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Review

Retreatment Strategies for Cases Containing Calcium Silicate-based Root Canal Sealer: A Comprehensive Review

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Abstract: This review explores the field of retreatment strategies for the cases filled with calcium silicate-based root canal sealers. Since the introduction of calcium silicate-based materials in dentistry, calcium silicate-based root canal sealers have become popular among dentists because of their biocompatibility, bioactivity, and sealing ability. Therefore, effective retreatment strategies are indispensable. This article aims to identify the challenges associated with the removal of calcium silicate-based sealers itself and gutta-percha with the sealers during retreatment, evaluate current techniques and materials, and provide future directions for research in this field. Regarding the strategies of removal of root canal sealers, calcium silicate-based sealers are still relatively new materials for clinicians compared with the traditional sealers such as epoxy- or eugenol-based sealers. First, no clinically established solvents have been reported. Second, calcium silicate-based sealers are currently utilized by clinicians in either cold sealer-based technique or warm vertical condensation technique. Third, the setting process of calcium silicate-based sealers generates byproducts primarily calcium hydroxide and secondarily hydroxyapatite, which could interact with dentine. Lastly, there is a lack of clinical studies evaluating the efficacy of retreatment protocols for teeth filled with calcium silicate-based sealers. Therefore, it is important to investigate chemo-mechanical properties of calcium silicate-based sealers itself and their reactions to solvents and/or mechanical instruments, and identify the interfacial properties of calcium silicate-based sealers in respect to dentine and gutta-percha. In addition, researchers in clinical field need to actively gather and report data on retreatments of teeth filled with calcium silicate-based sealers.

Keywords: calcium silicate-based root canal sealer; retreatment; solvent

Introduction

1. Calcium silicate-based sealer (CSS)

A surge in the popularity of calcium silicate-based sealers (CSS) has been noticed in recently in the field of endodontics. Since iRoot SPTM (Innovative Bioceramics) was first introduced in 2007, many new brands of CSS have been marketed, and more dentists are interested in using CSS. The properties of CSS are unique because of the setting process and its byproduct, which can contribute to their popularity.

1.1. Properties of CSS

The unique properties of CSS include their setting process and their byproduct. CCS are hydraulic sealers that require the presence of water for their setting. The setting process includes the reaction of CSS with water. This reaction results in the formation of calcium hydroxide as a byproduct[1].





The set sealer produced was found to be biocompatible and bioactive [2][3]. Hydroxyapatite, as a secondary byproduct, is deposited on the surface of the set sealer, which contributes to the bioactivity of the set CSS[3]. The release of calcium hydroxide ions from elevates pH, which contributes to the sealers' antimicrobial efficacy [2][4].

1.1.1. Outcome of root canal treatment using CSS

The outcomes of non-surgical initial root canal treatments and retreatments using CSS allow more clinicians to use CSS for obturation. In a non-randomized clinical trial, a calcium silicate sealer in combination with the single cone technique demonstrated a success rate comparable to that of epoxy resin-based sealer with the warm vertical condensation technique, ranging from 84 % to 90 %[5]. A randomized clinical trial compared the success rate of CSS with the single cone technique and epoxy-resin-based sealer with the continuous wave condensation technique. The results showed an average success rate of 94.3% for CSS with the single cone technique[6]. These promising results and favorable outcomes encourage and motivate clinicians to use CSS more extensively in the practice of endodontics. The increased use of CSS among endodontists and general practitioners has prompted the need to implement new strategies of retreatment for cases obturated with CSS. For instance, regaining patency is a potential challenge that can occur during the removal of CSS[7].

2. Retreatment

2.0.1. Reason for retreatment

In general, the success of endodontic treatment can be evaluated by the absence of signs and symptoms of infection or inflammation, including pain, tenderness to palpation and percussion, the absence of any soft tissue signs of infection, such as swelling, in combination with radiographic evidence of periapical lesion healing and bone formation and regaining mastication force and normal function of the treated teeth[8][9]. The presence of signs and/or symptoms is the main reason for retreatment. The purpose of retreatment is to eliminate the presence of persistent infection in the root canal system. Radiographic presence of the periapical pathology is an important diagnostic method that has been used to evaluate healing after root canal treatments[10][11][12]. Reinfection can occur because of various factors, such as poor coronal restoration or the presence of missed root canals [13][14][15]. The presence of radiographic radiolucency before the initial endodontic treatment was found to increase the possibility of failure and the need for retreatment as a result[16]. In addition, retreatment using modern technology was found to be beneficial to patients' quality of life[9].

2.1. Factors affecting outcome of retreatment

Numerous studies have discussed the outcome of endodontic retreatment. Endodontic retreatment showed high success rates in most of these studies. Ng et al. in their prospective study, which included annual clinical and radiographic evaluation of the teeth that were initially treated and retreated, found that the success rate of retreatment was comparable to that of initial treatment[17]. The success of retreatment is influenced by many factors. These factors include the presence of periapical radiolucency, radiolucency size[17], case selection[18][19], accessibility to the obturation material throughout coronal restoration[20], and retrievability of the different obturation materials[21]. The last factor is critical for clinicians to expect a favorable prognosis before executing the retreatments obturated with CSS due to the absence of solvents. Friedman et al. divided the obturation materials based on their setting process into soft-setting pastes, which are easy to remove and clean, and hard-setting cements, which might require the usage of solvents in combination with mechanical debridement to remove[21]. In addition to the obturation material, the obturation technique is another critical factor in determining the complicity of retreatment. DeLong et al. compared the push-out bond strength of 2 CSS (MTA Plus SealerTM and EndoSequence BC SealerTM) and an epoxy-resin-based sealer (AH PlusTM) using the single

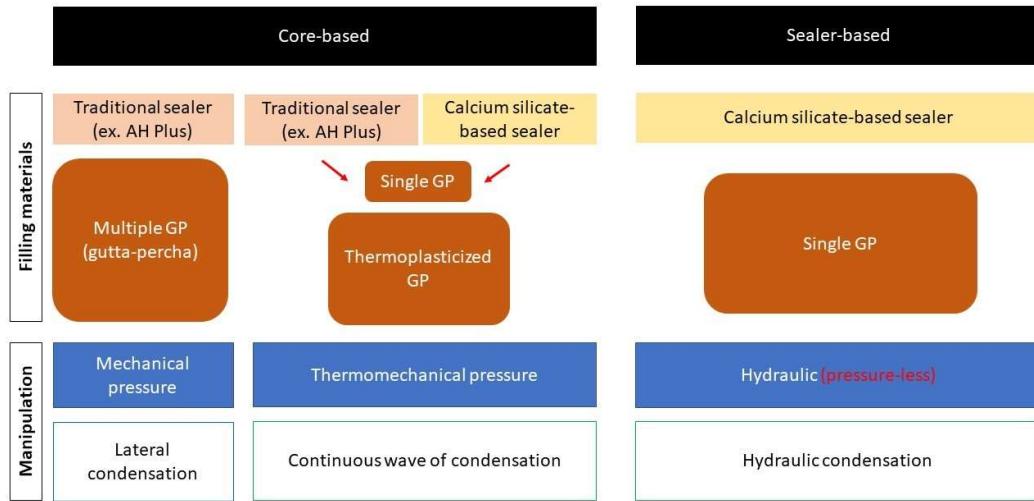


Figure 1. Schematic concepts of obturation methods

cone obturation technique and continuous wave obturation technique. They found that the continuous wave technique decreased the bond strength of MTA Plus SealerTM and that CSS with the single cone demonstrated the highest push-out resistance[22]. This study shows that the obturation technique might influence the setting properties of the sealers. Athkuri et al. compared the retrievability of root canal filling material obturated with cold lateral condensation, warm vertical condensation, and thermoplasticized injectable techniques along with AH PlusTM sealer and BioRoot RCSTM. The samples that were obturated with the thermoplasticized technique demonstrated a higher percentage of root filling residuals after the removal of root fillings rather than lateral condensation or warm vertical compaction. However, there were no significant relationships between the type of sealer used and the amount of residual filling[23]. This indicates that the obturation technique used during the initial endodontic treatment affects the retrievability of the root filling material during retreatment. Therefore, clinically, the outcome of retreatment is affected by multiple factors, and its outcome varies depending on the various scenarios.

2.2. Challenges and risks specific to CSS

No solvents have decisively proven to be effective in dissolving CSS. For this reason, the challenges associated with the retrievability of CSS might depend on the final setting of the sealer. Soft-setting CSS are easier to remove from the root canal system, whereas hard-setting CSS might necessitate the use of solvents in combination with mechanical debridement[21].

3. Literature Review

3.1. Calcium silicate-based sealers properties in relation to retreatment

The properties of calcium silicate-based sealers allow clinicians to use either a sealer-based technique or warm vertical condensation. Mann et al. studied the physicochemical and biological properties of EndoSequence BC Sealer HiFlowTM (CSS) and compared them with those of EndoSequence BC SealerTM (CSS) and AH Plus sealerTM (resin-epoxy-based sealer). Flow, solubility, antibacterial effect, and biocompatibility were some properties that were evaluated in this study. At room temperature, both CSS had a similar flow, which was lower than the flow of AH PlusTM sealer. However, upon increasing the temperature to 100°C, the flow of EndoSequence BC Sealer HiFlowTM turned to the highest, followed by AH PlusTM and EndoSequence BC SealerTM. Interestingly, increasing the temperature to 150°C put the flow of AH PlusTM ahead of the flow of EndoSequence BC Sealer HiFlowTM and EndoSequence BC SealerTM. Regarding solubility, both CSSs showed similar solubility,

which was significantly higher than the solubility of AH PlusTM. No difference was found among the 3 sealers regarding the antibacterial effect, whereas both CSS demonstrated higher biocompatibility than AH Plus[2]. These results indicate that it is necessary to thoroughly remove CSS from the root canal systems in retreatment because of the flowability of CSS, while CSS is more soluble than epoxy resin-based sealer. The capacity of adhesion between CSS and dentine was the scope of many studies. Resistance to dislodgement measures the capacity of adhesion between sealers and dentine. Sagsen et al. compared the push-out resistance of I Root SPTM, a calcium silicate-based sealer, MTA FillapexTM, a salicylate resin- and calcium silicate-based sealer, and AH PlusTM, an epoxy-resin-based sealer. They found that I Root SPTM has a similar push-out bond resistance to AH PlusTM. While MTA FillapexTM has the lowest among the 3 sealers[24]. In a similar study, Donnermeyer et al. compared three CSS (Total Fill BC SealerTM, Endo CPM SealerTM, BioRoot RCSTM) with an epoxy resin-based sealer (AH PlusTM). The study revealed that the dislodgment resistance of AH PlusTM to be significantly higher than that of all three CSS[25]. CSSs in these studies demonstrated different values of dislodgement resistance, while some types of CSS were comparable to the push-out resistance of epoxy-resin-based sealers.

Table 1. Sealers that were used in push out bond studies that were mentioned in this review.

Sealers	Manufacturers	Push-out force (N/mm ²)	References
I Root SP root canal sealer	Innovative BioCreamix Inc, Vancouver, Canada	1.52 to 2.6 ¹	[24]
MTA Fillapex	Angelus Solucxoes Odontologicas, Londrina, Brazil	0.6 to 1.37 ¹	[24]
AH Plus	Dentsply DeTrey GmbH, Konstanz, Germany	1.9 to 2.9 ¹	[24]
BioRoot RCS	Septodont, Saint-Maur-des-Fossés, France	1.96 to 2.76 ¹	[25]
Endo C.P.M. Sealer	EGEO, Buenos Aires, Argentina	1.47 to 1.82 ¹	[25]
Total Fill BC Sealer	FKG, La Chaux-de-Fonds, Switzerland	2.95 to 3.89 ¹	[25]
AH Plus	Dentsply, Konstanz, Germany	6.12 to 8.62 ¹	[25]

¹The study demonstrated a difference in the push-out bond strength depends on the position of the teeth's sections that were tested Corono-apically. A range was used here to demonstrate the difference in the push-out bond strengths.

3.2. Adhesion and interfacial space between CSS and gutta-percha

Research on the adhesive capacity of CSS has predominantly focused on their bonding force to dentine, with less attention given to their capacity with gutta-percha. It has been claimed by commercial manufacturers that gutta-percha cones treated with calcium silica particles have better and stronger adhesion to CSS than conventional gutta-percha. An SEM study compared the adhesion of TotalFill BC sealerTM and AH Plus sealerTM to conventional gutta-percha and BC gutta-percha using single cone and lateral condensation techniques. The study did not find a significant difference in the voids between the two types of gutta-percha and the two types of sealers regardless of the obturation technique[26]. The current literature on the adhesion capacity of CSS to gutta-percha is insufficient, and further investigation is needed. In an ex vivo micro CT study, De-Deus et al. showed the more common frequencies of the gaps between a single gutta-percha cone and CSS than between a single gutta-percha and AH Plus and theorized the hydrophobic nature of gutta-percha cone repulses CSS with its hydrophilic nature[27].

3.3. Potential changes of interfacial dentin by CSS

The impact of CSS on interfacial dentine microstructure is another topic of interest. Atmeh et al.[28] evaluated the effect of BiodentineTM (calcium silicate-based restorative material) on dentin using confocal laser scanning microscopy, scanning electron microscopy, micro-Raman spectroscopy, and two-photon auto-fluorescence and second harmonic- generation imaging. It was found that the interaction between dentine and BiodentineTM led to the formation of the "mineral infiltration zone"

(MIZ) because of the products that resulted from the hydration of the calcium silicate-based material. These products lead to degradation of the collagen component of the interfacial dentin. This leads to the movement of ions in the dentine and increases the mineralization in this region of dentin[28]. Jeong et al. also reported the formation of the MIZ in their study but, only with the samples that were incubated for 14 days after obturation and not with the samples that were incubated for 3 days only[29]. This leads to the conclusion that the formation of MIZ is a result of an extensive interaction that starts after the sealer is set. Despite the previous reports that investigated the presence of MIZ, its formation, and its chemical composition, there is currently insufficient evidence regarding its effect on the endodontic treatment.

3.4. Different scenarios in retreatment

While there is general agreement among clinicians that retreatment should cause the minimum change to the root canal anatomy, concerns are still present regarding the regain of apical patency in cases obturated with CSS, especially those cases where the gutta-percha does not reach the working length. In an ex vivo study, Hess et al.[30] created an experimental model in which they compared the possibility of regaining patency in samples obturated with AH Plus sealerTM and EndoSequence BC sealerTM. The teeth samples were divided into 4 groups. In two of the groups the samples were obturated with a gutta-percha that reached the working length, whereas in the other 2 groups, the samples were obturated with a gutta-percha that was 2 mm shorter than the working length. Heat, chloroform, rotary instruments, and hand files were used in the retreatment protocol. The success rate of regaining working length in samples where the gutta-percha reached the working length was 100% regardless of the sealer used. In samples where the gutta-percha was 2 mm shorter than the working length, the success rate was 100% for the samples obturated with AH PlusTM in comparison with 30% in the samples obturated with EndoSequence BC sealerTM. Patency was regained in 100% of the samples in both the groups obturated with AH PlusTM, while it was regained in 80% of the samples in the group that were obturated with EndoSequence BC sealerTM and gutta-percha reaching the working length. Patency was regained in 30% of the samples that were obturated with EndoSequence BC sealerTM and gutta-percha 2 mm shorter than the working length[30]. In contrast, a recent ex vivo study compared the potential of regaining patency in samples obturated with EndoSequence BC sealerTM in which gutta-percha was placed 1.5 mm shorter than the working length using 10% formic acid, 20% hydrochloric acid, and chloroform, patency was regained in 100% of samples retreated with 10% formic acid and 20% hydrochloric acid, which was not significantly different for the samples where chloroform was used (93%)[31]. This discrepancy in results between different studies can be attributed to the lack of standardization in preparing the samples rather than to the effect of the solvents or the techniques used. This highlights the importance of standardizing sample design in research on this topic.

3.5. Different nature of CSS

The physical strength of the set CSS is a critical factor that determines its retrievability. Different brands of CSS have different degrees of retrievability, mainly because of their different setting properties. Soft set sealers are easier in retrievability compared with hard set sealers[32]. Carillo et al. compared the possibility of regaining patency in canals that were obturated with three CSS: EndoSequence BC sealerTM, EdgeBIOCERAMICTM and NeoSEALERFloTM. It was shown that canals filled with NeoSEALERFloTM have a higher success rate in regaining patency than canals filled with the others[32]. The authors found that re-establishing patency could be affected by which CSS was used and NeoSEALERFloTM might be soft setting CSS. Therefore, the presence of hard setting CSS might lead to more difficulties and complications during the retreatment procedure. Some challenges that can be faced include the separation of instruments, perforation, and difficulty in reaching the proper working length[21].

3.6. Removal of CSS

Regaining patency in cases obturated with CSS during retreatment is one of the major prognostic factors for positive outcomes. The presence of CSS apical to the gutta-percha in cases where the gutta-percha did not reach the working length can demonstrate a real obstacle during retreatment [30].

In addition, the presence of CSS in areas of the root canal system that are inaccessible to mechanical means of debridement might form another obstacle preventing the complete removal of CSS in endodontic retreatment procedures. An ex vivo study that evaluated the removal of root canal filling material from the mesial canals of mandibular molars that are connected with an isthmus using XP-endo Finisher R instrument with or without solvent concluded, after comparing the micro CT scans of the samples before and after the treatment, that the use of solvent did not improve the removal of the filling materials from the canals or isthmuses, whereas mechanical debridement using XP-endo Finisher R instrument facilitated the removal of the filling materials but couldn't remove it completely[33]. Horvath et al. used SEM and photographs in an ex-vivo study to evaluate the efficacy of two solvents, chloroform, and eucalyptol, in removing the filling gutta-percha and sealers from the root canal walls and dentinal tubules. More remnants of gutta-percha and sealers on the canal walls and inside the dentinal tubules were found in groups where solvents were used compared with groups without solvents. It was suggested that more root canal filling material was pushed inside the dentinal tubules because of the dissolution of the root canal material by the solvents, which led to the compacting of the root canal filling material inside the dentinal tubules[34]. Donnermeyer et al. compared the retrievability of three calcium silicate sealers to AH Plus™ from round and patent root canals using mechanical instrumentation. They found that the complete removal of sealers was not achievable even in round and patent root canals, with the percentage of remaining sealer ranging from 2.1% to 28.2% for all 4 sealers in all the groups of the study[35]. The study showed that the complete removal of CSS from the dentine wall was not achieved regardless of the simple anatomy of the canals.

4. Current retreatment techniques

Current CSS retrieval techniques can be divided into chemical and mechanical techniques.

4.1. Solvents for gutta-percha

Gutta-percha cone is a semisolid obturation material. It is considered the material of choice in modern endodontics. Excessive mechanical removal of the gutta-percha can lead to alterations in the anatomy of the root canals. Solvents are commonly recommended to avoid any alteration in the anatomy and to facilitate the removal of the gutta-percha. Chloroform is the most effective solvent used for the removal of gutta-percha. Its properties of fast-acting, strength, and fast evaporation make it a proper choice as a solvent. However, chloroform was found to be cytotoxic and carcinogenic, therefore, extrusion beyond the apex should be avoided. The use of xylene and eucalyptol as alternatives to chloroform was suggested, but they were found to be less effective and impractical to use clinically. Wennberg and Orstavik suggested the use of methyl chloroform as an effective, less toxic alternative to chloroform. It was found to be less effective than chloroform but more effective than xylene and eucalyptol.[36][37].

4.2. Chemical dissolution of CSS

The possible chemicals that can be employed in the retrieval of CSS have been evaluated in many studies. Numerous studies have examined the difference in solubility between CSS and epoxy-resin-based sealers, and the effect of different solvents on CSS. Borges et al.[38] subjected AH Plus™, iRoot SP™, MTA Fillapex™, Sealapex™, and MTA-Angelus™ to solubility test to compare their surface structure changes and ion release. The samples of the sealers were assessed using scanning electron microscopy and energy-dispersive spectroscopy. The study found that iRoot™, MTA Fillapex™, and Sealapex™ to have a higher solubility than AH Plus™ and MTA-A™. The study also revealed that CSS exhibit a high release of calcium ions[38]. The pH of the surrounding environment was shown to be a critical factor in the solubility of CSS. EndoSequence BC Sealer™ found to be

significantly more soluble than AH Plus™ in low pH[39]. This implies that acids might have the potential to serve as solvents for CSS. Thermal treatment as a physical means was found to be effective in altering the structure of CSS and impacting the solubility[40]. Ideal solvents are intended to affect sealers only without affecting the integrity of dentine. Garrib et al.[41] studied the effect of irrigating with 17% EDTA along with either 10% or 20% formic acid on the integrity of TotalFill BC sealer™ and the integrity of dentine. The study found that irrigating with 17% EDTA and 10% formic acid did not affect the integrity of the dentine. However, irrigation affected the integrity of CSS used in the study and aided in its mechanical removal. The use of 20% formic acid was found to corrode the integrity of dentine[41]. The efficacy of 20% hydrochloric acid, and chloroform in comparison with 10% formic acid in regaining apical potency was investigated. There was no significant difference among them in regaining patency[31]. 10% formic acid is deemed a promising solvent when used to penetrate CSS and regain patency.

4.3. Mechanical removal of CSS

The use of conventional hand files and modern rotary and NiTi files in the removal of CSS was assessed in multiple studies. Donnermeyer et al. compared the efficacy and retreatment time of Hedström files, Reciproc R40, Mtwo retreatment file R 25/06, Mtwo 40.06, and F6 SkyTaper size 040 in the removal of CSS and epoxy-resin-based sealer. Regarding the amount of sealer remnants, all NiTi rotary files performed much better than Hedström hand files, regardless of the sealer type. F6 SkyTaper instruments were found to be the fastest compared with all the files that were assessed[35]. Furthermore, the use of reciprocating files occupied a portion of the interest in the mechanical techniques for removing CSS. Kırıcı et al., with the aid of micro-CT, compared 2 reciprocal systems, M-Wire Reciproc and Reciproc Blue, and evaluated their efficacy in the removal of CSS and their competence in preserving the root canal anatomy in curved canals. No significant difference in the amount of residual was found between the 2 systems. However, the apical canal transportation was found to be significantly higher in the M-Wire Reciproc group, but the formation of incomplete and complete cracks was witnessed with both systems[42]. Despite the positive results that were reached with different mechanical means for the removal of CSS, no mechanical technique was found to completely remove CSS from the root canal system.

4.4. Integrating technology into retreatment of CSS

The use of modern mechanical techniques has been discussed in various studies. Fruchi et al. [43] conducted a micro CT evaluation to measure the efficacy of sealer removal using Reciproc R25 instrument or WaveOne Primary files along with xylene and passive ultrasonic irrigation in curved canals. Reciproc instruments and WaveOne Primary instrument showed a removal efficacy of 93% and 92%, respectively. The use of xylene and PUI helped in the removal of the root canal filling material but did not increase the percentage of the removed filling material significantly [43]. Wright et al. compared the usage of 2 modern irrigation protocols, EndoVac, and GentleWave, to the efficacy of the usage of side-vented needle in the removal of the root canal filling materials. Micro-CT imaging was used to evaluate the percentage of the removal of the root canal filling material for all 3 irrigation techniques. GentleWave removed the highest ratio of the residuals of the root canal filling material, followed by the side-vented needle. EndoVac was found to remove the least amount of residuals of the root canal filling material [44]. Wright and Fruchi [43] [44] found that AH Plus was more difficult to remove than CSS. The efficacy of shock wave-enhanced emission photoacoustic streaming (SWEEPS) in the CSS removal was evaluated. Angerame et al. compared the efficacy of SWEEPS

Table 2. Sealers that were used in solubility studies mentioned in this review.

Sealers	Manufacturers	composition	Solubility (%)	reference

iRoot SP	Innovative BioCeramix Inc., Vancouver, Canada	Zirconium oxide, calcium silicates, calcium phosphate, calcium hydroxide, filler and thickening agents	20.64 ± 1.42	[38]
MTA Filapex	Angelus, Londrina, PR, Brazil	Components after mixture: resins (salicylate, diluting, natural), radiopaque bismuth, nanoparticulated silica, mineral trioxide aggregate, pigments	14.89 ± 0.73	[38]
Sealapex	Sybron Endo/Kerr Co, Orange, CA, USA	Calcium oxide, bismuth trioxide, zinc oxide, submicron silica, titanium dioxide, zinc stearate, tricalcium phosphate, ethyl toluene sulphonamide, poly(methylene methyl salicylate) resin, isobutyl salicylate and pigments	5.65 ± 0.80	[38]
MTA-A	Angelus, Londrina, PR, Brazil	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, bismuth oxide, iron oxide, calcium carbonate, magnesium oxide, crystalline silica and residues (calcium oxide, free magnesium oxide, potassium and sodium sulphate compounds)	-1.24 ± 0.19	[38]
AH Plus	Dentsply De Trey GmbH, Konstanz, Germany	Component A: epoxy resin, calcium tungstate, zirconium oxide, aerosil, iron oxide; Component B: adamantane amine, N,N-Dibenzyl-5-oxanonane, TCD-Diamine, calcium tungstate, zirconium oxide, aerosi	0.28 ± 0.08	[38]

AH Plus Jet	Dentsply DeTrey GmbH, Konstanz, Germany	Bisphenol A/F epoxy resin, calcium tungstate, zirconium oxide, silica, iron oxide pigments dibenzylidiamine, aminoadamantane, silicone oil	0.04 ± 0.11 to 0.26 ± 0.15 ¹	[39]
EndoSequence BC Sealer	Brasseler USA, Savannah, GA, USA	Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents	4.96 ± 0.94 to 12.88 ± 0.94 ²	[39]

Table 3. Materials and instruments that were used in treatment studies.

Name	Company	Type	Reference
XP-endo Finisher R instrument	FKG Dentaire, La Chaux-de-Fonds, Switzerland	Mechanical	[33]
Eucalyptol	Biodinamica, Ibiporã, PR, Brazil	Chemical	[33]
Reciproc R40 NiTi files	VDW, Munich, Germany	Mechanical	[35]
Mtwo retreatment file R 25/0.06	VDW GmbH, Munich, Germany	Mechanical	[35]
F6 SkyTaper size 040	KOMET, Lemgo · Germany	Mechanical	[35]
10% formic acid	Sigma Aldrich, Gillingham, UK	Chemical	[41]
20% formic acid	Sigma Aldrich, Gillingham, UK	Chemical	[41]
ProTaper Gold finisher file	Dentsply, Charlotte, USA	Mechanical	[41]
M-Wire Reciproc	VDW GmbH, Munich, Germany	Mechanical	[42]
Reciproc Blue	VDW GmbH, Munich, Germany	Mechanical	[42]
xylene	Not mentioned	Chemical	[43]
Reciproc R25 instrument	VDW, Munich, Germany	Mechanical	[43]
WaveOne Primary instrument	Dentsply Maillefer, Tulsa, USA	Mechanical	[43]
Reciproc Blue files	VDW GmbH, Munich, Germany	Mechanical	[45]
XP-endo Finisher R system	XPR; FKG Dentaire, La Chaux-de-Fonds, Switzerland	Mechanical	[46]

with that of passive ultrasonic irrigation (PUI) in the removal of CSS in ex vivo. The combination of reciprocating instrumentation with SWEEPS provided more satisfying results than the usage of reciprocating instrumentation combined with PUI[45]. The XP- endo Finisher R system removed more CSS compared to the ultrasonic-assisted irrigation or EndoActivator[46]. Despite continuous effort to assess the efficacy of mechanical techniques and modern irrigation technology in the removal of CSS, no technique has been proved to completely remove CSS from the root canal system in the literatures.

4.5. Clinical studies

¹ The study demonstrated a difference in the solubility related to time and pH. A range was used here to demonstrate the difference in solubility

Clinical studies describing the outcome of retreatment obturated with CSS are limited in number compared to the traditional sealers. CSS are still relatively new materials to be used in endodontics, and further examination and assessment are needed.

5. Future Directions

Regarding the retrievability of CSS, it is still insufficient to guide clinicians in their decision making. Therefore, researchers in the clinic field, need to develop more standardized protocols for clinical studies evaluating the effectiveness of CSS in retreatment.

5.1. Advancement of technology

The employment of modern techniques and technology was assessed as mentioned before in various studies, e.g., the ultrasonic-assisted irrigation, EndoActivator, passive ultrasonic irrigation, SWEEPS, and GentleWave. Some of these technologies demonstrate promising data. More studies are needed to explore their potential and to describe their limitations.

5.2. Research gaps

Many research gaps were found during the preparation of this paper. This is in addition to the lack of standardization in measuring the retrievability of CSS. For example, both Hess et al. and Rezaei et al. used a similar study design, but the distance of the short obturation was not standardized and was different between both studies[31][30]. In addition to that in similar study designs, the absence of voids in the sealer in the apical portion should be verified using the available modern technology. Such standardization would help in obtaining more accurate related results. The nature of the CSS setting should be the next point of focus. Carillio et al. investigated the possibility of regaining patency, but the hardness of the set sealer was not investigated[32]. We suggest that CSS should be categorized into soft and hard setting sealers depending on their setting process and properties, and each group should be studied extensively to reach a better understanding regarding their nature and properties and the clinical reflection of these properties. The effect of solvents on dentine, cells surrounding the root, and CSS should be studied more extensively using standardized methods. Cutting-edge analytical methods to measure the solubility of the sealers and the effect of solvents on the dentine would provide a deeper insight of the strategies in retreatment.

6. Conclusion

The complete retrievability of CSS from the root canal system using the current strategies and techniques has not yet been achieved. The persistent challenges of regaining patency and removing CSS from spaces that are inaccessible to instruments continue to be evident. The integration of mechanical and chemical removal techniques, combined with supplementary irrigation methods, is yielding promising outcomes in CSS retrieval. More standardized studies are needed regarding the nature of all available CSS, and the effectiveness of modern technology in their retrievability.

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