results of the first phase of the study (re-achieving patency), and suggest that the action of the tested solvents on BioRoot RCS is insignificant and comparable to distilled water. This concludes that the retrievability of BioRoot RCS in NSRCR is not a predictable procedure and will mainly rely on the mechanical action of endodontic instruments.

Conflict of Interests

The authors have no conflict of interests related to this study.

Funding Information

This study was supported by Jordan University of Science & Technology (20180017).

References

1. Friedman S, Mor C. The success of endodontic therapy-healing and functionality. J Calif Dent Assoc. 2004;32:493-503.
2. Gomes BP, Francisco PA, Godoi EP Jr, Endo MS, Barbosa-Ribeiro M, et al. Identification of culturable and non-culturable micro-organisms, lipopolysaccharides, and lipoteichoic acids from root canals of teeth with endodontic failure. J Endod. 2021;47:1075-1086.
3. Siqueira JF Jr. Aetiology of root canal treatment failure: Why well-treated teeth can fail. Int Endod J. 2001;34:1-10.
4. Siqueira JF Jr, Rôças IN. Present status and future directions: Micro-biology of endodontic infections. Int Endod J. 2022;55:512-530.
5. Zhang MM, Fang GF, Chen XT, Liang YH. Four-year outcome of non-surgical root canal retreatment using cone-beam computed tomography: A prospective cohort study. J Endod. 2021;47:382-390.
6. Ruddle CJ. Non-surgical retreatment. J Endod. 2004;30:827-845.
7. Gulabivala K, Ng YL. Factors that affect the outcomes of root canal treatment and retreatment: A reframing of the principles. Int Endod J. 2023;56:82-115.
8. Ricucci D, Siqueira JF Jr. Fate of the tissue in lateral canals and apical ramifications in response to pathologic conditions and treatment procedures. J Endod. 2010;36:1-15.
9. Friedman S, Stabholz A, Tamse A. Endodontic retreatment: Case selection and technique. 3. Retreatment techniques. J Endod. 1990;16:543-549.
10. Komabayashi T, Colmenar D, Cvach N, Bhat A, Primus C, et al. Comprehensive review of current endodontic sealers. Dent Mater J. 2020;39:703-720.
11. Colmenar D, Tamula T, Zhu Q, Ahn C, Primus C, et al. Micro CT pilot evaluation of removability of two endodontic sealers. J Oral Sci. 2021;63:306-309.
12. Dotto L, Sarkis-Onofre R, Bacchi A, Pereira GKR. The use of solvents for gutta-percha dissolution/removal during endodontic retreatments: A scoping review. J Biomed Mater Res-Part B: Appl Biomater. 2021;109:890-901.
13. Carpenter MT, Sidow SJ, Lindsey KW, Chuang A, McPherson JC. Regaining apical patency after obturation with gutta-percha and a sealer containing mineral trioxide aggregate. J Endod. 2014;40:588-590.
14. Agrafioti A, Koursoumis AD, Kontakiotis EG. Re-establishing apical patency after obturation with gutta-percha and two novel calcium silicate-based sealers. Eur J Dent. 2015;9:457-461.
15. McDonald MN, Vire DE. Chloroform in the endodontic operatory. J Endod. 1992;18:301-303.
16. Chutich MJ, Kaminski EJ, Miller DA, Lautenschlager EP. Risk assessment of the toxicity of solvents of gutta-percha used in endodontic retreatment. J Endod. 1998;24:213-216.
17. Yadav HK, Yadav RK, Chandra A, Thakkar RR. The effectiveness of eucalyptus oil, orange oil, and xylene in dissolving different endodontic sealers. J Conserv Dent. 2016;19:332-337.
18. Wennberg A, Orstavik D. Evaluation of alternatives to

chloroform in endodontic practice. Endod Dent Traumatol. 1989;5:234-237.
19. Martos J, Bassotto AP, González-Rodríguez MP, Ferrer-Luque CM. Dissolving efficacy of eucalyptus oil, orange oil, xylol and chloroform solvents on different root canal sealers. Int Endod J. 2011;44:1024-1028.
20. Hansen MG. Relative efficiency of solvents used in endodontics. J Endod. 1998;24:38-40.
21. Wourms DJ, Campbell AD, Hicks ML, Pelleu GB Jr. Alternative solvents to chloroform for gutta-percha removal. J Endod. 1990;16:224-226.
22. Ring J, Murray PE, Namerow KN, Moldauer BI, Garcia-Godoy F. Removing root canal obturation materials: A comparison of rotary file systems and re-treatment agents. J Am Dent Assoc. 2009;140:680-688.
23. Kwak SW, Koo J, Song M, Jang IH, Gambarini G, et al. Physico-ochemical properties and bio-compatibility of various bio-ceramic root canal sealers: An *in vitro* study. J Endod. 2023;49:871-879.
24. Camps J, Jeanneau C, El Ayachi I, Laurent P, About I. Bioactivity of a calcium silicate-based endodontic cement (bio-root rcs): Interactions with human periodontal ligament cells *in vitro*. J Endod. 2015;41:1469-1473.
25. Torabinejad M, Parirokh M. Mineral trioxide aggregate: A comprehensive literature review-Part II: Leakage and bio-compatibility investigations. J Endod. 2010;36:190-202.
26. ElReash AA, Hamama H, Eldars W, Lingwei G, Zaen El-Din AM, et al. Anti-microbial activity and pH measurement of calcium silicate cements *versus* new bio-active resin composite restorative material. BMC Oral Health. 2019;19:1-10.
27. Jun N-R, Lee S-K, Lee S-I. Bio-compatibility and bio-activity of four different root canal sealers in osteoblastic cell line MC3T3-El. J Dent Hyg Sci. 2021;21:243-250.
28. Haji TH, Selivany BJ, Suliman AA. Sealing ability *in vitro* study and bio-compatibility *in vivo* animal study of different bio-ceramic based sealers. Clin Exp Dent Res. 2022;8:1582-1590.
29. Hess D, Solomon E, Spears R, He J. Retreatability of a bio-ceramic root canal sealing material. J Endod. 2011;37:1547-1549.
30. Alzraikat H, Taha NA, Hassouneh L. Dissolution of a mineral trioxide aggregate sealer in endodontic solvents compared to conventional sealers. Braz Oral Res. 2016;30:e 16.
31. Schäfer E, Zandbiglari T.A comparison of the effectiveness of chloroform and eucalyptus oil in dissolving root canal sealers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002;93:611-616.
32. Camilleri J. Will bio-ceramics be the future root canal filling materials? Curr Oral Health Rep. 2017;4:228-238.
33. Viapiana R, Moinzadeh AT, Camilleri L, Wesselink PR, Tanomaru Filho M, et al. Porosity and sealing ability of root fillings with gutta-percha and Bio-Root RCS or AH Plus sealers; Evaluation by three *ex vivo* methods. Int Endod J. 2016;49:774-782.
34. Xuereb M, Vella P, Damidot D, Sammut CV, Camilleri J. *In situ* assessment of the setting of tricalcium silicate-based sealers using a dentin pressure model. J Endod. 2015;41:111-124.
35. Vertucci FJ. Root canal morphology of mandibular premolars. J Am Dent Assoc. 1978;97:47-50.
36. Carrillo CA, Kirkpatrick T, Freeman K, Makins SR, Aldabbagh M, et al. Retrievability of calcium silicate-based root canal sealers during retreatment: An ex vivo study. J Endod. 2022;48:781-786.
37. Kim H, Kim E, Lee SJ, Shin SJ. Comparisons of the retreatment efficacy of calcium silicate and epoxy resin-based sealers and residual sealer in dentinal tubules. J Endod. 2015;41:2025-2030.
38. Camilleri J. Sealers and warm gutta-percha obturation techniques. J Endod. 2015;41:72-78.
39. Uzunoglu-Özyürek E, Askerbeyli-Örs S, Türker SA. Evaluation of the amount of remained sealer in the dentinal tubules following re-treatment with and without solvent. J Conserv Dent. 2020;23:407-411.
40. Whitworth JM, Boursin EM. Dissolution of root canal sealer cements in volatile solvents. Int Endod J. 2000;33:19-24.