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Review Article

Dentistry Section

Retrievability of Bioceramic Sealers Assessed using Micro-computed Tomography and Scanning Electron Microscopy: A Literature Review

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ABSTRACT

Endodontic retreatment is a procedure to remove root canal filling material from the tooth, followed by cleaning, shaping, and obturation of the canals. Treatment outcomes may be influenced by incomplete removal of filling materials. The present literature review aimed to identify the techniques and materials used to remove Bioceramic Sealers (BCS) from the root canal system using Micro-Computed Tomography (Micro-CT) and Scanning Electron Microscopy (SEM). A search of the PubMed, Web of Science, Scopus, Science Direct, and Google Scholar databases using applicable keywords such as "BCS" and "calcium silicate-based sealer" and "retreatment" and "retreatability" and "micro-CT" and "SEM" identified studies on techniques and materials used to remove BCSs from the root canal system, as assessed by micro-CT and SEM. A total of 46 studies were included in the review. Of these, 32 studies used Nickel-titanium (NiTi) rotary instruments, 11 used reciprocating systems, and three compared continuous nickel-titanium rotary and reciprocating systems with rotary systems and reciprocation in removing filling materials. Apical patency and Working Length (WL) could be achieved in a canal obturated with gutta-percha and a BCS. The review revealed that removing filling materials using various instrumentation protocols can be successful but incomplete. Both rotary and reciprocating systems can efficiently remove root-filling material. Using supplemental techniques can improve the cleanliness of the root canal during retreatment. Solvents require less time to reach the WL and achieve patency; however, they leave a larger amount of residual root canal-filling material than non solvents. Additionally, the formation of dentinal microcracks remains controversial during the non surgical retreatment of canals filled using BCSs.

Keywords: Gutta-percha, Retreatment, Root canal, Root canal filling materials, Treatment outcome

INTRODUCTION

In endodontically treated teeth, the incidence of apical periodontitis is 41.3% [1]. Non surgical root canal retreatment eliminates filling materials, debris, and microorganisms through proper cleaning, reshaping, and refilling of the root canal system [2-4]. Solomonov M et al., root canals are considered effectively cleaned when only 0.5% of the root canal-filling material remains [5]. Treatment outcomes may be influenced by incomplete removal of filling materials because obturation prevents the contact of irrigation solutions with persistent microorganisms [4-6]. Endodontic retreatment can be influenced by the morphology of the root canal system, status of the periapical tissues, material and technique of obturation, and type of endodontic sealers used [7,8]. Retreatment enables access to the root canal system and the removal of filling material to allow for effective disinfection [9]. After retreatment, the remaining filling material may harbour bacteria that are resistant to antimicrobial agents, potentially triggering apical periodontitis [9]. The presence of hydroxyapatite crystals can be detected at the interface between dentin and calcium silicate-based sealers. However, removing these crystals from the dentinal wall and tubules can pose a challenge. Additionally, the ability of the sealer to penetrate into dentin may impact its retrievability. Dentin penetration does not impede canal retreatment. However, deep material penetration and dentin tubule blockage can complicate canal retreatment. Additionally, residual material can impair the adhesion of the new root canal-filling material to the radicular dentin, leading to retreatment failure [10]. The chemical composition of the root canal sealers and techniques used for obturation can influence the effectiveness of root canal-filling material removal [11]. The type of endodontic sealer used influences the ability to retreat the root canal system [12,13]. Removal of bioceramic root canal sealers during retreatment concerns clinicians who have recently become interested in exploring new methods and techniques. Thus, the present paper aimed to review the techniques and materials used to remove BCS from the main root canal walls, evaluate the time required to remove the filling material, and establish foramen patency.

LITERATURE SEARCH

Article selection: A literature search was conducted based on the following criteria: articles retrieved in PubMed, Web of Science, Scopus, Science Direct, and Google Scholar using the following keywords: "BCS" and "calcium silicate-based sealer" and "retreatment" and "retreatability" and "micro-CT" and "SEM"; articles in the English language; and articles published between January 2009 and July 2023.

The article titles and abstracts underwent screening based on predetermined inclusion and exclusion criteria, with the removal of any duplicates. Articles not sufficiently related to the review's subject, based on the abstract and title, were excluded. Ex-vivo studies in English assessing the retrievability of BCS in mature human permanent teeth using micro-CT and SEM were included. Clinical studies, unpublished articles, narrative reviews, book chapters, conference abstracts, and expert opinions in other languages including animals, artificial teeth, or endodontic training blocks, and those deploying Cone Beam Computed Tomography (CBCT), optical microscopy, stereomicroscopy, or dental operating microscopy were excluded. In total, 638 articles were identified. A total of 46 articles met the inclusion criteria [13-58].

Analysis of remaining root canal filling materials: Research in these areas is better carried out using micro-CT and SEM, based

on quantifying the remaining filling materials, cleanliness of the root canal system, and removal of filling materials. Eight studies [14-21] used SEM to evaluate the BCS remaining after retreatment, whereas 36 studies [13,22-56] used micro-CT. One study used micro-CT and SEM [57], and another used micro-CT, SEM, CBCT, and digital microscopy [58].

None of them showed that conventional retreatment techniques were unable to completely remove the BCS. Micro-CT is non destructive, repeatable, and can quantitatively measure remnants with minimal operational control. The same sample can be used for several tests without destruction [59], allowing evaluation of the volume before and after instrumentation, quality of root canal obturation, and material removal from the root canal (retreatment). Additionally, micro-CT facilitates repeat scanning [60] and image manipulation using specific software. However, it cannot be used for in-vivo studies because it exposes live samples to high radiation levels. Furthermore, micro-CT allows the investigation of specimens of limited size, which limits some analyses. Despite its low resolution, CBCT can be used in patients [61]. The nature of the remaining materials is not disclosed by CBCT. According to digital microscopy, it was observed that the prevalent residual materials consisted of calcium silicate sealers, along with minor volumes of gutta-percha residue [58].

Obturation techniques used: Gutta-percha was utilised as the core obturation material, and the various obturation techniques are described in [Table/Fig-1] [13-58].

Ma J et al., found that the continuous wave of condensation group had a larger mean volume of remaining material than the cold lateral condensation group, particularly in the apical part of the root canal system ($p<0.05$) [22].

Authors	Obturation technique and type of sealer	Conclusion
Liu H et al., 2021 [13]	Single Cone Obturation (SCO) with AH Plus sealer (Dentsply Sirona Endodontics) or EndoSequence BC sealer (Brasseler USA Dental LLC, Savannah, GA, USA), and warm vertical compaction with AH Plus sealer (AHW).	Material removal from canals filled using warm vertical condensation in the critical apical area remains a concern.
Hess D et al., 2011 [14]	Continuous wave compaction technique with AH Plus sealer (Dentsply, Tulsa, OK) and single cone technique 0.04 tapered GP point with EndoSequence (Brasseler USA, Savannah, GA).	The WL was not regained in 70% of samples with BCS/master cone short of the WL. Patency was not re-established in 20% of samples with BCS/master cone to the WL or in 70% of samples with BCS/master cone short of the WL.
Simsek N et al., 2014 [15]	Lateral compaction technique with iRoot SP (Innovative BioCeramix Inc., Vancouver, Canada), MM Seal (Micro-Mega, Besançon, France), and AH Plus (Denstply DeTrey, Konstanz, Germany) sealers.	None of the retreatment techniques was able to remove debris in the root thirds completely, regardless of the sealer.
Sherif D et al., 2017 [16]	Cold lateral compaction technique with EndoSequence Bioceramic Sealer (BCS) (Brasseler USA, Savannah, Georgia, USA).	Using chloroform during removal of root canal filling material using rotary instruments was associated with larger amount of residual root canal filling material compared to using rotary instruments only.
Kakoura F Pantelidou O 2018 [17]	Single cone technique with AH26 sealer (Dentsply Maillefer, Tulsa, USA), TotalFill BC Sealer (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) and BioRoot RCS (Septodont, St. Maur-des-Fossés, France).	Residual material debris was observed in all samples regardless of the sealer used. All the sealers were removed to a similar extent. The WL and patency were re-established sufficiently in all groups.
Abdelrahman MH and Hassan MY 2020 [18]	Lateral condensation technique with ADSEAL (Meta Biomed, Korea), Well-Root ST (Vericom, Gangwon-Do, Korea) and Ceraseal (Meta Biomed Co., Ltd.,).	None of the investigated sealers could be totally removed from root canal walls.
Hassan R and Elzahar S 2022 [19]	Warm vertical compaction technique with TotalFill HiFlow BCS (FKG Dentaire).	The apical third of the root canal is the most difficult area to clean.
Rezaei G et al., 2023 [20]	SCO technique with EndoSequence BC Sealer (Brasseler USA, Savannah, GA).	Patency may be achieved for most of the cases obturated with gutta-percha and EndoSequence BC Sealer.
Khosasi A et al., 2023 [21]	Single cone technique with EndoSequence BC Sealer (Brasseler USA, Savannah, GA).	The elimination of bc-coated gutta-percha is more challenging compared to conventional gutta-percha.
Ma J et al., 2012 [22]	Continuous wave of condensation or cold lateral condensation techniques with iRoot SP sealer (Innovative BioCreamix Inc, Vancouver, Canada).	Remaining filling material was observed in all specimens. The mean volume of remaining material was higher in the continuous wave of condensation groups than in the cold lateral condensation groups, especially in the apical portions of the root canals ($p<0.05$).
De Siqueira Zuolo A et al., 2016 [23]	Continuous wave obturation technique with Pulp Canal Sealer EWT (Sybron Dental Specialties, Orange, CA) and BCS (Brassler, Savannah, GA).	Remaining filling material was observed in all samples regardless of the technique or sealer used.
Oltra E et al., 2017 [24]	Continuous wave compaction technique with EndoSequence sealer (Brasseler USA, Savannah, GA, USA) and AH Plus sealer (Dentsply International Inc., York, PA, USA).	The BC Sealer group retreated with chloroform showed significantly less sealer than the BC Sealer group without chloroform.
Suk M et al., 2017 [25]	Cold lateral condensation technique with EndoSequence BC Sealer (Brassler, USA), Mineral Trioxide Aggregate (MTA) Fillapex (Angelus Solucoes Odontologicas, Londrina, Brasil), and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany).	There was significant reduction in the amount of filling material after the rotary phase of retreatment in all groups ($p<0.05$), the highest in the MTA Fillapex group ($p<0.001$) and no difference between the EndoSequence BC and the AH Plus ($p=0.608$).
Athkuri S et al., 2019 [26]	Cold lateral condensation, warm vertical compaction, and thermoplasticized injectable techniques with AH Plus (DenTsply, Germany) and BioRoot RCS (Septodont, France).	The percentage of remaining filling material was higher in teeth obturated with thermoplasticized technique ($p<0.05$). The type of obturating technique used for initial root canal treatment has influenced the amount of remaining filling material and retreatment time.
Aksel H et al., 2019 [27]	Single cone technique with AH Plus (Dentsply Sirona Endodontics), NeoMTA Plus (Avalon Biomed Inc, Bradenton, FL, USA) or Endosequence BC (Brasseler, Savannah, GA, USA).	After initial retreatment, the volume of the remaining filling among the groups was similar ($p>0.05$).
Wulandari A et al., 2019 [28]	Single-cone technique with Bioceramic-sealer-base (IRoot Sp, Innovative Bioceramix,Inc, Canada).	Filling remnants were observed within the canal of all examined teeth.
Kim K et al., 2019 [29]	Continuous wave technique with AH Plus (Dentsply Maillefer, Ballaigues, Switzerland) and single cone technique with EndoSeal MTA ((Maruchi, Wonju, Korea), EndoSequence BC sealer (BC sealer; Brasseler USA, Savannah, GA, USA).	No significant differences in the percentage of remaining filling material in single and double rooted teeth, although EndoSeal MTA showed the highest value in C-shaped roots ($p<0.05$). The percentage of remaining filling material of AH Plus and EndoSeal MTA was significantly higher in C-shaped roots than in single- or double-roots ($p<0.05$), while that of BC sealer was similar across all root types.
Pedulla E et al., 2019 [30]	Single cone technique with BioRoot RCS (Septodont, Saint-Maur-des-Fosses, France) and GuttaFlow Bioseal (Coltene/Whaledent AG, Langenau, Germany).	Specimens filled with GuttaFlow Bioseal were associated with a significantly smaller volume of root filling remnants compared with BioRoot RCS.
Elsherief SA et al., 2019 [31]	Cold lateral compaction technique with BCS (Dentsply De-Trey, Konstanz, Germany).	The highest mean value was recorded in the apical that was extremely significantly higher than the coronal and middle segments in all groups.

Romeiro K et al., 2020 [32]	Single cone technique with Endosequence BC Sealer (Brasseler EUA, Savannah, GA) and AH Plus sealer (Dentsply Maillefer, Ballaigues, Switzerland).	There were no significant differences in the reduction of the volume of obturator material or dentin removal between groups (p>0.05).
Almeida A et al., 2020 [33]	Single cone technique with AH Plus sealer (Dentsply Maillefer, Ballaigues, Switzerland) and Endosequence BC Sealer (Brasseler EUA, Savannah, GA).	Complete elimination of root canal filling and sealer cannot achieved either with AH Plus and Endosequence BC Sealer.
Garrib M and Camilleri J 2020 [34]	Single cone technique with Totalfill BC sealer (FKG Dentaire, La Chaux-de-Fonds, Switzerland).	Achieving over 95% removal for both gutta-percha and the bioceramic coated version and also achieving patency and reestablishment of WL.
Volponi A et al., 2020 [35]	Single cone technique with Bio-C Sealer (Angelus, Londrina, PR, Brazil).	None of the tested supplementary cleaning techniques completely removed the residual filling material.
Alsubait S et al., 2020 [36]	Single cone technique with BioRoot RCS (Septodont, Saint-Maur-des-Fosses, France) and AH Plus (Dents-ply DeTrey, Konstanz, Germany).	Canals filled with BioRoot RCS exhibited significantly less remaining filling material than canals filled with AH Plus (p<0.05).
Crozeta BM et al., 2021 [37]	Single cone technique with AH Plus (epoxy resin–based sealer; Dentsply DeTrey GmbH, Konstanz, Germany) and BC Sealer (BCS, Brasseler USA, Savannah, GA, USA).	Lower values of remnant filling material were found for BC Sealer (16.06±14.34) compared to AH Plus (28.30±10.54).
Zhang W et al., 2022 [38]	SCO or warm vertical compaction (WVC) techniques with HiFlow sealer (Brasseler USA, Savannah, GA). Retreatment after 2 weeks or 6 months.	Obturation of the oval shaped canal with tricalcium silicate-based sealers using the SCO technique in the coronal area needs to be optimised. The retreatment was less efficacious in freshly filled canals than aged filled canals.
De Almeida SM et al., 2021 [39]	Continuous wave compaction technique used TotalFill BC (FKG Dentaire, La Chaux-de-Fonds, Switzerland) and AH Plus sealer (Dentsply-Maillefer).	The volume of obturation and the volume of remaining filling material in the entire root canal and in the cervical, middle and apical thirds of the canal between the groups were not statistically different (independent t-test, p>0.05).
Luciana da Cruz RJ et al., 2021 [40]	Single Cone Technique with Total Fill BC Sealer (FKG, La Chaux-de-Fonds, Switzerland).	Retreatment of mesial roots of mandibular molars filled with a silicate-based root canal filling material do not influence the formation of dentinal microcracks.
Jin HR et al., 2021 [41]	A single-c one technique (SCT with Endoseal TCS (Maruchi, Wonju, Korea) and continuous wave technique (CWT) resin-based sealer (AH Plus).	The AH plus group showed significantly fewer remnants than the Endoseal TCS group after GP removal (p<0.05). Re-treated canals and initially treated canals had similar void volumes (p>0.05).
Eid BM et al., 2021 [42]	Warm vertical condensation with Totalfill BC sealer (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland).	Rotary retreatment files failed to totally remove the root canal filling material.
Mufti DG and Al-Nazhan SA 2021 [43]	Single-matched gutta-percha cone (size 25, taper 06) with EndoSequence BC Sealer [Meta-Biomed, Cheongju, Republic of Korea) and continuous wave condensation technique with AH Plus Sealer De Trey Dentsply, Konstanz, Germany).	Residual filling material in most of the specimens in the Bioceramic group and AH Plus group at different levels, regardless of the root curvature angle.
Rajda M et al., 2021 [44]	Single cone technique with AH Plus sealer (DeTreyDentsply, Konstanz, Germany) and TotalFill (FKG, La Chaux de Fonds, Switzerland).	A combination of BCS and bioceramic gutta-percha was more effectively removed from canals using a reciprocating instrument, with a filling remnants volume of 4.01±3.13 mm^3, in comparison to the combination of epoxy resin-based sealer and gutta-percha (6.96±2.70 mm^3) (p<0.05).
Sinsareekul C and Hiran-Us S 2022 [45]	Single cone technique with iRoot SP (Innovative BioCeramix, Vancouver, BC, Canada).	The XP endo Finisher R and Passive Ultrasonic Irrigation (PUI) exhibited greater efficacy compared with syringe irrigation in the reduction of residual filling materials after retreatment in root-filled teeth with a BCS.
Agrawal S et al., 2022 [46]	Cold lateral compaction technique with iRoot SP BCS Innovative Bioceramic, Vancouver, Canada) and AH Plus epoxy resin-based sealer.	Percentage of residual volume of AH Plus sealer (0.02%) was lower than that of iRoot SP sealer group (0.06%) and this difference was statistically significant (p<0.05).
Tavares KIMC et al., 2023 [47]	Continuous wave condensation technique with NeoMTA Plus (NuSmile, Houston, Texas, United States) or AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany).	NeoMTA Plus or AH Plus did not influence the retreatment of curved root canals.
Barakat RM et al., 2022 [48]	Single cone technique with TotalFill BC sealer (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland).	A significant increase occurred in the number of cracks post retreatment protocols.
Kapetanović Petričevitimes G et al., 2022 [49]	Single Cone Obturation (SCO) technique with BioRoot RCS (BioRoot RCS, Septodont, France).	The results of the study showed that all the tested irrigation techniques reduced a statistically significant amount of the remnant filling material at retreatment (p<0.05).
Angerame D et al., 2022 [50]	SCO technique with BioRoot RCS (BioRoot RCS, Septodont, France).	Percentage of residual was less in Shock Wave Enhanced Emission Photoacoustic Streaming (SWEEPS).
Almohareb RA al., 2023 [51]	Single standardised master cone of Gutta-percha (GP) size 30 and 4% taper with TotalFill BC sealer (FKG Dentaire SA).	The amount of material removed following ultrasonic and diode laser was significantly greater than that of manual irrigation (p<0.0001).
Jamleh A et al., 2022 [52]	SCO technique with TotalFill Bioceramic (TFBC) FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) and AH Plus (AHP) sealer (Dentsply, Tulsa, OK, USA).	A higher amount of remaining obturating materials was found in the AH Plus compared to that in the TotalFill bioceramic.
Amin AD 2023 [53]	Single cone approach with Total Fill BCS (FKG Dentaire, La Chaux de Fonds, Switzerland) and Dia-ProSeal epoxy resin-based sealer (Dia dent, Korea).	All specimens had residual filling material after retreatment.
Madarati MA et al., 2023 [54]	Continuous waves compaction technique with BioRoot RCS (Septodent, France).	The remaining filling materials after using rotary systems (10.1%) was greater than after using reciprocating systems (3.8%) (p<0.001).
Colombo JA et al., 2023 [55]	Single-cone technique with AH Plus (Dentsply Sirona, Konstanz, Germany) and and Bio-C Sealer (Angelus Indústria de Produtos Odon-tológicas S/A, Londrina, Paraná, Brazil).	No technique was able to completely clear the canals of filling material.
Baraba A et al., 2023 [56]	Cold single cone technique and a warm core-carrier technique with AH Plus sealer (DeTreyDentsply, Konstanz, Germany)+Reciproc gutta-percha (VDW, Munich, Germany), TotalFill BC sealer (TotalFill, FKG, La Chaux de Fonds, Switzerland)+TotalFill BC Points (TotalFill, FKG, La Chaux de Fonds, Switzerland), AH Plus sealer+Guttafusion obturator (VDW, München, Germany), and MTA Fillapex (Angelus Soluções Odontológicas, Londrina, Brazil)+Guttafusion obturator.	The root canal filling was not removed completely from any of the samples.
Yang R et al., 2021 [57]	Single-cone technique with iRoot SP (Innovative Bioceramix, Vancouver, BC, Canada).	None of the additional techniques in this study completely removed the residual iRoot SP and gutta-percha.
Farrayeh A et al., 2023 [58]	Single cone technique with Ceraseal, (Metabiomed, Cheongju, Republic of Korea).	Residual filling material was detected in all specimens.

[Table/Fig-1]: Type of obturation technique and sealer used [13-58].

The ease of retrieval for Endoseal MTA, EndoSequence BCS, and AH Plus sealers in single and double-rooted canals did not exhibit any significant differences. Conversely, significant remnants were present in the C-shaped root canals that were obturated with Endoseal MTA, followed by AH Plus and EndoSequence BCS [29]. Teeth filled using the thermoplasticized technique exhibited a significant increase in the amount of remaining filling material ($p<0.05$) [26].

Retreatment Technique Solvent

Solvents used during the retreatment of canals filled with BCSs are described in [Table/Fig-2] [16,20,22,24]. The use of chloroform and rotary instruments resulted in more residual root canal-filling material than rotary instruments alone [16]. Using 10% FA, 20% HCl, and chloroform may achieve patency for most cases obturated with gutta-percha and EndoSequence BCS [20]. The BCS group that underwent retreatment with chloroform exhibited a significant decrease in sealer when compared to the BCS group without chloroform [24]. Contrastingly, the time to reach the WL in the solvent group (chloroform) was significantly shorter than that in the groups without solvents ($p<0.05$). However, less time was needed to achieve satisfactory gutta-percha removal and root canal refinement in the non-solvent group than in the solvent group ($p<0.05$) [22].

Reciprocating and rotary systems: A total of 32 studies used continuous rotary files during retreatment [13-22,24,27,29,30,34,36, 38,39-43,45,48,49,51-53,57,58]. Eleven studies used reciprocating files during retreatment [23,32,33,35,37,44,46,47,50,55,56], and three studies compared continuous nickel-titanium rotary and reciprocation systems during retreatment [28,31,54] as described in [Table/Fig-3].

No significant differences ($p\geq0.05$) in gutta-percha and sealer removal were found between Trushape and Reciproc files (RC). The reciprocating file allowed for faster filling removal than the Trushape files ($p<0.05$) [23]. In all groups, there was a significant decrease in the amount of filling material after retreatment with ProTaper Universal rotary instruments (Maillefer, Baillaigues, Switzerland) ($p<0.05$). The MTA Fillapex group showed the highest reduction ($p<0.001$), and there was no difference between the EndoSequence BCS and the AH Plus groups ($p=0.608$) [23]. Specifically, rotary motion instruments were compared with reciprocal motion instruments, and reciprocal motion instruments reportedly removed a greater amount of filling material from the root canal, especially from the apical third [28]. ProTaper and Gates Glidden (GG) showed a higher mean value than RC ($p=0.023$). These findings indicated that RC files remove more filling materials than ProTaper and GG with H files [31]. Reciproc and Reciproc Blue (RB) are suitable for treating severely curved root canals that have been filled with either bioceramic- or resin-based sealers [32].

The effectiveness of the one curve rotary file in removing the filling materials did not show any improvement [43]. R25 Reciproc

Authors	Type of solvent	Conclusion
Sherif D et al., 2017 [16]	With and without chloroform solvent.	Using chloroform during removal of root canal filling material using rotary instruments was associated with larger amount of residual root canal filling material compared to using rotary instruments only.
Rezaei G et al., 2023 [20]	10% Formic Acid (FA), 20% Hydrochloric Acid (HCl), and chloroform.	Patency was achieved in all canals, except for 1 in the chloroform group. A 20 percent hydrochloric acid was superior to 10% % formic acid and chloroform in achieving patency in teeth obturated with EndoSequence BC Sealer. Regardless of the solvent used, patency may be achieved for most of the cases obturated with gutta-percha and EndoSequence BC Sealer.
Ma J et al., 2012 [22]	with and without a solvent chloroform.	The time required to reach a WL was significantly less in the solvent groups than in the non-solvent groups ($p<0.05$). However, in the non-solvent groups, less time was required to achieve satisfactory gutta-percha removal and root canal refinement than in the solvent groups ($p<0.05$).
Oltra E et al., 2017 [24]	With or without chloroform.	The BC Sealer group retreated with chloroform showed significantly less sealer than the BC Sealer group without chloroform. WL and patency were re-established in 93% of teeth in group canals obturated with GP/BC sealer and retreated using chloroform. In contrast, although WL was re-established in 93% of group canals obturated with GP/BC sealer and retreated without chloroform teeth, patency could only be re-established in 14% of the cases, which was significantly different from the other groups ($p<0.0001$).

[Table/Fig-2]: Type of solvents used during retreatment of Bioceramic endodontic sealers [16,20,22,24].

Authors	Types of machine file	Conclusion
Liu H et al., 2021 [13]	D-Race DR1 instrument (size 30, 0.10 taper; FKG Dentaire) was used to remove the coronal 3 mm of the root filling material to facilitate initial penetration of the XPS (FKG Dentaire, La Chaux-de-Fonds, Switzerland)	The XP-endo Shaper (XPS) removed more filling material in the SCO using EndoSequence BC sealer and SCO using AH Plus sealer groups, compared with the AHW group ($p<0.05$).
Hess D et al., 2011 [14]	EndoSequence 0.04 tapered NiTi rotary (Brasseler USA, Savannah, GA)	Conventional retreatment techniques are not able to fully remove Bioceramic Sealer (BCS).
Simsek N et al., 2014 [15]	R-Endo files (Micro-Mega, Besançon, France)	There was no difference among the sealers and retreatment techniques. All of the retreatment systems in each group left remnants, regardless of the sealer.
Sherif D et al., 2017 [16]	ProTaper universal retreatment (Dentsply Maillefer, Ballaigues, Switzerland)	None of the used retreatment techniques were capable of completely removes the filling material within root canals.
Kakoura F and Pantelidou O 2018 [17]	ProTaper Universal Retreatment Dentsply Maillefer, Ballaigues, Switzerland)	There was no statistically significant difference in the WL and patency recovery among the groups. All specimens exhibited filling residues in the root canal walls.
Abdelrahman MH and Hassan MY 2020 [18]	Protaper retreatment universal system (Dentsply Maillefer, Ballaigues, Switzerland)	The quantity of remnants of root filling material with well root and ceraseal were significantly more, compared to ADSEAL.
Hassan R and Elzahar S 2022 [19]	D-Race rotary files (FKG Dentaire)	All of the used methods failed to produce completely clean canal walls.
Rezaei G et al.,2023 [20]	The coronal third was softened and removed using an activated touch and heat (Dentsply Tulsa Dental) at 160 C. The 40/0.04 Vortex Blue rotary file (Dentsply Tulsa Dental)	The amount of residual sealer remaining on the walls was not evaluated.
Khosasi A et al., 2023 [21]	ProTaper Universal Retreatment files (Dentsply Maillefer, Ballaigues, Switzerland)	The supplementary use of XP-Endo Finisher enhances the cleanliness of the root canal walls during endodontic retreatment procedures.
Ma J et al., 2012 [22]	ProTaper Universal Retreatment system (Dentsply/Maillefer, Ballaigues, Switzerland)	None of the retreatment techniques were able to completely remove all gutta-percha/sealer from the oval canals.
De Siqueira Zuolo A et al., 2016 [23]	Reciproc (VDW, Munich, Germany) or Trushape files ((Dentsply Tulsa)	No significant differences ($p\geq0.05$) in gutta-percha and sealer removal were found between Trushape and Reciproc files. The reciprocating file allowed for faster filling removal than the Trushape files ($p<0.05$).

Oltra E et al., 2017 [24]	ProFile ISO Rotary Files (Dentsply Maillefer) of size 45/0.04 taper at 300 rpm were used until WL was reached or resistance was met. If the WL was reached, crown-down instrumentation was performed using Vortex Blue (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) size 45/0.04 at 500 rpm to WL to remove the remaining obturation material	Conventional retreatment techniques are not always able to fully remove all the filling material from the canal.
Suk M et al., 2017 [25]	ProTaper Universal rotary instruments (Maillefer, Baillaigues, Switzerland)	The MTA Fillapex was the most easily removed during rotary phase of the retreatment, and there were no differences in the amount of the remaining filling material between EndoSequence BC and the AH Plus groups after rotary phase of the retreatment.
Athkuri S et al., 2019 [26]	Retreatment instruments M Two R1 (#15/.05) and M Two R2 (#25/.05) (VDW GmbH, Germany)	Significantly more filling material debris was observed in apical third ($p<0.05$). Retreatability of the BioRoot RCS sealer was similar to the AH Plus sealer.
Aksel H et al., 2019 [27]	ProTaper Universal Retreatment files (PTUR, Dentsply Sirona Endodontics)	The amount of filling materials in each group decreased significantly after retreatment with rotary files ($p<0.05$).
Wulandari A et al., 2019 [28]	ProTaper Universal Retreatment System (Dentsply Maillefer, Ballaigues, Switzerland) and R25 Reciproc Blue (VDW, Switzerland)	Compared with the rotary motion instrument, the reciprocal motion instrument removes a larger amount of filling material from the root canal, particularly at the 1/3 apical area.
Kim K et al., 2019 [29]	ProFile system (Dentsply Maillefer) was used with MAF sizes of 40/0.06	The percentage of remaining filling material of AH Plus and EndoSeal MTA was significantly higher in C-shaped roots than in single or double roots ($p<0.05$), large amount of EndoSeal MTA remained after retreatment, especially in C-shaped root canals.
Pedullà E et al., 2019 [30]	R-Endo nickel-titanium rotary instruments (Micro-Mega, Besançon, France)	Significantly smaller volumes of root filling remnants of GuttaFlow Bioseal, than BioRoot RCS, were present after their removal with rotary instruments and irrigation.
Elsherief SA et al., 2019 [31]	ProTaper retreatment files (Dentsply Maillefer, Ballaigues, Switzerland), Reciproc R25 file (Reciproc; VDW, Munich, Germany) and GG drills (Dentsply Maillefer) to remove gutta-percha from the coronal third; H files	ProTaper and GG groups showed a statistically higher mean value compared to Reciproc ($p=0.023$). However, there was no significant difference between ProTaper and GG files. Reciproc file removes more filling materials than ProTaper and GG with H files. None of the techniques completely removes the filling materials from the large oval root canal.
Romeiro K et al., 2020 [32]	Reciproc file (VDW, Munich, Germany) and/Reciproc Blue file (VDW, Munich, Germany)	Reciproc and Reciproc Blue can be indicated in retreatment of severely curved root canals filled either with bioceramic or resin-based sealers. All tested instruments obtained similar efficacy in filling material removal procedures, although no system completely removed the filling material. There were also no differences in the amount of extruded material or apical transportation ($p>0.05$).
Almeida A et al., 2020 [33]	Reciproc R40 file (VDW, Munich, Germany) and/Reciproc Blue RB40 file (VDW, Munich, Germany)	The use of AH Plus and EndoSequence BC Sealer, and filling material removal using RC and RB instruments did not induce dentinal defects.
Garrib M and Camilleri J 2020 [34]	ProTaper Gold finisher file (ProTaper Gold; PTG, Dentsply, Tulsa, OK) with three different solutions 17% ethylene diamine tetracetic acid (Cerkamed, Stalowa Wola, Poland), 10% formic acid (Sigma Aldrich, Gillingham, UK) and 20% formic acid (Sigma Aldrich, Gillingham, UK)	10% formic acid used in conjunction with mechanical instrumentation was the most efficient method to remove the obturation material from the root canal. 17% Ethylenediaminetetraacetic acid (EDTA) and 10% formic acid applied for 5 min did not damage the dentine but effected the structural integrity of the sealer.
Volponi A et al., 2020 [35]	Reciproc R40 (40/0.06) system (VDW, Munich, Germany)	Reciproc R40 file reached the WL, and foraminal patency could be maintained with a #15 K-type file (Dentsply Maillefer).
Alsubait S et al., 2020 [36]	ProTaper Universal retreatment system (Dentsply Maillefer, Ballaigues, Switzerland)	The canals that had been filled with BioRoot RCS exhibited significantly less remaining filling material than canals that had been filled with AH Plus after retreatment with rotary files and after the additional use of PUI ($p=0.048$ and $p=0.006$, respectively).
Crozeta BM et al., 2021 [37]	R50 (50.05) instrument (VDW GmbH, Munich, Germany)	The remaining filling material was observed in all samples regardless the filling material.
Zhang W et al., 2022 [38]	ProTaper Universal Retreatment files (PTUR, Dentsply Sirona Endodontics) and Reciproc R40 (VDW, Munich, Germany)	The efficiency of retreatment in the oval-shaped canal was closely related to the storage time rather than the filling technique using a tricalcium silicate sealer. The retreatment was less efficacious in freshly filled canals than aged filled canals.
De Almeida SM et al., 2021 [39]	ProTaper Universal Retreatment (PTUR) sequence (Dentsply-Maillefer)	The filling material could not be entirely removed from any specimen.
Luciana da Cruz RJ et al., 2021 [40]	ProTaper Universal Retreatment (PTUR) (Dentsply-Maillefer)	New dentinal microcracks were not observed after removal of the filling material.
Jin HR et al., 2021 [41]	ProTaper universal Retreatment files (Dentsply Sirona, Ballaigues, Switzerland)	Endoseal TCS sealer and AH Plus sealer had a similar Retreatment efficacy, regardless of which sealer was used in the previous treatment.
Eid BM et al., 2021 [42]	Mani NRT-GPR system (Mani Inc, Tokyo, Japan)	Rotary retreatment files failed to totally remove the root canal filling material.
Mufti DG and Al-Nazhan SA 2021 [43]	One Curve; size 25, taper 06; Micro-Mega, Besançon, France)	It is difficult to achieved complete removal of bioceramic filling material from the root canal system using rotary file.
Rajda M et al., 2021 [44]	R25 Reciproc instruments (VDW, Munich, Germany)	A reciprocating instrument was more effective in removing BCSs than epoxy resin-based sealers, although none of the root canal filling materials were completely removed from the root canals.
Sinsareekul C and Hiran-Us S 2022 [45]	ProTaper Universal retreatment files (Dentsply Maillefer)	None of the techniques completely removed the filling materials.
Agrawal S et al., 2022 [46]	V-Blue reciprocating file system (Dentsply Tulsa Dental Specialties Dentsply International, Inc)	iRoot SP sealer remained after retreatment using V-Blue file as compared with AH Plus sealer.
Tavares KIMC et al., 2023 [47]	ProDesign Logic (PDL RT; Easy Equipamentos Odontológicos, Belo Horizonte, Minas Gerais, Brazil) RT 25/0.08, reciprocating PDR 25/0.06 and apical preparation with PDR 35/0.05	Percentage of remaining filling material was similar between the root canals filled with NeoMTA Plus or AH Plus sealer after retreatment using PDR 35/0.05, and after additional apical preparation using PDL 50/0.01 ($p>0.05$). However, PDL 50/0.01 significantly decreased the percentage of remaining filling material in the apical third after the additional apical preparation for both sealers ($p<0.05$).

Barakat RM et al., 2022 [48]	D-Race NiTi rotary instruments (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland)	NiTi rotary root canal retreatment was associated with a significant increase in dentinal microcracks. A significant increase occurred in the number of cracks post retreatment protocols, specifically in the coronal and middle canal thirds, compared to pre and post instrumentation (p=0.0001).
Kapetanović Petričević G et al., 2022 [49]	RB 40 (40/0.06) file (VDW Dental, München, Germany)	All tested techniques had similar efficacy in the removal of the remaining filling remnants.
Angerame D et al., 2022 [50]	Reciproc R40 file then R50 Reciproc Blue (VDW GmbH, Munich, Germany)	The reciproc/Shock Wave Enhanced Emission Photoacoustic Streaming (SWEEPS) technique showed the better performance in intact teeth compared with PUI technique.
Almohareb RA et al., 2023 [51]	D-Race retreatment NiTi rotary files employed in a crown-down fashion, followed by Race Evo file (FKG Dentaire SA) size 30, with 0.04 taper	The use of ultrasonic and diode laser adjuncts to NiTi rotary retreatment techniques showed significant improvement in gutta-percha with BC sealer removal. However, surfactants had no effect on the efficacy.
Jamleh A et al., 2022 [52]	XP Shaper (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland)	Endodontic sealer had an influence on retreatability, and the TotalFill bioceramic showed less remaining obturating materials and lower retreatment forces in the apical direction compared to the AH Plus in extracted teeth with oval canals.
Amin AD 2023 [53]	Fanta retreatment kit (Fanta dental materials, China)	Fanta files and XP endo finisher R activation, the canals that had been filled with Total fill showed considerably less filling material than the canals that had been filled with Dia proseal (p=0.048 and p=0.006, respectively).
Madarati MA et al., 2023 [54]	35 WaveOne-Gold files (Dentsply Sirona) powered by the Silver-Reciproc motor (VDW, Germany), Reciproc-Blue R40 file (VDW) powered by the Silver-Reciproc motor (VDW), #40 R-Motion reciprocating files (FKG) were used by the Silver-Reciproc motor (VDW), Fanta-AF-One (#35/06) (Fanta Dental) rotary files and Tango-Endo (#30/04) (Essential Dental Systems) rotary files	The remaining filling materials after using WaveOne-Gold (2%) and Reciproc-Blue systems (2.6%) were less than those in the R-Motion (6.8%), Tango-Endo (9.5%) and Fanta-AF-One (10.7%) systems (p<0.05).
Colombo JA et al., 2023 [55]	Reciproc R40 file (VDW GmbH, Germany)	After instrumentation with the Reciproc R40, the volume of residual filling material was significantly greater in the BC group than in the AH group (p=0.035). Bio-C sealer was more difficult to remove with the Reciproc file than AH Plus.
Baraba A et al., 2023 [56]	R25 Reciproc instruments (VDW, Munich, Germany)	The additional treatment with SWEEPS significantly reduced the volume of the root canal filling materials in all experimental groups compared to the removal of root canal filling using only reciprocating instruments (p<0.05).
Yang R et al., 2021 [57]	ProTaper Universal retreatment (PTUR) system (Dentsply, Maillefer, Baillaigues, Switzerland)	All groups had residual root filling materials in the root canals after mechanical retreatment.
Farrayeh A et al., 2023 [58]	D-Race retreatment system (FKG Dentaire, La-Chaux-de Fonds, Switzerland) and ProTaper Universal Retreatment system (Dentsply Maillefer, Ballaigues, Switzerland)	No retreatment system was able to totally remove the calcium silicate-based sealer from the root canal at the middle and apical thirds (p>0.05).

[Table/Fig-3]: Type of NiTi used for retreatment [13-58].

instruments (VDW, Munich, Germany) were more effective in removing BCSs than epoxy resin-based sealers [44]. A significant reduction in the amount of remaining filling material in the apical third was observed after the additional apical preparation when using ProDesign Logic 50/0.01 (PDL RT; Easy Equipamentos Odontológicos, Belo Horizonte, Minas Gerais, Brazil) (p<0.05) [47]. Calcium silicate-based sealer fillings were found to be more efficiently removed by endodontic reciprocation systems, albeit at a slightly longer duration compared to rotary systems [54]. The BCS group exhibited a significantly higher volume of residual filling material compared to the AH group (p=0.035) following instrumentation with the Reciproc R40 [55].

Regaining apical patency and re-establishing Working Length (WL): Only six studies mentioned regaining apical patency and re-establishing WL [14,17,20,24,34,35]. In 70% of the samples, the WL was not achieved when the BCS/master cone was short of the WL. However, patency was re-established in 80% of samples with the BCS/master cone to the WL [14]. Furthermore, the utilisation of 10% FA in combination with mechanical instrumentation proved to be the most effective approach in eliminating the obturation material from the root canal. This method successfully achieved a removal rate of over 95% for both gutta-percha and bioceramic-coated versions, in addition to the achievement of patency and re-establishment of WL [34]. Another study compared three different sealers: Gutta-percha (GP)/AH26, GP/TotalFill BCS, and GP/BioRoot RCS. No significant differences were found in the WL and patency recovery among the sealers. Residual debris was observed in all samples, regardless of the sealer used. All sealers were similarly removed, and the WL and patency were re-established with all types of sealers [17]. Achieving patency in teeth obturated with EndoSequence BCS was found to be more successful when utilising 20% HCl compared to 10% FA and chloroform. Regardless of the solvent utilised, patency could be achieved in the majority of cases where GP and EndoSequence BCS were used for obturation [20]. All procedures continued until the Reciproc R40 file reached the WL, and foraminal patency could be maintained with a #15 K-type file [35]. Canals obturated with GP/BCS and retreated using chloroform, WL and patency were successfully re-established in 93% of teeth. However, only 14% of these cases were able to regain patency, which showed a significant difference compared to the other groups (p<0.0001) [24].

Time: Bioceramic-based sealers formed hydroxyapatite with the root dentin, which may pose challenges in removing these sealers during retreatment procedures [13].

A total of 14 studies included the time taken for retreatment of the BCS-filled teeth [14,15,20,22,23,26,30,32,36,38,52-54,58]. The time required to remove the filling materials using the Tango-Endo (3.7 min), Fanta-AF-One (4.1 min), and R-Motion (4.1 min) systems was shorter than that required by the RB (5.4 min) and WaveOne-Gold (4.9 min) systems [54]. TotalFill bioceramic required less retreatment time than AH Plus; however, the difference was not statistically significant {44.38 (±13.73) versus 53.93 (±23.34) s} (p=0.418) [52]. The mean time to complete retreatment of canals filled with BioRoot RCS and GuttaFlow Bioseal was not significantly different (25.52 and 21.56 min, respectively) (p>0.05) [30]. Hess D et al., found that using BCS with a single GP master cone placed to the full WL resulted in a longer retreatment time compared with when the master GP cone was trimmed to fit approximately 2 mm short of the WL.

Simsek N et al., found that there was no significant difference in the time required to remove the AH Plus, iRoot SP, or MM Seal (p>0.05) [15]. The time to reach the WL was significantly shorter in the solvent groups than in the non-solvent groups (p<0.05) [22]. Moreover, no significant difference was found in the time to achieve patency between chloroform and 10% FA. The median time to achieve patency for the chloroform and FA groups was 28.2 and 33.2 seconds, respectively (p>0.05). However, there was a significant difference between chloroform and HCl. The median time to achieve patency for the chloroform and HCl groups was 28.2 and 14.8 seconds, respectively (p<0.05). The median time to

achieve patency for the 10% FA and 20% HCl groups was 33.2 and 14.8 seconds, respectively (p<0.05) [20]. For the retreatment of roots filled with BCS, the time taken was 180.0±22.5 sec using the Reciproc file and 253.3±31.5 sec with the Trushape file. It was longer than roots filled with a pulp canal sealer and retreated using the Reciproc file (133.4±14.9 sec) and Trushape file (199.2±18.8 sec) (p<0.05) [23]. Moreover, a significantly shorter retreatment time was required for the AH Plus group than for the BioRoot RCS group (p<0.05) [36]. Retreatment of canals filled with BCS was more time-consuming than that of canals filled with AH Plus sealer. Moreover, the retreatment time for the AH Plus/Reciproc group was significantly shorter than that for the BCS/Reciproc, BCS/RB, and AH Plus/RB groups (p=0.004) [32]. Total Fill bioceramic required less retreatment time than AH Plus, albeit with no statistical significance 44.38±13.73 versus 53.93±23.34 S (p=0.418) [52].

The mean time to complete the retreatment of canals filled with BioRoot RCS and GuttaFlow Bioseal was not significantly different (25.52 minutes and 21.56 minutes, respectively) (p>0.05) [30]. The Dia-ProSeal group had considerably less retreatment time than the TotalFill BCS group (p<0.05) [53]. Additionally, the time is affected by the obturation technique. Significantly less time was required for retreatment in teeth obturated with the lateral condensation technique (p≤0.05) than for teeth obturated with warm vertical compaction and thermoplasticized injectable techniques [26]. The time taken to remove the filling material was longer in the warm vertical compaction group than in the Single Cone Obturation (SCO) group [38]. The motion of NiTi files also affected time. The time required to achieve the full working length was significantly higher with the Protaper Universal Retreatment and Protaper Universal Retreatment followed by the use of XP-Endo Finisher, as compared to D-Race or D-Race followed by the use of XP-Endo Finisher R, respectively (p<0.05) [58].

Supplementary Techniques for Retreatment

According to Schirrmeister JF et al., it is crucial to completely remove any previous obturation materials as the presence of necrotic tissue and bacteria within the remaining Gutta-percha (GP) and sealer can potentially lead to post-treatment disease [12]. Many new techniques are expected to allow greater removal of the remains of GP and sealers. Supplementary techniques were used in 25 of the included articles and are described in [Table/Fig-4] [13,15,19,21,23,25,27,30,35-38,42,45,48-58]. Supplementary techniques such as ultrasonic-assisted irrigation [15,19,23,30,35-37,45,54,55] and laser-activated irrigation [25,56], ultrasonic-assisted irrigation, and laser-activated irrigation [48-51,57].Significantly improved gutta-percha with BC sealer removal was observed when incorporating UI and LI adjuncts into NiTi rotary retreatment techniques. However, the efficacy of surfactants remained unaltered [51]. The Shock Wave-enhanced

Authors	Supplementary technique	Conclusion
Liu H et al., 2020 [13]	XP-endo Shaper (XPS) and XP-endo Finisher R (XPFR) (FKG Dentaire, La Chaux-de-Fonds, Switzerland)	The combined use of XPS and XPFR instruments efficiently removed filling material in the SCO using EndoSequence BC sealer group, followed by the SCO using AH Plus sealer and warm vertical compaction using AH Plus sealer groups (p<0.05).
Simsek N et al., 2014 [15]	ESI ultrasonic tips ultrasonic tips of different sizes (15-35) (EMS, Nyon, Switzerland)	Both R-Endo and ultrasonic tips performed similarly in terms of operating time.
Hassan R and Elzahar S 2022 [19]	XP Finisher, XP Finisher R (FKG Dentaire, La Chaux-de-Fonds, Switzerland), Syringe irrigation and PUI	The cleaning efficiency of XP Finisher R and XP Finisher was superior to that of PUI after the retreatment of the hydraulic calcium silicate sealer.
Khosasi A et al., 2023 [21]	XP-Endo Finisher (FKG, La Chaux de Fonds, Switzerland)	The supplementary use of XP-Endo Finisher significantly enhances the cleanliness of the root canal walls during endodontic retreatment procedures. However, XP-Endo Finisher could not completely remove all obturation material.
De Siqueira Zuolo A et al., 2016 [23]	CPR-7 Ultrasonic Tip (Obtura Spartan End-odontics, Algonquin, IL)	The percentage of remaining filling material was higher in BCS than in the groups filled with Pulp Canal Sealer (p<0.05).
Suk M et al., 2017 [25]	Laser-activated irrigation (Photoninitiated Photoacoustic Streaming (PIPS)	There was significant reduction of the filling remnants after the PIPS in all groups (p<0.05). The PIPS was the most successful in the removal of the MTA Fillapex material (p<0.05), followed by the EndoSequence BC, and the least removed AH Plus material (p<0.05).
Aksel H et al., 2019 [27]	XP-Endo Finisher file (FKG, La Chaux-de-Fonds, Switzerland)	Additional preparation with the XP-Endo Finisher improved the removal of filling materials regardless of the sealer type (p<0.05).
Pedullà E et al., 2019 [30]	Ultrasonically Activated Irrigation (UAI) (Irrisafe 25, Satelec Acteon, Merignac, France), Syringe irrigation. and Tornado Brush (M.I.B, Suresnes, France)	BioRoot RCS, Tornado Brush and UAI were associated with a significantly smaller volume of root filling remnants compared with syringe irrigation (p<0.05).
Volponi A et al., 2020 [35]	Ultrasonic assisted irrigation (Helse Ultrasonic, Santa Rosa do Viterbo, SP, Brazil), EndoActivator system (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) and XP-endo Finisher R instrument (FKG Dentaire, La Chaux-de-Fonds, Switzerland)	XPR was more effective than UAI and EAI in removing filling material in mandibular premolars with oval canals. No significant difference was observed among the residual volumes found for XPR, UAI and EAI before (p>0.05) or after (p>0.05) performing the supplementary irrigation techniques.
Alsubait S et al., 2020 [36]	PUI (Irri-safe; Satelec Acteon Group, Merignac, France)	The addition of PUI resulted in a significant decrease in the residual material in both groups (p<0.05).
Crozeta BM et al., 2021 [37]	Ultrasonic tips (Helse Ultrasonic, São Paulo, SP, Brazil) and XP-endo Finisher R instruments (FKG, La Chaux-de-Fonds, Switzerland)	Lower values of remnant filling material were found for the ultrasonic tip (18.95±11.05) compared to XP-endo Finisher R (25.41±15.81) (p=0.025).
Zhang W et al., 2021 [38]	XPFR files (XPFR; FKG Dentaire, La Chaux-de-Fonds, Switzerland)	The percentage volume of the filling material removed after initial retreatment and XPFR cleaning was significantly higher in the six-month group than in the two-week groups (p<0.05). The XPFR instrument proved effective in the removal of the remaining materials from the oval-shaped canal.
Eid BM et al., 2021 [42]	XP-endo Finisher R (FKG, La Chaux-de-Fonds, Switzerland)	Supplementary removal approaches significantly improved filling material removal (p<0.05). Supplementary methods have improved root canal filling material removal, where XP-FR significantly removed more filling than manual H-filing.
Sinsareekul C and Hiran-Us S 2022 [45]	Conventional Syringe Irrigation (CSI), PUI and XP-endo Finisher R (FKG Dentaire, La Chaux-de- Fonds, Switzerland)	The XPR removed significantly more residual filling materials (p<0.01) followed by PUI and CSI (p<0.05). Similar efficacy was found in the total root canal and all root thirds.
Barakat RM et al., 2022 [48]	PUI using a size 15 ultrasonic K file (Satelec Ultrasonic Unit) and laser-activated irrigation (laser diode 300 µm fiber tip)	Ultrasonic or laser-activated irrigation as adjunct retreatment techniques did not reveal a significant increase in dentinal microcracks within the roots.

Kapetanović Petričević G et al., 2022 [49]	Ultrasonically-activated Irrigation (UAI), Conventional Syringe Needle Technique (SNI) and SWEEPS mode of the Erbium-doped Yttrium Aluminium Garnet (Er:YAG) laser	All the tested irrigation techniques reduced a statistically significant amount of the remnant filling material at retreatment ($p<0.05$), and there were no statistically significant differences in efficacy between the three methods.
Angerame D et al., 2022 [50]	PUI and SWEEPS	The minor percentage of residues were observed in SWEEPS, with a volume of 0.447±0.356% of the endodontic space ($p<0.001$).
Almohareb RA et al., 2023 [51]	Diode laser (LI) (Master lase/expert lase, Kavo, Biberach/Riß) and ultrasonic (UI) activated irrigation	The use of ultrasonic and diode laser adjuncts to NiTi rotary retreatment techniques showed significant improvement in gutta-percha with BC sealer removal. However, surfactants had no effect on the efficacy.
Jamleh A et al., 2022 [52]	XP Shaper system (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland)	Total Fill bioceramic showed less remaining obturating materials and lower retreatment forces in the apical direction compared to the AH Plus in extracted teeth with oval canals.
Amin AD 2023 [53]	XP endo finisher R (FKG, La Chaux-de-Fonds, Switzerland)	The Total fill and Dia proseal groups, the percentages of remaining filling material significantly decreased with the addition of XP endo finisher R activation (p 0.001 and p=0.001, respectively).
Madarati AA et al., 2023 [54]	With and without PUI	Using PUI resulted in less remaining filling materials (1.44%) when compared to using only rotary or reciprocating systems (6.27%) [$p<0.001$]. The PUI significantly improved removal of the root-canals' filling materials. Reciprocating systems and PUI are recommended whenever root-canals retreatment is considered regardless of using calcium silicate-based sealers.
Colombo J et al., 2023 [55]	Continuous Ultrasonic Irrigation (CUI)	CUI improved the removal of residual filling material regardless of sealer type.
Baraba A et al., 2023 [56]	SWEEPS	SWEEPS can be used to enhance the removal of both epoxy-resin-based and calcium-silicate-containing sealers, in combination with single-cone and carrier-based obturation techniques.
Yang R et al., 2021 [57]	CSI, PUI and Photon-Initiated Photoacoustic Streaming (PIPS)	Additional use of PIPS removed significantly higher volume of root fillings than PUI and CSI techniques ($p<0.05$). None of the additional techniques in this study completely removed the residual iRoot SP and gutta-percha.
Farrayeh A et al., 2023 [58]	XP endo finisher R (FKG, La Chaux-de-Fonds, Switzerland)	Xp-Endo Finisher R significantly increased the ability to remove materials regardless of the initially used retreatment system ($p<0.05$).

[Table/Fig-4]: Type of supplemental techniques used [13,15,19,21,23,25,27,30,35-38,42,45,48-58].

Emission Photoacoustic Streaming (SWEEPS) mode of the Er:YAG laser, UAI, and Syringe Needle Technique (SNI) all demonstrated comparable effectiveness in eliminating residual filling remnants [49]. The additional application of PIPS resulted in a significant decrease in the quantity of root fillings when compared to the PUI and Conventional Syringe Irrigation (CSI) techniques ($p<0.05$) [57]. Interestingly, all supplementary techniques observed enhanced cleanliness of the root canal walls during endodontic retreatment procedures. Supplementary techniques enhanced the retrievability of the root canal-filling material compared to the primary technique.

Dentinal Microcracks

Only a few comparative studies on dentinal microcracks exist. Three articles investigated dental microcracks during the retreatment of root canal systems filled with a BCS [33,40,48]. Almeida A et al., removed a root canal filling with two different sealers using RC and RB [33].

The use of AH Plus and EndoSequence BCS, as well as the removal of the filling material using RC and RB instruments, did not induce dentinal defects. In contrast, Luciana da Cruz RJ et al., utilised GP and total fill BCS to fill the canal [40]. They then employed rotary ProTaper Retreatment files to eliminate the filling material. Interestingly, the presence of silicate-based root canal-filling material in the mesial roots of mandibular molars did not impact the development of dentinal microcracks. Barakat RM et al., revealed a significant increase in the number of cracks following the implementation of post-retreatment protocols, particularly in the coronal and middle thirds of the canals, compared to both pre- and post-instrumentation ($p=0.0001$) [48]. However, the utilisation of ultrasonic or laser-activated irrigation did not result in a significant increase in crack formation ($p=0.345$). Conversely, the use of D-Race NiTi rotary instruments for root canal retreatment was associated with a substantial increase in dentinal microcracks.

DISCUSSION

Despite the introduction of various sealers in the market, their retreatability remains unknown. Moreover, the efforts to develop an ideal sealer have predominantly prioritised achieving complete obturation of the root canal, rather than retreatability. Recently, BCS materials have become increasingly popular as sealer filling materials due to their biocompatibility, antibacterial properties during the setting process, and minimal shrinkage upon setting [29]. The chemical bonding of BCS with tooth structures is facilitated by the formation of tags along dentinal tubules, rendering retreatability challenging [24].

The type of GP affects retreatability; BC-coated GP is more challenging compared to conventional GP endodontics [21]. Moreover, the sealer influences retreatability [52]. The apical third had significantly more filling material debris ($p<0.05$) [26]. However, only the apical third of the BCS/Reciproc group presented a significantly greater reduction in residual filling material compared to the BCS/Reciproc Blue [32]. Additionally, in both the mesiobuccal and distobuccal canals, the tricalcium silicate-based material was removed as rapidly as the zinc oxide-eugenol sealer [62].

The SCO technique is recommended with calcium silicate-based sealers according to the manufacturer's recommendations. The obturation technique during the initial treatment affected the residual material amount independently of the sealer type, and the remaining root canal-filling material was between 15% and 24%. Moreover, the obturating technique also influenced the retreatment time [26]. A possible explanation for this result may be that the continuous wave compaction technique fills the canal in 3-D obturation, whereas the cold lateral condensation and single cone do not.

More time may be required when retreating canals filled with BCS [32]. Warm vertical compaction takes longer retrieval time than SCO [38]. Retrieval of a single GP master cone placed to the full WL took longer using EndoSequence than using the master GP cone trimmed to fit approximately 2 mm short of the WL [14]. There was no significant difference in the time to reach the WL between AH Plus, iRoot SP, or MM Seal ($p>0.05$) or the time from starting the removal to the completion of the cleaning process using R-Endo versus ultrasonic tips ($p>0.05$) [15]. For teeth obturated with the lateral condensation technique, significantly less time was required for retreatment ($p\leq0.05$) compared to warm vertical compaction and thermoplasticized injectable techniques. A possible explanation for this might be differences in the retreatment files, the tooth morphology, the obturation technique, and the period between the initial treatment and retreatment [26].

Different instrumentation protocols can be applied to effectively remove filling materials from the root canal system, although not entirely. The use of solvents enhances the penetration of files, but it can also impede the cleaning process of the root canal. To facilitate the removal process and minimise the chances of altering the original canal shape, straightening, or perforation, it is recommended to utilise a solvent to soften the GP [63-65]. However, a greater amount of root canal-filling material remained with the use of chloroform [16]. The ability of four commonly used endodontic solvents was compared to chloroform, Endosolv R (Septodont, Saint-Maur, France), Endosolv E (Septodont), or eucalyptol to soften GP and MTA Fillapex to allow for the re-establishment of apical patency. The result showed that all solvents used effectively softened GP and MTA Fillapex, thereby assisting in the re-establishment of apical patency. The observed decrease in these studies when using solvents implicates that dissolving GP can increase the adherence of GP and sealer to the canal wall; however, as mentioned above, using solvents allows the re-establishment of patency and reaching the full WL [66].

Cutting capacity is a crucial characteristic of instruments, particularly for the removal of filling materials. Various factors influence the cutting ability, including the helical angle, rake angle, and cross-sectional design. The helical angle is the angle formed between the cutting edge and the longitudinal wall of the dentin. Sizes of the preparation affect the removal of root canal-filling [67,68]. Excessive enlargement of the root canal should be avoided, as this may predispose the root to fractures [67]. The amount of remaining filling materials after using rotary systems (10.1%) was higher than that after using reciprocating systems (3.8%) ($p<0.001$) [54].

The utilisation of reciprocating systems proved to be more efficient in the removal of a combination of BCS and bioceramic GP from the canal [44]. There are several possible explanations for these results. The alternating movement of the reciprocating files could better dislodge the filling material, particularly the hard-set MTA-sealer, from the root canal walls, improving its removal coronally if the instrument design (cross-sectional shape and the helical angle) allowed such removal. Moreover, reciprocating systems have better centring ability than rotary systems [69,70].

Regaining WL and patency in retreatment cases is regarded as significant indicators of success in root canal retreatment [68,71] and shown to substantially improve the periapical healing rates [71]. Retreatment may be compromised if WL and/or patency cannot be regained, as it hinders the proper cleaning and shaping of the apical canal space, which may harbour bacteria [14,24]. The time needed to attain apical patency in root canals can be impacted by the operator's expertise, regardless of the filling material used or the type of canal [62].

The WL and patency were re-established sufficiently in AH26, TotalFill BCS, and BioRoot RCS [17]. Patency could be re-established in canals filled with BCS in 84.4% of cases [23]. This may be explained by the capacity of small hand files to navigate through voids within the BCS or bypass the sealer in a canal with an irregular shape. The hardness of bioceramics upon setting makes it unlikely for files to penetrate the BCS, although there are cases where unset sealers may be penetrable. The remaining BCS sealer, due to its hardness upon setting, is nearly impenetrable by NiTi files, thus impeding the proper cleaning and shaping of the apical canal space [62].

In recent years, researchers have investigated a variety of approaches to remove the remaining GP and sealer. The complex root canal anatomy is one of the challenges during retreatment due to the difficulty in engaging the rotary instruments in the apical root region, as well as the filling material lodging into the canal irregularities, making it difficult to remove during retreatment. All the included studies using supplementary techniques showed a significant reduction in the filling remnants and sealer compared with the settings not involving supplementary techniques. PIPS showed a significant reduction in the filling remnants with EndoSequence BCS, MTA Fillapex, and AH Plus sealer ($p<0.05$) [25].

A significantly smaller volume of root-filling remnants of BioRoot RCS was achieved by using Tornado brush and UAI compared with syringe irrigation ($p<0.05$) [30]. The removal of SCO using EndoSequence BCS was efficiently removed by the combined use of XP-endo Shaper (XPS) and XP-endo Finisher R (XPFR) instruments ($p<0.05$) [13]. The six-month group exhibited a significantly higher percentage volume of the filling material removed after the initial retreatment and XPFR cleaning compared to the 2-week groups ($p<0.05$) [38]. The amount of material removed following ultrasonic and diode laser was significantly greater than that following manual irrigation ($p<0.0001$) [51]. XP Finisher R and XP Finisher had better cleaning ability compared with PUI in all thirds of each root canal ($p<0.001$) [19]. Regardless of the sealer type, the efficacy of removing filling materials was significantly improved through additional preparation with XP-Endo Finisher ($p<0.05$) [27]. The efficacy of XPR in removing the filling material in mandibular premolars with oval canals was found to be superior to that of both UAI and EAI methods [35]. However, there were no statistically significant differences in efficacy between the SWEEPS mode of the Er:YAG laser, UAI (Irri S, 25/25, VDW), and conventional SNI. Similar effectiveness was observed among all tested techniques in the removal of the remaining filling remnants [49].

None of the articles included in the present study could completely remove the GP and BCS from the root canal system. Researchers conducted a systematic review of laboratory studies utilising micro-CT to evaluate the residual filling materials. The findings indicated that none of the instruments were able to achieve total removal of GP and sealer from root canals. The mean percentage of residues was less than 10% [68]. The presence of residual sealer material creates an environment conducive to bacterial colonisation, impeding the formation of an effective seal with the new filling material and resulting in failure during subsequent retreatment [29].

The absence of dentinal defects was noted following the use of AH Plus and EndoSequence BCS, along with the utilisation of RC and RB instruments for the elimination of filling material from the mesial root of mandibular molars [33]. The formation of dentinal microcracks was not affected by the utilisation of ProTaper Universal Retreatment during the retreatment process of mesial roots in mandibular molars filled with a silicate-based root canal-filling material [40]. However, retreatment of single canal teeth using D-Race NiTi rotary instruments showed an increased number of cracks after retreatment protocols, particularly in the coronal and middle third of the canal, compared with those at pre-treatment and post-treatment ($p=0.0001$) [48]. Using supplemental irrigation such as 17% Ethylenediaminetetraacetic acid (EDTA) and 10% FA applied for five minutes did not damage the dentine but affected the structural integrity of the sealer [34].

The differences in these results could be attributed to the differences in methodologies (i.e., different retreatment files and tooth types). Numerous authors have reported that the formation of dentinal defects can be attributed to various factors, such as tip design, cross-section geometry, constant or progressive taper design, constant or variable pitch, and flute form [72,73]. One limitation of the present review is the absence of clinical studies evaluating the effects of the remaining BCS on retreatment outcomes. Thus, future research should aim to investigate this issue.

CONCLUSION(S)

The results of the studies varied significantly owing to differences in methodologies. Initial obturation techniques affected the remaining GP during retreatment. Both rotary and reciprocating systems can effectively remove root-filling material. However, reciprocating systems required more retreatment time compared to the use of rotary files.

The use of supplemental techniques can enhance the cleanliness of the root canal during retreatment. Solvents helped establish patency and reach the WL. Overall, this review revealed that no techniques or methods can completely remove BCS during retreatment, as complete sealer removal was not observed in any of the studies.

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