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A laboratory study to assess the physico-chemical properties of BioRoot RCS and BioRoot Flow exposed to citric acid and EDTA irrigating solutions

Goda Bilvinaitė^{1*}, Saulius Drukteinis², Simas Šakirzanovas¹, Paul MH Dummer³

¹ Department of Applied Chemistry, Faculty of Chemistry and Geoscience, Vilnius University, Vilnius, Lithuania

² Institute of Dentistry, Faculty of Medicine, Vilnius University, Vilnius, Lithuania

³ School of Dentistry, College of Biomedical and Life Sciences, Cardiff University, Cardiff, UK

* Corresponding author: goda.bilvinaite@gmail.com; Naugarduko 24, LT-3225, Vilnius, Lithuania; +370-602-93389

ABSTRACT

Objective

To assess physico-chemical properties of BioRoot RCS (powder-to-liquid formulation) and BioRoot Flow (pre-mixed formulation) after exposure to citric acid (CA) and EDTA.

Methods

BioRoot RCS and BioRoot Flow specimens (5 x 2 mm) were incubated for 28 days at 37°C before being treated with test solution (distilled water, 17% EDTA, 10% CA, 20% CA or 40% CA). Changes in mass, ion release (inductively coupled plasma optical emission spectroscopy), phase composition (X-ray diffraction and Raman spectroscopy), surface morphology (scanning electron microscopy and energy dispersive spectroscopy) were evaluated. The Shapiro–Wilk, Levene and one-way ANOVA, followed by Tukey’s test, were used for statistical analysis ($p < 0.05$).

Results

The greatest mass loss, ion release and surface morphological changes (pores and cracks) of BioRoot RCS and BioRoot Flow occurred in 10% and 20% CA. No significant differences were identified between BioRoot RCS and BioRoot Flow in distilled water and EDTA ($p > 0.05$), whereas BioRoot Flow was significantly more soluble than BioRoot RCS in all CA solutions ($p < 0.001$). The main phase identified for both materials was zirconium oxide, which remained unaffected by the solutions.

Conclusions

Within the limitations of the study, 10% and 20% CA were more effective than distilled water, 17% EDTA and 40% CA in terms of dissolving BioRoot RCS and BioRoot Flow. The BioRoot Flow was significantly more soluble in all CA solutions than BioRoot RCS.

Clinical significance

10% and 20% CA solutions may have a potential to be used as a solvent for hydraulic calcium silicate sealers during endodontic retreatment.

Keywords: calcium silicate; citric acid; EDTA; retreatment; sealer; solvent

Introduction

Hydraulic calcium silicates (HCS) are well-established clinical materials for a wide range of endodontic procedures. HCS sealers have gained popularity as root canal filling materials because of their advantageous physical, chemical and biological properties [1]. Clinical studies confirm that root canal treatment, based on proper root canal cleaning, shaping and subsequently filling with HCS sealer and gutta-percha, is a safe and predictable treatment procedure with high clinical success rates [2]. However, none of the existing root canal treatment protocols can guarantee success, with the result that post-treatment endodontic disease may persist or emerge.

Root canal retreatment is the first option for a root filled tooth with persistent or secondary endodontic infections [3]. Reduction of the microbial load within canals below a critical threshold, which can be

subsequently controlled by the immune system, is generally assumed to be the primary goal of root canal retreatment and may be effectively achieved only by the removal of previous filling materials [3,4]. However, it has been reported that even when using state-of-the-art instruments and devices, the complete removal of HCS materials from root canal system is challenging as a consequence of their hardness and ability to gradually form precipitates, which fill the empty spaces and reduce the overall porosity of the root canal filling [5-7]. The concept of using HCS sealers in conjunction with gutta-percha cones is commonly assumed to facilitate the retreatability of these root canal fillings, as gutta-percha can be relatively easily removed mechanically alone or in combination with organic solvents, such as chloroform, eucalyptol or orange oil [8,9]. Nevertheless, when a master gutta-percha cone does not reach the full working length or HCS material is intentionally used as an apical plug, it is likely that the apical extent of the root canal is filled with HCS sealers alone.

HCS materials placed apically are considered to be impenetrable by hand or rotary instruments and thus may prevent the achievement of apical patency and the reestablishment of the working length, which are prerequisite for effective root canal disinfection [3]. Attempts to remove the remaining cement by flexible ultrasonic files, particularly beyond the curvature of the root canal, may also lead to the excessive removal of sound dentine and even create complications, such as canal transportation, ledging or perforation, which have a negative impact on the long-term prognosis and survival of the affected tooth [3,6]. Therefore, a solvent, which could modify the structure of HCS sealers in a way that facilitates their removal from root canals with minimal or no detrimental effect on the structure and physical properties of dentine, would be highly desirable in root canal retreatments.

Preliminary studies have demonstrated that citric acid (CA) irrigating solution, a strong organic chelating agent commonly used for smear layer or calcium hydroxide removal [10,11], is more effective than ethylenediamine-tetraacetic acid (EDTA) in terms of dissolving HCS materials and may have a potential to be used as a solvent [12]. Moreover, it is apparent that the efficacy of CA solution may depend on the formulation of HCS sealers, with pre-mixed materials having a significantly lower acid resistance. However, the chemical composition and synthesis methods, which differ among manufacturers [13,14], can be a more decisive factor for solubility rates than the actual sealer formulation itself. Therefore, manufacturing variables make it difficult to precisely evaluate the impact of sealer formulation on physico-chemical properties.

BioRoot RCS was introduced to the market by Septodont (Saint-Maur-des-Fosses, France) in 2015. This powder-to-liquid root canal sealer is a well-known and widely investigated material, which has antibacterial properties and promotes the deposition of hard tissues and periapical healing [15]. The published clinical studies demonstrate that BioRoot RCS ensures high healing rates even in teeth with apical periodontitis [2,16]. However, BioRoot RCS is a HCS sealer that is recommended for use only with cold lateral compaction or single-cone filling techniques, as heat can negatively affect its thickness and flowability [17]. Recently, Septodont introduced BioRoot Flow sealer as a pre-mixed formulation of BioRoot RCS. According to the manufacturer, BioRoot Flow possesses all the desirable physico-chemical properties of BioRoot RCS and is highly biocompatible, bioactive and immunomodulatory [15,17]. Due to its lower viscosity and non-water-based vehicle, the material can be used with cold and warm filling techniques, just like many other premixed HCS sealers [17].

Since these two materials have a similar chemical composition and are manufactured using the same primary raw materials and patented Active Biosilicate Technology [13], the present study aimed to assess changes in the physico-chemical properties of BioRoot RCS (powder-to-liquid formulation) and BioRoot Flow (pre-mixed formulation) after exposure to CA and EDTA irrigating solutions. The null hypothesis tested was that BioRoot Flow and BioRoot RCS reacted in a similar manner when exposed to CA and EDTA.

Materials and Methods

The manuscript of this laboratory study complies with the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines [18]. The research process and the main findings are showed in the PRILE flowchart (Fig. 1). The sample size was calculated by using G*Power v.3.1 software (Heinrich, Heine, Dusseldorf, Germany) with α error probability of 0.05 and power (1- β error probability) of 80%. An effect size of 0.7 was estimated based on previous study [12]. A minimum size of 8 samples per group was determined.

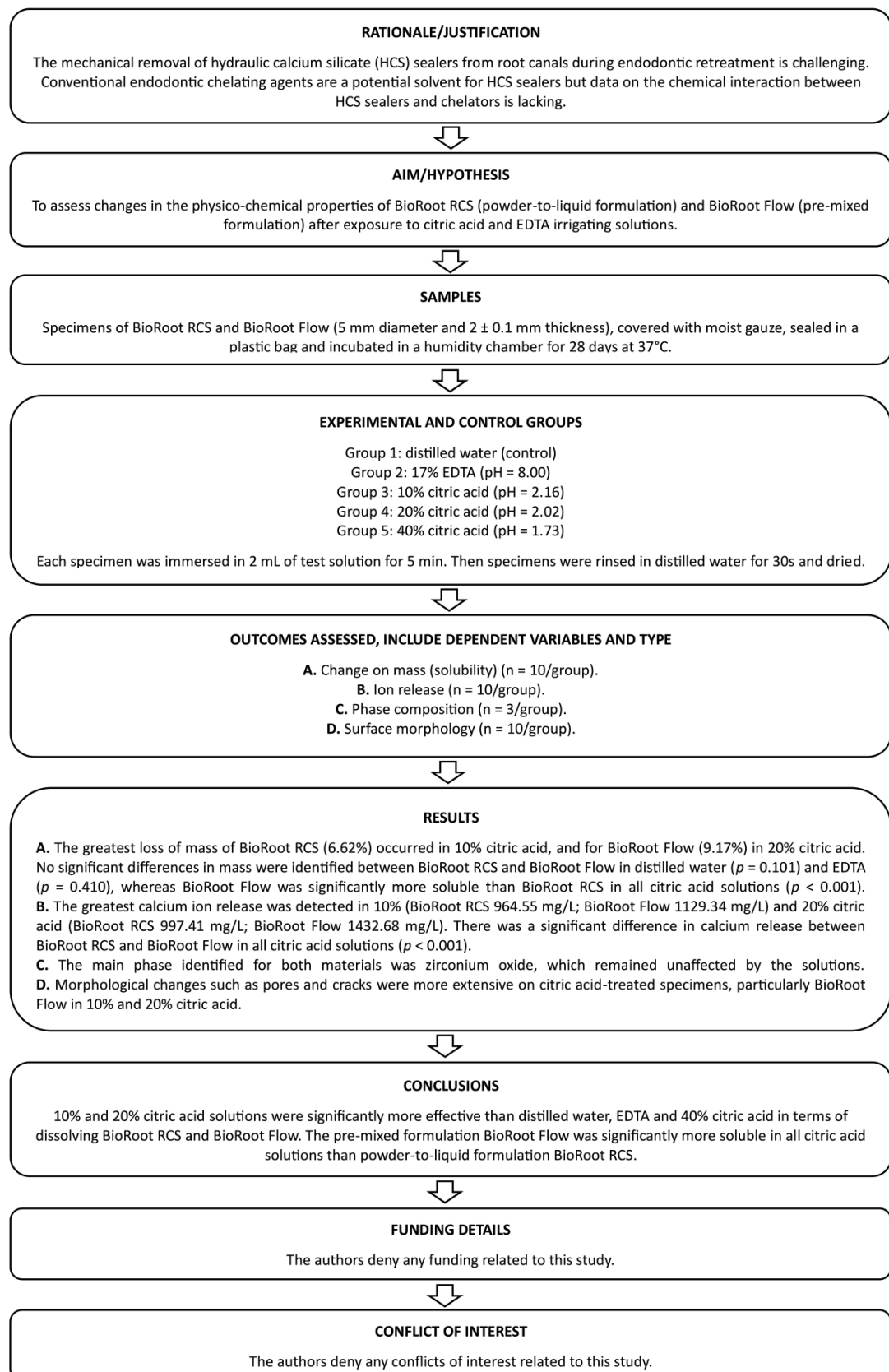


Fig. 1 PRILE flowchart.

Specimen preparation

BioRoot RCS and BioRoot Flow specimens (5 mm diameter and 2 ± 0.1 mm thickness) were prepared using cylindrical plastic moulds. A previously published methodology was followed to incubate the specimens [19]. Briefly, the filled moulds were covered with a gauze soaked in Hank's balanced salt solution (HBSS) without calcium and magnesium (Thermo Fisher Scientific, Waltham, MA, USA), sealed in a plastic bag and incubated in a humidity chamber at 37°C for 28 days (the setting time declared by the manufacturer for BioRoot RCS is < 4 h and for BioRoot Flow < 8 h). The moist gauze was replaced weekly. After 28 days, fully set specimens were polished under continuous flow of water using Sof-Lex fine (3 – 9 μm) polishing discs (3M ESPE, Seefeld, Germany), removed from the moulds, rinsed in distilled water for 30 s, dried from visible moisture with absorbent paper and incubated for 24 h at 37°C and 5% CO_2 to evaporate the liquid before further analysis. Specimens were then radiographed using a Kodak RVG 5100 digital sensor (Kodak Co., Rochester, NY, USA) and exposure parameters of 65 kV, 7 mA and 0.2 s. Specimens with radiographic signs of pores or cracks were discarded and replaced. The thickness of specimens was checked with a digital caliper (Mitutoyo MTI Corp, Tokyo, Japan).

Change on mass

The prepared specimens were weighed to an accuracy of 0.0001 g (the mass recorded as M_0) and then randomly allocated into five groups ($n = 10/\text{group}$): distilled water (control group), 17% EDTA (pH = 8.00; Cerkamed, Stalowa Wola, Poland), 10% CA (pH = 2.16), 20% CA (pH = 2.02) and 40% CA (pH = 1.73; Cerkamed, Stalowa Wola, Poland). The 10% and 20% CA irrigating solutions were prepared by diluting 40% CA with distilled water. Each specimen was immersed in 2 mL of test solution for 5 min. Then specimens were rinsed in distilled water for 30 s, dried from visible moisture with absorbent paper and incubated for 24 h at 37°C and 5% CO_2 before weighting (the mass recorded as M_1). The percentage difference between the final M_1 and the initial M_0 mass was used as a measure of solubility.

Ion release

Solutions collected when measuring the change in mass were subjected to elemental analysis of calcium, silicon and zirconium using an inductively coupled plasma optical emission spectrometer Perkin Elmer Optima 7000DV (Waltham, MA, USA) with the detection limit of 0.01 ppm. Calibration solutions were prepared by diluting stock standard solutions (Single-Element ICP Standards 1000 mg/L, Carl Roth, Karlsruhe, Germany).

Phase composition

Phase identification was performed by recording X-ray diffraction (XRD) and Raman spectra. For XRD analysis, intact new specimens were ground to a fine powder using a mortar and pestle. A total of 0.4 g powder was exposed to a fresh 2 mL of distilled water, EDTA or CA for 5 min. The test solution was then filtrated and the powder obtained was dried in the incubator for 2 h at 65 °C and 5% CO_2 . The re-grounded powder was placed on the sample holder, and XRD patterns were recorded with Rigaku MiniFlex II diffractometer (Rigaku, Tokyo, Japan) using a $\text{CuK}\alpha$ radiation ($\lambda = 1.5418 \text{ \AA}$) in the 2θ range of $10^\circ - 80^\circ$ with a 0.01° step and scanning rate of $7.0^\circ/\text{min}$.

Raman spectra were recorded using inVia Raman microscope (Renishaw, Wotton-under Edge, UK) equipped with a thermoelectrically cooled (-70°C) CCD camera. The new specimens in tablet form were immersed in fresh 2 mL of each test solution for 5 min ($n = 3/\text{group}$), rinsed in distilled water for 30 s, dried from visible

moisture with absorbent paper and incubated for 2 h at 65°C and 5% CO₂. Raman spectra was measured at 5 different positions on the specimen surface using 532 nm (1800 lines/mm; 2.4 mW) laser excitation and 2 s acquisition time with 40 average accumulations.

Surface characterization

Surface characterization was performed using a scanning electron microscope (SEM) Hitachi TM3000 (Hitachi, Tokyo, Japan) equipped with an energy-dispersive X-ray (EDX) spectrometer. The specimens used in the mass change study were attached to an aluminum stub and examined at ×500 magnification with an accelerating voltage of 15kV. The criteria for assessing the specimens included the visual presence or absence of visible superficial defects, such as pores (pits in the surface), cracks (surface micro-fractures without a complete separation) and fractures (complete specimen separation into two or more pieces). The analysis was performed by a single operator blinded to the experimental groups.

Statistical analysis

Statistical analysis was performed using RStudio v.4.1.1 software (RStudio Inc., Boston, MA, USA). The assumption of normality and homogeneity of variance were confirmed with the Shapiro–Wilk and Levene’s tests, respectively. One-way analysis of variance, followed by Tukey’s test, was used to detect significant differences between groups. The significance level was set at 95%.

Results

Change in mass

All CA irrigating solutions dissolved the HCS sealers more effectively compared to EDTA and distilled water (Table 1). The greatest loss of mass of BioRoot RCS (6.62%) occurred in 10% CA, and for BioRoot Flow (9.17%) in 20% CA. However, the efficacy of 10% and 20% CA solutions was similar for each material ($p = 0.382$ between BioRoot RCS values and $p = 0.249$ between BioRoot Flow values). No significant differences in mass were identified between BioRoot RCS and BioRoot Flow values in distilled water ($p = 0.101$) and EDTA ($p = 0.410$), whereas BioRoot Flow lost significantly more weight in all concentrations of CA than BioRoot RCS ($p < 0.001$).

Table 1. Composition of BioRoot RCS and BioRoot Flow declared by the manufacturer, and mass changes of both sealers after exposure to distilled water, EDTA and citric acid solutions.

Material	Composition declared by the manufacturer	Mean percentage of mass loss ± standard deviation (min – max range)				
		Distilled water	17% EDTA	10% citric acid	20% citric acid	40% citric acid
BioRoot RCS	Powder: tri-calcium silicate, zirconium oxide, povidone. Liquid: water, calcium chloride, polycarboxylate.	2.06 ± 0.11 ^A (1.92 – 2.25)	3.29 ± 0.11 ^B (3.09 – 3.39)	6.62 ± 0.47 ^C (6.09 – 7.28)	6.41 ± 0.32 ^C (6.04 – 6.84)	4.68 ± 0.40 (4.24 – 5.17)
BioRoot Flow	Tri-calcium silicate, propylene glycol, povidone, calcium carbonate, Aerosil, zirconium	2.21 ± 0.17 ^A (2.06 – 2.51)	3.15 ± 0.38 ^B (2.69 – 3.77)	8.84 ± 0.44 ^D (8.25 – 9.56)	9.17 ± 0.51 ^D (8.42 – 9.88)	6.46 ± 0.38 (6.02 – 6.90)

	oxide, acrylamide / sodium acryloyldimethyltaurate copolymer, isohexadecane, polysorbate.					
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Values with the same superscript letter were not significantly different ($p > 0.05$).

Ion release

Both sealers released a significantly greater concentration of calcium ions in 10% and 20% CA compared to other irrigating solutions ($p < 0.001$; Table 2). The concentration of calcium and silicon ions released by BioRoot RCS in 10% and 20% CA was similar (Ca: $p = 0.778$; Si: $p = 0.834$), whereas BioRoot Flow demonstrated significantly greater release of calcium ions in 20% CA than 10% CA ($p < 0.001$). The amount of leached zirconium was negligible, with no detection in distilled water. Similar to the results of change in mass, no significant differences were detected between the materials in distilled water (Ca: $p = 0.317$; Si: $p = 0.058$) and EDTA (Ca: $p = 0.907$; Si: $p = 0.719$; Zr: $p = 0.576$), whereas in all CA irrigating solutions BioRoot Flow released significantly more calcium ions than BioRoot RCS ($p < 0.001$).

Table 2. Mean concentration (mg/L) $\pm$ standard deviation and min – max range of calcium, silicon and zirconium ions, leached from BioRoot RCS and BioRoot Flow during the exposure to distilled water, EDTA and citric acid solutions.

Material	Element	Distilled water	17% EDTA	10% citric acid	20% citric acid	40% citric acid
BioRoot RCS	Ca	48.56 $\pm$ 15.11 (36.99 – 65.65)	316.90 $\pm$ 62.90 (258.21 – 383.30)	964.55 $\pm$ 21.16 (943.71 – 993.62)	997.41 $\pm$ 122.31 (856.22 – 1071.00)	552.27 $\pm$ 31.73 (530.08 – 588.65)
	Si	6.32 $\pm$ 0.30 (6.04 – 6.63)	21.77 $\pm$ 3.43 (18.17 – 25.01)	105.11 $\pm$ 11.40 (92.09 – 113.33)	102.85 $\pm$ 13.16 (94.25 – 118.01)	40.73 $\pm$ 4.00 (36.24 – 43.92)
	Zr	not detected	0.01 $\pm$ 0.01 (0.01 – 0.02)	0.06 $\pm$ 0.02 (0.03 – 0.08)	0.06 $\pm$ 0.02 (0.03 – 0.09)	0.04 $\pm$ 0.01 (0.03 – 0.04)
BioRoot Flow	Ca	38.23 $\pm$ 4.02 (35.35 – 42.82)	322.40 $\pm$ 43.98 (287.20 – 371.71)	1129.34 $\pm$ 33.94 (1099.02 – 1166.01)	1432.68 $\pm$ 45.76 (1380.98 – 1468.01)	852.3 $\pm$ 85.47 (770.64 – 941.13)
	Si	7.16 $\pm$ 0.46 (6.64 – 7.53)	20.97 $\pm$ 0.92 (20.05 – 21.89)	107.43 $\pm$ 21.53 (82.88 – 123.11)	105.21 $\pm$ 24.43 (78.22 – 125.84)	76.38 $\pm$ 6.07 (70.53 – 82.65)
	Zr	not detected	0.01 $\pm$ 0.01 (0.00 – 0.02)	0.07 $\pm$ 0.02 (0.03 – 0.09)	0.08 $\pm$ 0.02 (0.04 – 0.10)	0.05 $\pm$ 0.01 (0.04 – 0.06)

Phase composition

The main phase identified for BioRoot RCS and BioRoot Flow was zirconium oxide, which demonstrated no changes after exposure to the test solutions. Additional peaks of calcium hydroxide and calcium carbonate, both associated with sealer hydration during setting [20], were observed for BioRoot RCS (Fig. 2) and BioRoot Flow (Fig. 3) in distilled water. However, the main BioRoot RCS peaks of calcium hydroxide (at 18.0°, 34.1° and 47.1° 2 θ in XRD) and calcium carbonate (at 280, 711 and 1084 cm⁻¹ in Raman spectra) disappeared or significantly reduced in intensity after exposure to EDTA and CA irrigating solutions. The same tendency was observed for BioRoot Flow peaks of calcium hydroxide (at 18.0° and 47.1° 2 θ in XRD) and calcium carbonate (at 29.4°, 39.5°, 43.2° and 47.6° 2 θ in XRD, and 1084 cm⁻¹ in Raman spectra).

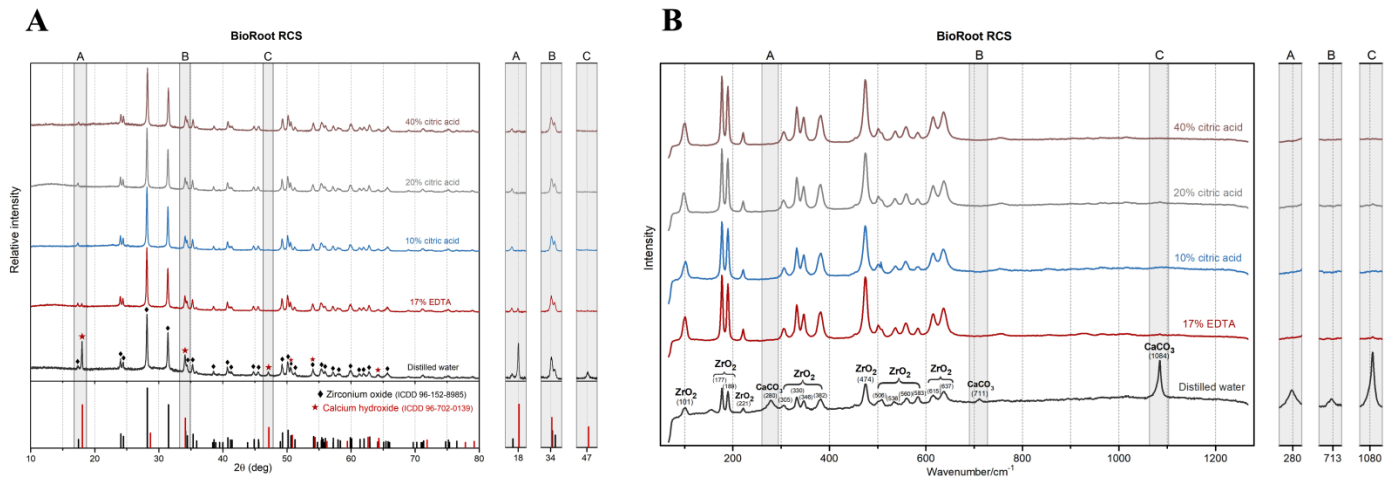


Fig. 2 XRD (A) and Raman (B) patterns demonstrating the main identified phases (zirconium oxide, calcium hydroxide and calcium carbonate) of BioRoot RCS. Peaks of calcium hydroxide and calcium carbonate, which disappeared or significantly reduced in intensity after the exposure to EDTA and citric acid solutions, are marked in a grey box.

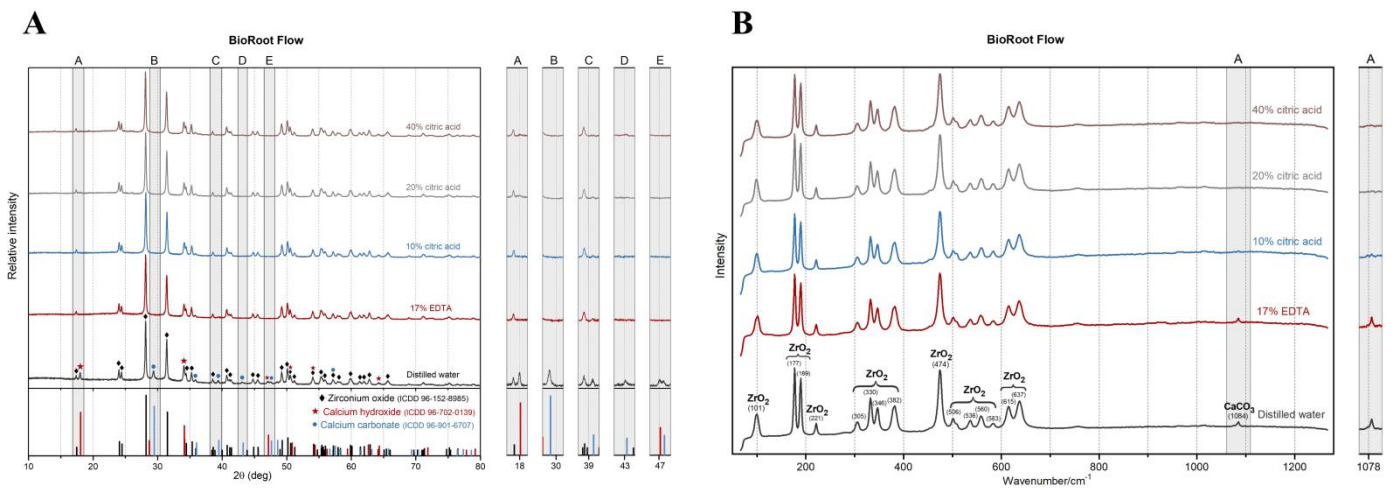


Fig. 3 XRD (A) and Raman (B) patterns of BioRoot Flow, demonstrating the identified phases of zirconium oxide, calcium hydroxide and calcium carbonate. Peaks of calcium hydroxide and calcium carbonate that were affected by EDTA and citric acid solutions are marked in a grey box.

Surface characterization

The SEM analysis revealed that the HCS sealers lacked acid resistance, as morphological changes associated with pores and crack formation were present on all specimens exposed to EDTA and CA, while specimens in distilled water had a densely packed solid surface (Fig. 4). However, the CA-treated specimens, particularly those of 10% and 20% concentration, had a more complex and extensive crack network compared to EDTA. The quantity and depth of surface defects were also visually higher for BioRoot Flow than BioRoot RCS.

The EDX spectrum suggested that the observed structural changes corresponded to the decalcifying effect of EDTA and CA, as significantly lower amounts of calcium were identified for acid-treated specimens. The main components of etched surfaces were zirconium and oxygen.

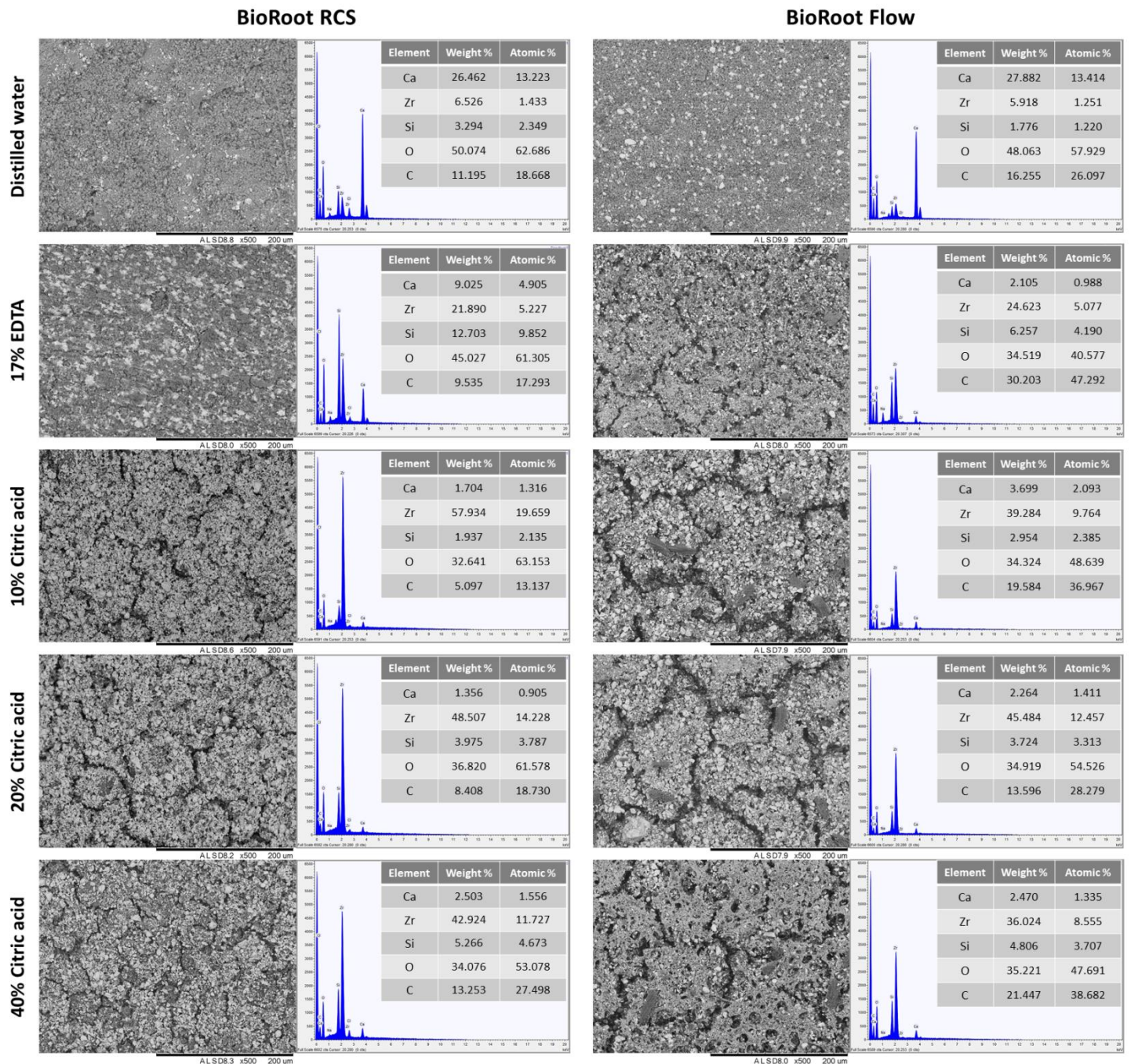


Fig. 4 Representative SEM images and EDX spectrum of BioRoot RCS and BioRoot Flow after the exposure to distilled water, EDTA and citric acid solutions. The SEM images show morphological changes associated with pore and crack formation, whereas the EDX spectrum reveals the decrease in calcium for acid-etched surfaces.

Discussion

The results of this study align with previous reports that pre-mixed formulations of HCS sealers are more prone to dissolution in CA irrigating solutions [12]. However, the type of irrigating solution used may also be a factor of importance in the solubility rates of pre-mixed and powder-to-liquid sealers. The data from the present study clearly demonstrated that BioRoot Flow was significantly more soluble in all CA irrigating solutions than BioRoot RCS, while no significant differences were observed between the materials in distilled water and 17% EDTA. Therefore, the null hypothesis that BioRoot Flow, a pre-mixed sealer formulation, performs in a similar manner to BioRoot RCS (powder-to-liquid formulation) can only be partially accepted.

According to the data declared by the manufacturer (Table 1), BioRoot RCS and BioRoot Flow are not identical materials. The sealers have different vehicles (BioRoot RCS – water and BioRoot Flow – propylene glycol), which can change the characteristics of the materials [13]. Moreover, BioRoot Flow has more additives (e.g. acrylamide / sodium acryloyldimethyltaurate copolymer, isohexadecane, polysorbate), which could also potentially contribute to the differences in CA resistance. However, the details of the reaction mechanisms between these additives and CA remain unclear. On the other hand, the main phase identified by XRD and Raman spectroscopy for both filling materials was the same – zirconium oxide. It is noteworthy that the main component of BioRoot RCS and BioRoot Flow, as for any other commercially available HCS material, is generally assumed to be calcium silicate [21]. The absence of calcium silicate peaks in the XRD and Raman patterns could be due to the detection limits for amorphous structures and the overlapping of some peaks in the multi-phase material [22]. Nevertheless, the predominance of the zirconium oxide phase corresponds to the fact that the amount of zirconium oxide in HCS materials is usually greater than that of calcium silicate [13,23]. This presumably explains the relatively low solubility rates (not exceeding 10%) of HCS sealers in a strong organic chelating agent (e.g. CA), as zirconium oxide is well-known for chemical stability and slowly dissolves only in concentrated hydrofluoric acid under specific conditions [24,25]. Nevertheless, the application of hydrofluoric acid in daily endodontic practice is not possible due to its ability to readily destroy soft tissues and bone [26,27]. Therefore, this suggests that a safe and effective solvent for HCS materials is unlikely to exist.

However, the obtained results propose the idea that CA solutions may still have the potential advantages for the removal of HCS sealers from root canals. The superior dissolving properties of CA over EDTA are theoretically attributed to its lower pH level (pH ranged from 1.73 to 2.16 in the present study) as compared to EDTA (pH = 8). It has been reported that the decalcifying efficacy of various acids depends on their pH [28], and the calcium silicate hydrate, which is formed by the hydration of di- and tri-calcium silicates during the setting, begins to destabilize at pH levels below 8.8 [29]. Therefore, the more acidic environment, provided by the CA solutions, is expected to accelerate the material degradation process by dissolving calcium containing compounds more efficiently. In addition, the released calcium ions react with the acid to form salts, and the extent of material damage can also be influenced by properties of these salts – soluble salts are leached from the material by leaving pores and cavities of various size, whereas deposition of insoluble or less soluble salts may result in the expansion and crack propagation [30]. Although both mechanisms of the material deterioration can be determined in most cases, the citric acid characteristics are more associated with the formation of sparingly soluble and voluminous calcium citrate salt [29], presumably explaining a greater number of cracks observed for citric acid-etched specimens in the present study.

The more extensive structural damage can be considered a desirable effect, as wider cracks and various types of fractures typically indicate an increased penetrability of the material and hence may facilitate the removal of the main bulk of root canal filling when using hand or rotary files. However, it must also be noted that the higher concentration of CA solution does not guarantee a higher degradation rate – all performed test methods clearly demonstrated that 10% and 20% CA irrigating solutions are significantly more efficient in dissolving HCS sealers than 40% CA. Therefore, a lower concentration of CA solution would be a more rational choice for retreatment cases owing to safety (less expected erosion of dentine) and effectiveness (higher solubility of HCS sealers).

Further studies are necessary to confirm the promising results of 10% and 20% CA irrigating solutions as a potential solvent for removing HCS sealers during root canal retreatments. Laboratory investigations typically provide a more controlled environment to analyze the direct interaction between the irrigating solutions and filling materials, and thus it is a necessary initial step to better understand the efficacy of irrigating solution alone. Attempting to minimize the potential limitations, all freshly prepared specimens received a controlled amount of moisture to enable the hydration while eliminating the risk of material washout. Although there is still no evidence-based data on the amount of intra-tubular moisture, which HCS sealers are exposed to at the

post-operative stage during their setting, a widespread method to keep the specimens dry or immediately submerged in the storage medium was avoided, as both conditions do not mimic the clinical situation and may adversely affect the intrinsic properties of HCS sealers [21]. The specimens were covered with gauze soaked in HBSS with no calcium and magnesium due to the similarity of HBSS to physiological dental fluids. The exclusion of magnesium and calcium ions was based on reports that the presence of supplemental magnesium and calcium can change the structure of calcium silicate hydrate and its stability [31,32]. Moreover, a relatively small volume of irrigating solutions was used owing to the fact that lower volumes provide more realistic results closer to the actual material performance in root canals [33].

The 5 min exposure of irrigating solutions was selected following the previous recommendation to maintain fresh irrigating solution in contact with materials for 5 min during the resting phase of the irrigation protocol [34]. However, the short exposure time could be considered the weakness of the present study as root canal retreatment, particularly the removal of HCS sealers along with irrigation, clinically takes longer. Another weakness is the lack of clinical conditions, e.g. contact with the dentin. The clinical environment is more complex than a simplified laboratory model and various additional factors, such as root canal anatomy, structure of dentine, endodontic instruments, irrigation type and operator experience, may also influence the overall efficacy of retreatment procedures. Since the promising results of CA solutions were obtained in the present study, further well-designed investigations simulating clinical conditions and situations are warranted to validate the applicability of CA for removing HCS sealers from previously root filled teeth.

Conclusions

Five minute exposure of 10% and 20% CA irrigating solutions were significantly more effective than distilled water, 17% EDTA and 40% CA in terms of dissolving BioRoot RCS and BioRoot Flow. BioRoot Flow, a pre-mixed sealer formulation, was significantly more soluble in all CA irrigating solutions than BioRoot RCS that has a powder-to-liquid formulation. Further studies using the root canal retreatment model and longer exposure times of irrigating solutions are necessary to confirm the potential advantages of citric acid in endodontic retreatments.

Compliance with Ethical Standards

Conflict of Interests

Authors deny any conflict of interest related to this study.

Ethical Approval

Not Applicable

Informed Consent

Not Applicable

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