EAS Journal of Dentistry and Oral Medicine
Abbreviated Key Title: EAS J Dent Oral Med
ISSN: 2663-1849 (Print) & ISSN: 2663-7324 (Online)
Published By East African Scholars Publisher, Kenya

OPEN ACCESS

Volume-6 | Issue-6 | Nov-Dec-2024 | DOI: https://doi.org/10.36349/easjdom.2024.v06i06.008

Original Research Article

The Effect of the Smear Layer on the Adhesion Capacity of Bioceramic Sealers to Root Dentin: A Systematic Review of the Literature

Emna Garouachi[1*], Amira Kikly[2], Sabra Jaafoura[2], Neila Zokkar[3], Nabiha Douki[3]

[1]DDS, Department of Dentistry, University Hospital, Sahloul, Tunisia, Faculty of Dental Medicine, University of Monastir, Avicenna Street, 5000 Tunisia, Research Laboratory LR12ES11, University of Monastir, BP 56 Avenue Taher Hadded, Monastir 5000, Tunisia
[2]DDS, Associate Professor, Department of Dentistry, University Hospital, Sahloul, Tunisia, Faculty of Dental Medicine, University of Monastir, Avicenna Street, 5000 Tunisia, Research Laboratory LR12ES11, University of Monastir, BP 56 Avenue Taher Hadded, Monastir 5000, Tunisia
[3]DDS, Professor, Department of Dentistry, University Hospital, Sahloul, Tunisia, Faculty of Dental Medicine, University of Monastir, Avicenna Street, 5000 Tunisia, Research Laboratory LR12ES11, University of Monastir, BP 56 Avenue Taher Hadded, Monastir 5000, Tunisia

Article History
Received: 09.11.2024
Accepted: 14.12.2024
Published: 28.12.2024

Journal homepage:
https://www.easpublisher.com

Quick Response Code

Abstract: ***Aim*****:** This systematic review aims to qualitatively synthesize available evidence on the effect of the smear layer (SL) on the adhesion of bioceramic root canal sealers to dentin. ***Methods*****:** An advanced literature search was conducted in PubMed and Cochrane, *targeting in vitro studies on human teeth published between January 2013 and January 2024, in English*. ***Results*****:** The search yielded 479 articles where 16 studies met the inclusion criteria and were included. Data were collected according to the number of teeth studied, canal preparation, smear layer removal methods, adhesion tests, and sealer types. The review found no consensus on the SL's impact on the adhesion and sealing ability of bioceramic sealers. While MTA-based sealers showed improved adhesion due to the SL's role in forming an interfacial layer, calcium silicate-based sealers either experienced reduced adhesion or were unaffected by the SL. ***Conclusion*****:** The effect of the smear layer on bioceramic sealer adhesion remains unclear, with variations depending on sealer type, smear layer properties, and irrigants used. For MTA-based sealers, the smear layer plays a significant role in enhancing adhesion. Further research is needed to clarify these interactions.

Keywords: Bioceramic sealers, mineral trioxide aggregate (MTA), calcium silicate-based sealer, smear layer, bond strength, endodontic irrigation.

INTRODUCTION

Endodontic treatments aim to meticulously clean and shape the root canal system, followed by sealing it with a permanent filling to prevent leakage [1]. Gutta-percha is the standard material for root canal obturation, but it alone cannot achieve a complete three-dimensional seal. Therefore, sealers are used with gutta-percha to fill the gaps between the core material and the root canal walls, and to reach accessory canals and resorptive lesions [2]. Since their inception in the early 20th century, the properties of sealers have been extensively studied for their biological and technical importance [3].

Bioceramic-based sealers (BC), used for over thirty years, are gaining popularity due to their high biocompatibility and chemical stability. They expand during setting, form hydroxyapatite, and have an alkaline pH that enhances antibacterial activity and biocompatibility [4]. These sealers also exhibit radiopacity and good adhesion to dentinal walls, which is crucial for effective root canal filling [4].

The adhesion of a root canal sealer depends on factors such as dentin penetrability, sealer flowability, film thickness, viscosity, obturation technique, setting time, sealer integrity, surface tension, solubility, and smear layer (SL) removal [2].

The SL, which consists of inorganic and organic materials from the root canal instrumentation [1], can impact the adhesion of bioceramic sealers. Some studies suggest the SL impedes proper adaptation and prevents

***Corresponding Author:** Emna Garouachi
DDS, Department of Dentistry, University Hospital, Sahloul, Tunisia, Faculty of Dental Medicine, University of Monastir, Avicenna Street, 5000 Tunisia, Research Laboratory LR12ES11, University of Monastir, BP 56 Avenue Taher Hadded, Monastir 5000, Tunisia

effective sealing [5], while others propose it may enhance bonding [1]. The effect of SL on bioceramic sealer adhesion remains a subject of debate. Thus, this study aimed to assess the effect of the presence and the removal of the SL on the adhesion capacity of BC-based sealers, through a systematic review.

Material and Methods

Search Strategy

This study used a systematic review to assess the effect of the smear layer (SL) on bioceramic (BC) sealers' adhesion. The PICO-model question was: "What is the in vitro evidence on how the smear layer impacts the push-out bond strength of BC sealers?" Searches were conducted in MEDLINE (via PubMed) and Cochrane for English-language articles published between January 2013 and January 2024, with the final search in June 2023. Only in vitro studies on BC sealers' adhesion were included. The detailed search strategy, using PubMed MeSH and specific terms of cochrane, is presented in Table I.

Table I: Search strategy

PUBMED
((((((((bioceramic) AND (sealer))) OR (mineral trioxide aggregate [Text Word])) OR (biodentine [Text Word])) AND (bond)) AND (strength)) AND (smear layer [Text Word])) OR (smear layer [MeSH Terms])
Cochrane
bioceramic sealer in All Text OR calcium silicate-based sealer in All Text AND "adhesion" in Keyword OR "bond strength value" in Keyword AND "smear layer" in Keyword

Additionally, an exhaustive manual search was conducted on the basis of the titles, abstracts and keywords of the articles under consideration.

Results

1. Study selection and flowchart: Figure 1 illustrates the search strategy flowchart. An initial search identified 479 studies (341 from PubMed, 100 from Cochrane, and 38 from Google Scholar). After removing nine duplicates, 425 articles were excluded based on titles and abstracts, leaving 45 for full-text review. Of these, 29 did not meet inclusion criteria, resulting in 16 studies selected for the systematic review.

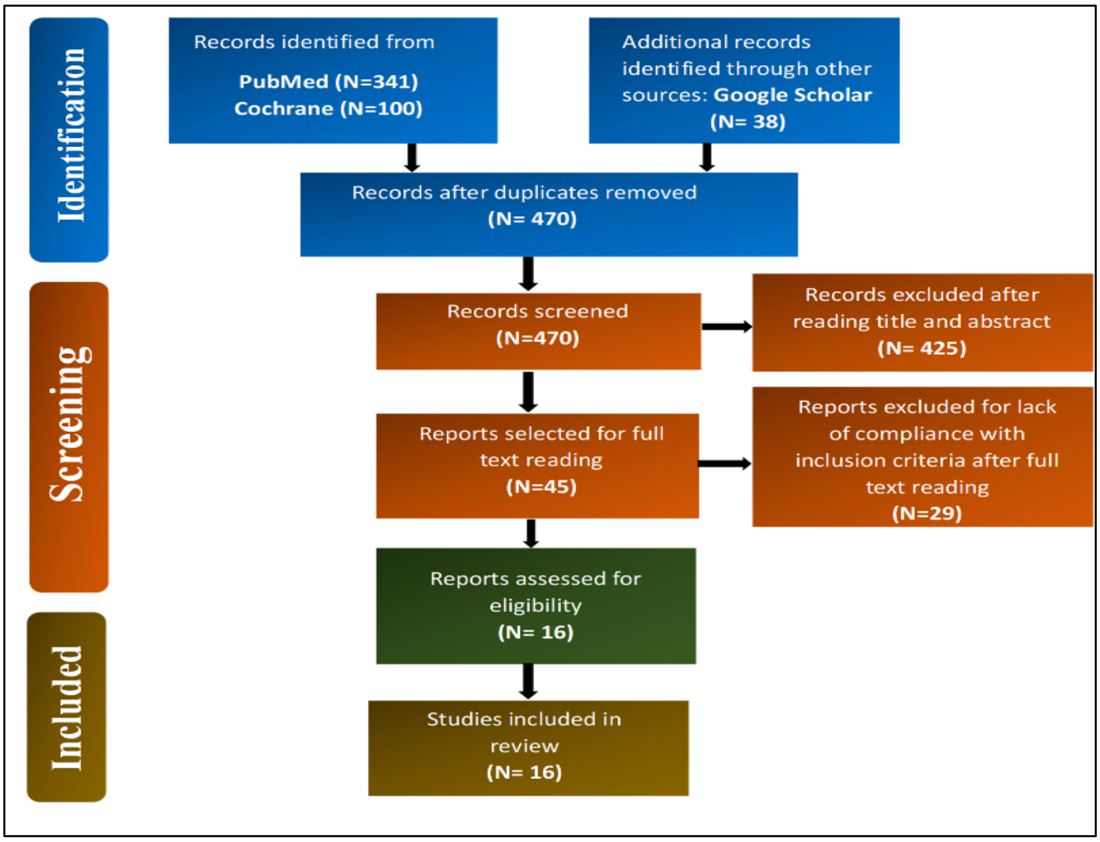

Figure 1: **Flowchart representing the study selection process**

2. Included studies: After reviewing the abstracts and full texts and applying the inclusion criteria, a total of 16 articles were included in this study. A summary of the data obtained from these 16 studies is presented in Table II.

Table II: **Extracted variables from the studies included**

Authors /Year	Teeth/ sample	Canal preparation	Irrigation solutions		Bioceramic materials	Adhesion test	Main findings
			During endodontic treatement	Final endodontic treatment			
Özata, Merve Yeniçeri, *et al*., (2023) [6]	Mandibular Premolar Teeth n=60	Reciproc R25 (VDW, Munich, Germany) single file system	5,25% NaOCl	-EDTA Group :5ml 17% EDTA+5ml 5,25% NaOCl -Glycolic acid (GA): 5ml 10% GA+5ml 5,25% NaOCl -Phytic Acid (inositol hexaphosphate-IP6) :5ml IP6+5ml 5,25% NaOCl -Distilled water (DW): 5ml DW+5ml 5,25% NaOCl	Well-Root ST	Push-out bonding strength (POBS) test (Instron device): 2mm slices ;1mm/min (middle third)	*DW-treated (control) samples had significantly lower bond than well-Root ST *The rate of adhesive failure was higher in the DW group (66,7%): the result of insufficient sealer-dentin bonding. *Highest POBS observed in the GA and EDTA groups: high efficiency in the removal of SL **Conclusion:** The presence of SL has a negative effect on adhesion between dentin and the Well Root ST
Carvalho, N. K *et al*., (2017) [7]	-Maxillary Incisors N=30 -Disc Samples Produced n= 90	0.8 cylindrical carbide bur	2,5% NaOCl (15min) + bi-distilled water	-17%EDTA (3min) -2,25% peracetic acid (PA) 3min -10% citric acid (CA) 3min Then final rinse: DW +2,5% NaOCL+ bi-distilled water	-MTA-Fillapex -Total Fill BC	Push-out bonding strength (Instron, Canton, MA, USA): 1mm slices with 3 holes (one for each material tested; AH Plus used as a reference material) ;0,5mm/min (middle third)	*Neither the tested Chelating solutions (17% EDTA,2.25% PA or 10% CA) significantly influenced the push-out behavior of the sealers *Results showed no difference in sealer bond strength to root dentine after SL removal with different chelating agents
Al-Hiyasat, Ahmad S., and Wafa' A. A. Yousef. (2022) [8]	Maxillary first premolars n=60	ProTaper files up to F5	20ml 5,25% NaOCl	2 subgroups: -SL (+): no final irrigation -SL (-) :1ml 17% EDTA+ 2ml 5,25 NaOCl	-MTA -biodentine -TotalFill FS	POBS (Jinan Testing Equipment IE corporation, China): 3mm slices (apical, middle and coronal 1/3) ;0,1mm/min	*With or without SL, Biodentine exhibited the highest bond strength to dentin, followed by MTA. In contrast, Total Fill FS exhibited the weakest bond strength. *The bond strength values, of all three materials decreased in the presence of the SL; for Total Fill FS the bond strength was found to be decreased by more than 50%. *In the SL groups, the bond values Biodentine was notably superior to that of MTA and Total Fill FS *In the groups where the SL was removed, the reduction in the bond strength for the MTA and Total Fill FS was considerable. **Conclusion:** Removing the SL reduced the bond strength of the three materials. The reduction was found to be significant for MTA and Total Fill FS, while for Biodentine, it was not found to be significant.

Paulson, Liz, Nidambur Vasudev Ballal, and Abhishek Bhagat (2018) [11]	Shokouhinejad, Noushin, *et al*., (2013) [10]	Attash, Israa Muwafaq, and Wiaam M. AL- Ashou (2022) [9]	Shamsy, Enass, *et al*., (2019) [1]
Single-rooted teeth n=50	Single-rooted teeth n=56	First mandibular premolars n=60	Mandibular premolars n=40
Rotary ProTaper system up to a size F3	Mtwo rotary instruments (VDW) to apical size 35/.04.	Nickel-Titanium ProTaper universal rotary system instruments up to size F3.	Size #40 K files
-Group1,2,3: 5ml 2,5% NaOCl -Group4: 5mL 2.5% NaOCl/9% Dual Rinse Etidronic acid (HEDP) -Group5 (control) :5ml DW	3ml 5,25% NaOCl	-Group1 :3ml 2,5% NaOCl -Group2 :3ml 0,9% normal saline	-Group1: 1ml DW -Group2: 1ml 5,25% NaOCl
-Group1: 2,5% NaOCl -Group2: 5ml 17% EDTA -Group4: 5mL 2.5% NaOCl/9% Dual Rinse HEDP Then final rinse: 5ml DW	-SL maintained group (group3) :5ml 5,25% NaOCl -SL removed (group4): 5ml 17% EDTA+5ml 5,25% NaOCl	-Group1: 3ml DW+5ml 17% EDTA+5ml NaOCl -Final rinse (Group1&2): 5ml DW	-Group1: 5ml DW -Group2: 3ml 17% EDTA+3ml 5,25% NaOCl+5ml DW
Biodentine	Endosequence BC Sealer	Gutta Flow Bioseal	WMTA (Pro- Root MTA)
POBS test (Instron, Norwood, MA) :1,5mm slices (middle third) ;1mm/min	POBS test ((Z050, Zwick/Roell, Ulm, Germany) :1mm slices (middle third); 0,5mm/min	POBS test (Gester; China): 2mm slices (coronal, middle and apical third); 1mm/min	Dye infiltration: *Teeth surfaces coated with two layers of nail varnish leaving the apical foramen of the root exposed, then put into test-tubes containing 0.2% rhodamine solution *Linear dye penetration evaluation: teeth sectioned longitudinally (0,3mm slices and examined under stereomicroscope
-The use of various irrigation protocols had a differential effect on the pushout bond strength of Biodentine: -the DW (control: smear layer+) demonstrated the lowest push-out bond strength, with a value of 11.5 MPa. -Group 4 (2.5% NaOCl/9% Dual Rinse HEDP) exhibited the highest bond strength, with a value of 19.5 MPa. -Bond strength values in the specimens treated with only 2.5% NaOCl were lower(15,5MPa); may be attributed to the inferior SL removal property of NaOCl -The mode of bond failure in the control group :10% adhesive,80% cohesive and 10% mixed, while in other groups only cohesive and mixed modes were to be observed. **Conclusion:** There is a clear correlation between the removal of the SL and the adhesion of Biodentine to the root dentin canal.	-No significant difference in the mean bond strength of Gutta- percha/EndoSequence BC Sealer, smear layer (+) group (1,77MPa) compared to Gutta-percha/EndoSequence BC Sealer, smear layer (-) group (1,57MPa) **Conclusion:** The presence or absence of the SL had no impact on the adhesion strength of the BC root filling materials.	-The mean bond strength of Gutta Flow Bioseal in group 2(with SL) is significantly higher (2,275MPa) compared to group1(without SL;0,822MPa) **Conclusion:** Maintenace of the SL seems to have a positive influence on the adhesion of Gutta Flow Bioseal material.	*Group 2 (without SL) had a higher frequency of medium infiltration (dye penetration>3mm) and lower frequency of infiltration loss (dye penetration<1,5mm) *Group 1(with SL) Has the lowest mean of leakage **Conclusion:** *The presence of SL resulted in a statistically significant reduction in leakage compared to the control group without SL. *SL acts as a coupling agent, enhancing the bonding between MTA and the tubular dentin.

Lotfi, Mehrdad, *et al*., (2014) [13]	Shokouhinejad, Noushin, *et al*., (2013) [12]	Bolbolian, Marjan, *et al*., (2022) [2]
Maxillary anterior teeth n=60	-Single- rooted teeth n=44 -Sectioned horizontally: 1022, 2mm disks (middle third)	Single-rooted maxillary central incisors and mandibular premolars n=30
Gates-Glidden burs (2 to 5)	Tapered bur (larger diameter = 2.70 mm; smaller diameter = 2.30 mm; length =2 mm).	Rotary system (Perfect China) up to file T3 (equivalent to Pro Taper F3 file).
	5,25% NaOCl (20min)	1ml 1% NaOCl
-Group1 and 3 (SL+):2ml normal saline -Group2 and 4 (SL-): 2ml 5,25%NaOCl+1ml normal saline+17% EDTA Final rinse: 2ml DW	-Group1: 17% EDTA (1min) -Group2: 17% EDTA(1min) +5,25% NaOCL (5min) -Group3: 17% EDTA(1min) +2% CHX(5min) -Group4: 17% EDTA (1min) + saline (5min)	-SL removed group: 2ml 17% EDTA+3ml 5,25% NaOCl Final rinse: DW
-Calcium- enriched mixture cement (CEM) -ProRoot MTA (WMTA)	EndoSequence BC Sealer	Endoseal MTA
POBS test (Hounsfield test equipment, Model H5K-S, Surrey, England): 3mm slices (middle third); 1mm/min	POBS test (Z050, Zwick/Roell, Ulm, Germany) ;0,5mm/min	Evaluation of sealer's penetration depth: Scanning electron microscopy (Vega II x mu, Tescan, Czech Republic); 0,2mm slices (apical, middle and coronal thirds) -Preparation for microscopic evaluation: *Removal of the debris: samples placed in ultrasonic device then immersed in 17%EDTA (3min) +5,25% NaOCl(3min) +DW *Dehydration and mounting of the samples in aluminum stub and gold-sputtered.
-The mean bond strengths of CEM with and without removal of the SL are respectively 3,07MPa and 1,44MPa -The mean bond strengths of MTA with and without removal of the SL are respectively 2,82MPa and 2,17MPa - The removal of the SL significantly enhanced the push-out bond strength of CEM, yet had no impact on the retention of WMTA. This may be attributed to the endogenous release of hydroxyapatite by CEM, which penetrates the dentinal tubules opened after removal of the SL forming tag-like structures (TS). This interlocking seems to improve the retention of the material. **Conclusion:** The SL removal did not have a significant impact on the retention characteristics of WMTA in a manner comparable to CEM.	-The use of 17% EDTA for 1 min alone or followed by 5.25% NaOCl, 2% CHX, or saline was effective in complete removal of the smear layer. -Final irrigation of the dentin disks with 2% CHX and 5.25% NaOCl did not affect the bond strength of EndoSequence BC Sealer; they lack the ability to remove the SL - The mean bond strength of group1(EDTA alone) =1,8 MPa is higher than the other groups but with no significant difference.	- Three-way ANOVA was used to evaluate the dentin penetration of the endodontic sealers with and without removing the SL: the mean penetration depths in Endoseal MTA with and without SL were respectively 6.39±8.85 and 8.56±9.56 µm. -The penetration depth decreased toward the apical third; might be attributed to the complex anatomy of the apical area and the presence of sclerotic dentin. **Conclusion:** The penetration depth of the BC sealer exhibited a greater depth when the SL was absent, as opposed to when the SL was present.

Bidar, Maryam, *et al*., (2014) [16]	El-Ma' aita, Ahmad M., Alison JE Qualtrough, and David C. Watts. (2013) [15]	Reyhani, Mohammad Forough, *et al*., (2014) [14]
Single-rooted premolar teeth n=82	Single-rooted teeth n=80	Maxillary central incisors n=60
-Gates-Glidden drills #5, #4, #3, and #2 (coronal and middle third) -Step-back instrumentation up to apical file #35(apical third)	ProTaper files up to F5(50/05)	RaCe rotary system up to #25/0,06
5ml 5,25% NaOCl	1% NaOCl	-Three groups: 2,5% NaOCl -three groups: normal saline
-SL (+) groups (1,3): 10ml DW -SL (-) groups (2,4): 3ml 17% EDTA -Final rinse: 10ml DW	-Group B; SL (-): 1ml 17%EDTA+ 2ml NaOCl -Final rinse (group A, B): 5ml sterile water	-Three groups: 17% EDTA -Three groups: normal saline
-IRootSP -MTAFillaplex (MF)	-ProRoot MTA -Harvard MTA -Biodentine	MTA-Fillaplex (MF)
Fluid filtration technique (evaluation of apical leakage): roots connected to the fluid filtration system. Water Movement through obturated canals was measured under a pressure of 3 psi (0.2 atm) by monitoring the movement of an in-line bubble at 2- min intervals for 8 min. -The First fluid transport measurement was made after 2 weeks and repeated after 3 months.	POBS test (Roell Z020, Zwick GmbH & Co. KG, Germany): 2mm slices (coronal, middle and apical thirds); 1mm/min	POBS test (Hounsfield Test Equipment, Model H5K-S, Surrey, England): 2mm slices (coronalthird); 1mm/min
-For MF, results showed no significant difference between the smear-positive and negative groups for root canals obturated with MTA Fillapex (P=0.962 at 2 weeks; P=0.639 at 3 months). -For IRootSP, the degree of leakage was greater in the smear- positive group than in the smear-negative group after 2 weeks (P =0.007) - Regardless of the presence of the SL, iRoot SP exhibited significantly less microleakage compared to MTA Fillapex. **Conclusion:** The presence of a SL did not significantly affect the microleakage of CSC. Additionally, the sealing ability of these sealers remained stable over time.	-The results demonstrated that roots obturated with Biodentine exhibited the highest bond strength values, regardless of whether the SL was removed or preserved (7.71 and 8.79 MPa, respectively). -There was no notable difference in the POBS between the ProRoot MTA and Harvard MTA in both the preserved (ProRoot MTA: 7.54, Harvard MTA: 7.64 MPa) and removed (ProRoot MTA: 6.58, Harvard MTA: 6.47 MPa) SL groups -For all three CSCs, the removal of the SL resulted in a decrease in the bond strength; it seems that the SL is important in the formation of the interfacial layer and possibly has an active role in the mineral interaction between the CSC and radicular dentin. **Conclusion:** Removing the SL has a negative effect on the adhesion capacity between CSC and root canal dentin.	-The mean bond strength of MF in the NaOCl+ EDTA group (SL-) is higher(1,98MPa) compared to the normal saline group (SL-)(1,59MPa) -The samples with SL showed the lowest bond strengths, likely due to the SL creating an interfacial layer on the dentin surface. This layer can hinder the sealer's penetration into the dentinal tubules and the formation of sealer tags. **Conclusion:** Removing the SL enhanced the displacement resistance of the sealer.

Kuçi, Astrit, *et al.*, (2014) [19]	Türker, Sevinç Aktemur, Emel Uzunoğlu, and Nuhan Purali. (2018) [18]	Hamid, Hamid A., and J. Abdul-kareem. (2013) [17]
Single-rooted mandibular premolars n=45	Single-rooted mandibular premolars n=90	Single-rooted mandibular premolars n=60
K-files #10 to 25+ SAF file	ProTaper Universal file system up to #40/06	Rotary ProTaper (NiTi) system from SX-F3.
2,6% NaOCl	2,5% NaOCl	5ml 5,25% NaOCl
-SL (-) group: 2ml 5% EDTA+ 1ml 2,6% NaOCl	-SL (-) group: 3ml 17%EDTA+ 3ml NaOCl –Final rinse: 5ml DW	-SL (+) groups (A1, B1, C1) :5ml 5,25% NaOCl+5ml DW -SL (-) groups (A2, B2, C2): 5ml 17%EDTA+ 5ml 5,25% NaOCl+5ml DW
MTA Fillaplex	-MTA Plus -BioRoot RCS	IRootSP (groupC)
-Sealer penetration evaluation: CLSM (Sealer is fluorescent labeled by adding rhodamine B)	-POBS test (Instron Corporation, Canton, MA, USA): 1mm slices (middle third); 0,5mm/min -Penetration depth evaluation: slices were photographed under a confocal laser microscopy (CLSM); images analyzed in the CLSM Image Browser (Carl Zeiss): depth of penetration measured from the canal wall to the point of maximum sealer penetration.	POBS test (Tinius-Olsen Universal Testing Machine): 1mm slices (Coronal, middle and apical thirds); 0,5mm/min
-No fluorescence or tubular penetration was observed in the control teeth (SL (+)) -Removal of the SL increased the penetration of MTA Fillaplex when used with cold lateral compaction as The obturation technique. -The penetration was greater, generally, at the coronal and middle sections compared with the apical section. **Conclusion:** The SL that forms after instrumentation does not act as an impermeable barrier, even though it may partly impede the MTA Fillapex penetration.	-The mean POBS values for BioRoot RCS when SL was preserved and removed are respectively :2,03MPa and 1,97MPa -The mean POBS values for MTA Plus, when SL was preserved and removed are respectively :2,02MPa and 1,58MPa -The removal of the SL resulted in a notable decrease in the retention of MTA Plus. In terms of penetration depth, MTA Plus demonstrated deeper penetration than Bio- Root RCS, with the SL preserved. **Conclusion:** -The SL plays a significant role in the development of the interfacial layer between the MTA Plus and root dentin, thereby enhancing its adhesive properties. However, this was not the case for the BioRoot RCS -Dentinal tubule penetration had limited effect on the adhesion of the root canal sealers.	The results showed: -The highest mean value of POBS was observed in Group C2 that used iRoot SP sealer with removed smear. -Regarding segments, the bond strength was notably higher in the middle and apical specimens compared to the coronal specimens in group C1(SL- positive) and highly significant in group C2(SL- negative) **Conclusion:** The bond strength of the BC Sealer was not significantly influenced by the presence or absence of the SL.

3. Characteristics of Included Studies:

Sample

All of the selected articles employed human teeth as their primary material. In summary, four of the articles utilized anterior teeth, whereas eight employed posterior teeth. Furthermore, four articles did not specify the type of teeth that were evaluated.

Root Canal Instrumentation

Six articles employed the ProTaper system (DENTSPLY Maillefer, Ballaigues, Switzerland) for root canal preparation, while two articles utilised the Reciproc system (VDW GmbH, Munich, Germany) and two articles employed Gates Glidden burs. A minority opted to use manual instrumentation, including the Perfect (China) system, the RaCe rotary system, and cylindrical carbide or tapered burs.

Irrigation during canal preparation

Of the 16 selected articles, a total of 10 utilized NaOCl as an irrigation solution for root canal preparation. This varied among the articles in terms of both the quantity used and its concentration. Three articles used NaOCl in the first group and distilled water

(DW) or saline in the second group. One article used a combination of NaOCl and bi-DW, and one article used three different irrigation solutions: NaOCl, combination of NaOCl+ Etidronic acid (HEDP) and DW, for each group.

Final irrigation for the removal of the SL

In their final irrigant solutions, 10 articles employed a combination of 17% EDTA and NaOCl, either alone or in conjunction with DW, saline solution or sterile water. In two articles, EDTA was utilized either in isolation or in combination with DW or saline solution. One article used EDTA alone or in combination with NaOCl, chlorhexidine, or saline. One article used NaOCl combined with EDTA, GA (glycolic acid), IP6(phytic acid) or DW. On the other hand, two articles utilized a distinct final irrigant based on the intervention group being investigated. Within these groups, the following irrigants were employed: EDTA, PA (peracetic acid), CA (citric acid), NaOCl, HEDP (etidronic acid) and distilled or bi-distilled water.

Sealers studied

The bioceramic sealers evaluated in these studies were: Well-Root ST, MTA Fillapex, TotalFill BC, Biodentine, TotalFill FS, ProRoot MTA, Gutta Flow Bioseal, Endosequence BC sealer, Endoseal MTA, calcium enriched cement (CEM), harvard MTA, IRoot SP, MTA Plus and Bioroot RCS.

Adhesion evaluation

Dentin adhesion of bioceramic-based sealers was assessed by the push-out bond strength (POBS) in 12 articles. Dye infiltration, fluid filtration method, confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM), were used in each of the remaining four articles. Additionally, the studies employed a range of slice thicknesses, including 0.2 mm, 1 mm, 1.5 mm, 2 mm, and 3 mm. The majority of the articles utilized slices with a thickness of 1 mm.

Effect of the smear layer

Articles included in our systematic review showed controversies regarding the impact of the SL on the adhesion and the sealing ability of BC-based sealers. Among the 16 articles reviewed, 5 articles showed that the presence of the SL is of considerable significance in the formation of the interfacial layer between the BC sealer and root dentin, thereby enhancing its adhesion ability. On the other hand, 6 articles approved that the presence of the SL has a negative effect and its removal is highly recommended for the adhesion of the tested BC sealers. In the remaining 5 articles, it has been concluded that the SL's presence or absence did not affect the adhesion of BC canal sealers.

4. Quality assessment (Risk of Bias)

To evaluate the methodological quality of the included studies, we used the "modified CONSORT checklist for in vitro studies on dental materials" by Faggion *et al*., (2012) [20]. Each study was assessed against 14 criteria, calculating compliance as the percentage of completed items. Table III summarizes the results, with an average compliance rate of 74% (range: 55%-91%). All 16 articles showed consistent data quality, particularly in introductions, objectives, and hypotheses (items 1 and 2). Methodological details and results were well-reported, but only three studies addressed sample size calculations (item 5), and none met criteria for randomization (items 6-9). All studies detailed statistical analyses (items 10 and 11), four addressed methodological limitations (item 12), and 11 disclosed funding sources (item 13). Only one article referenced a protocol (item 14). Overall, the selected studies provide robust evidence to address the research questions.

Table III: Quality assessment of the included studies

	Modified CONSORT checklist															
Articles	**1**	**2a**	**2b**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**%**
Shamsy, Enass, *et al*., (2019)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	Y	Y	N	82%
Carvalho, N. K., *et al*., (2017)	Y	Y	Y	Y	Y	Y	-	-	-	-	Y	Y	N	Y	N	82%
Paulson *et al*., (2018)	Y	Y	Y	Y	Y	Y	-	-	-	-	Y	Y	N	Y	N	82%
Shokouhinejad, Noushin, *et al*., (2013)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	Y	N	73%
Bolbolian, Marjan, *et al*., (2022)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	N	N	64%
Kuçi, Astrit, *et al*., (2014)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	Y	N	73%
Özata, Merve Yeniçeri, *et al*., (2023)	Y	Y	Y	Y	Y	Y	-	-	-	-	Y	Y	Y	-	N	90%
Al-Hiyasat, *et al*., (2022)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	Y	Y	Y	91%
Attash *et al*., (2022)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	N	N	64%
Shokouhinejad, Noushin *et al*., (2013)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	N	N	64%
Lotfi, Mehrdad, *et al*., (2014)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	Y	N	73%
Reyhani, Mohammad Forough, *et al*., (2014)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	Y	N	73%
El-Ma'aita, Ahmad M *et al*., (2013)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	N	N	64%
Bidar, Maryam, *et al*., (2014)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	N	Y	N	73%
Hamid, Hamid A., *et al*., (2013)	Y	Y	N	Y	Y	N	-	-	-	-	Y	Y	N	N	N	55%
Türker, Sevinç Aktemur *et al*., (2018)	Y	Y	Y	Y	Y	N	-	-	-	-	Y	Y	Y	Y	N	82%

Abbreviations: -, non-applicable; N, not reported in the study; Y, reported in the study, %, percentage of compliance per article.

DISCUSSION

Adhesion of BC-based sealers

1. Adhesive strength tests

The most commonly methods used in our reviewed studies are the push out bond strength test in most of the articles, fluid infiltration technique, CLSM, SEM and stereomicroscope.

1.1. The push out bond strength test

The POBS assay is a widely used method for studying the dislodgment resistance of cements, recognized for its reliability in measuring the bond strength of root canal sealers, even at low values. This test simulates clinical conditions by placing materials in prepared canals with typical tubular structures. The push-out bond strength is measured using a universal machine, with samples secured on a metal base and pushed out using plungers of varying diameters. A vertical load is applied at a speed of 0.1 mm/min to replicate forces during endodontic procedures, and the maximum dislodgement force is recorded to calculate the bond strength (8). Subsequently, the POBS, expressed in megapascals, is computed for each sample using the following formula:

Push-out bond strength (MPa) = F-max / adhesion surface area (mm^2), where F-max represents the maximum force.

1.2. Dye penetration

An alternative method for evaluating the adhesive capability of sealing cements is the dye penetration test, valued for its simplicity and lack of advanced material requirements [21]. Methylene blue is often used in studies of marginal sealing, but it can discolor when exposed to alkaline substances, such as calcium hydroxide formed from materials like MTA, which raises the pH [22, 23]. To avoid this issue, rhodamine B dye is preferred for assessing MTA's sealing effectiveness [24]. In the study, infiltration levels were evaluated using Escobar *et al*.,'s criteria [25]:

0: Infiltration loss (dye penetration $0 \leq 1.5$ mm).

1: Simple infiltration (dye penetration 1.5–3 mm).

2: Medium infiltration (dye penetration > 3 mm).

1.3. Fluid filtration method

This method is praised for producing consistent quantitative results, making it reliable and suitable for longitudinal studies [26]. Moradi *et al*., [27], describe a system that measures fluid transport via bubble movement, using an oxygen tank connected to an Erlenmeyer flask and micropipette. A three-valve tube controls the bubble, and a digital camera records its displacement.

1.4. Scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM)

SEM offers high-magnification imaging to observe and measure sealer penetration into dentinal tubules but is time-consuming, requiring tooth preparation and risking dehydration, cracks, and artifacts. In contrast, CLSM provides detailed information on the presence and distribution of sealers within tubules, eliminates artifacts, and doesn't require specific sample preparation or sectioning [28].

2. Irrigants for smear layer removal

2.1. Sodium hypochlorite (NaOCl): A simple endodontic irrigant with organic tissue-dissolving properties but ineffective in SL removal [29]. Paulson *et al*., [5] found that specimens treated with 2.5% NaOCl had the lowest POBS due to its poor SL removal ability. NaOCl also interacts with calcium silicate cement, potentially affecting adhesion [30].

2.2. Chlorhexidine (CHX): CHX doesn't significantly affect the bond strength of sealers like EndoSequence BC Sealer due to its inability to dissolve organic material or remove SL [31]. Shokouhinejad *et al*., [12] found that 2% CHX as a final rinse did not affect bond strength [32, 33].

2.3. EDTA: A common chelating irrigant. Shokouhinejad *et al*., [12] reported that 17% EDTA for 1 minute alone or followed by NaOCl, CHX, or saline effectively removed the SL. Prolonged use (over 1 minute) can cause excessive dentin erosion (34). To minimize damage, several authors recommend limiting EDTA application to 1 minute [1, 9, 10, 35]. SEM analysis showed that using 17% EDTA for 1 minute followed by NaOCl effectively removed SL in the coronal and middle root canal sections [10]. EDTA also alters dentin's calcium and phosphorus levels, potentially affecting the adhesion of calcium silicate-based sealers (7). While most studies used 17% EDTA, Kuçi *et al*., [19] used 5% EDTA, which also effectively removed SL, with SEM analysis showing no significant difference in efficacy between varying concentrations [21, 36].

2.4. Organic Acids: Other chelating agents like phosphoric acid (PA), citric acid (CA), and glycolic acid (GA) have shown similar SL removal efficacy to EDTA [7]. GA, a less toxic alternative to EDTA, is biodegradable and promotes collagen and fibroblast proliferation [37, 38]. A study comparing 17% EDTA, 10% GA, and 1% IP6 found that GA and EDTA provided comparable SL removal, with GA's acidic pH increasing dentin roughness, potentially enhancing micromechanical bonding [39]. Phytic acid (IP6), a biocompatible EDTA substitute, also showed effective SL removal and comparable POBS to GA [6].

2.5. Combination of Solutions: Most studies show that combining NaOCl with 17% EDTA achieves superior SL removal [40, 41]. However, alternating NaOCl and 17% EDTA may reduce calcium silicate cement adhesion due to altered Ca/P ratios and interactions [1, 8, 42]. Conversely, Paulson *et al*., found that combining 2.5% NaOCl with 9% HEDP improved bond strength in biodentine more than NaOCl or NaOCl with EDTA alone, due to HEDP's minimal impact on cement hydration [5, 43]. The NaOCl and HEDP combination, known as "continuous chelation," is as effective as EDTA for SL removal [41].

3. Effect of the SL on the adhesion of BC-based sealers:

In this review, a discrepancy among studies was noted regarding the effect of the SL on the adhesion of bioceramic sealers. Some studies indicate that its maintaining enhances adhesion, others suggest that it does negatively impact adhesion, and some show that it has no effect. Indeed, the effect of the SL on adhesion varies depending on the type of the bioceramic sealer used.

1. MTA-based sealers:

Studies consistently agree that maintaining the smear layer (SL) enhances adhesion. Shamsy *et al*., [1] observed greater apical leakage with MTA in SL-free root canals compared to those with intact SL, suggesting that SL enhances the bond between MTA and tubular dentin by retaining moisture essential for MTA's hydrophilic setting. Similarly, El Ma'aita *et al*., [15] found reduced MTA bond strength after SL removal, highlighting SL's role in forming a hydroxyapatite-like interfacial layer and tag-like structures that improve mechanical retention [15, 44, 45].

EDTA application for SL removal negatively impacts MTA's hydration and microhardness, as residual EDTA may interact with calcium ions, impairing the formation of hydrated products necessary for the interfacial layer. Al-Hiyasat *et al*., [8] reported a significant decrease in white MTA (WMTA) bond strength after SL removal, attributed to calcium release, which depends on its 55% tricalcium silicate content [46]. The particle size of materials relative to dentinal tubule diameter (0.9–2.5 µm) also influences penetration. ProRoot WMTA, with particles ranging from 2.96 to 2.36 µm, fails to penetrate tubules, as confirmed by SEM studies [47, 48]. Notably, SL removal does not improve MTA's bond strength, further supporting the importance of SL in adhesion.

2. Calcium silicate- based sealers:

For calcium silicate-based this review has shown controversies among the studies about the effect of the SL on the adhesion.

2.1. MTA Fillapex:

MTA Fillapex, a calcium silicate-based sealer containing MTA, salicylate resin, natural resin, bismuth oxide, and silica, leverages MTA's bioactivity to form an apatite layer upon contact with phosphate-containing fluids [49]. Reyhani *et al*., [14] found that removing the smear layer (SL) increased the sealer's bond strength, as the SL impairs sealer penetration into dentinal tubules, reducing tag formation and micromechanical adhesion. They also noted a direct correlation between tubule penetration and adhesion. In contrast, Carvalho *et al*., [7] reported no effect of SL removal on MTA Fillapex's bond strength, suggesting the sealer relies more on mechanical interlocking than chemical interaction. The chemical interaction forms a "mineral infiltration zone," resulting from calcium hydroxide-induced alkaline etching at the interface [50]. Bidar *et al*., [11] similarly observed that SL presence did not affect sealing properties. MTA Fillapex's smaller particles and improved viscosity, compared to MTA, enhance its ability to penetrate dentinal tubules.

2.2. MTA Plus

MTA Plus is a material based on powdered tricalcium and dicalcium silicate, that has a similar composition to MTA but with smaller particle size [51]. I this review, Türker *et al*., [18], stated that the SL improved the adhesion of MTA Plus to root canal walls. They corroborated the hypothesis from earlier research indicating the significant role of the SL in forming the interfacial layer between MTA Plus and root dentin. Additionally, concerning the depth of penetration into dentinal tubules, the study revealed that MTA Plus exhibited deeper penetration when the SL was maintained than the other cements tested. MTA Plus is comparable to white MTA, with both containing similar constituents, but MTA Plus stands out due to its more finely ground particle size and a higher specific surface area in its powdered form [52]. These characteristics suggest that MTA Plus may have an optimal particle size profile, potentially leading to improved penetration into dentinal tubules.

2.3. IRoot SP

IRoot SP is a premixed, ready-to-use, injectable white cement paste composed of calcium, calcium phosphate, calcium hydroxide, and zirconium oxide. This composition is similar to that of WMTA, which is also known as EndoSequence BC Sealer. In this review, several authors [10, 12, 16, 17] have stated that the presence or absence of the SL does not affect the bond strength of this calcium silicate-based sealer. In other words, the open tubules and absence of SL had no impact on sealer adhesion. However, they did not impair the sealing properties of IRoot SP. It has been suggested that the sealer has a low particle size and favorable viscosity, enabling it to flow readily into dentinal tubules. Furthermore, it is claimed that it chemically bonds to root canal walls [16].

2.4. Biodentine

Biodentine, a CSC with shorter setting time and less discoloration than MTA, shows higher bond strength than MTA regardless of smear layer (SL) presence, as reported by El Ma'aita *et al*., [15] and Al-Hiyasat *et al*., [8]. SL removal reduces its bond strength but remains critical for forming an interfacial layer. Biodentine's superior performance is attributed to its higher tricalcium silicate content (80.1% vs. 55% in MTA), smaller particle size, and greater calcium and silicon ion release, enhancing biomineralization and tag-like structures.

However, Paulson *et al*., [33] noted lower bond strength when SL was preserved, indicating mixed effects on adhesion

2.5. Gutta Flow Bioseal

GuttaFlow Bioseal, a silicone-based sealer containing bioactive ceramic glass, polydimethylsiloxane, zirconium oxide, and platinum, forms hydroxyapatite upon contact with tissue fluids [56]. Attash *et al*., [9] found lower bond strength when the smear layer (SL) was removed, compared to preserved SL. Chelating solutions, while removing the SL, demineralize dentin, expose collagen fibers, and create a hydrophobic surface that reduces the sealer's adhesion [23]. However, the bioactive material releases calcium silicate, forming hydroxyapatite deposits and tag-like structures that improve adhesion and push-out bond strength [57]. Preserving the SL enhances dentinal moisture, further supporting adhesion

2.6. Calcium enriched mixture (CEM)

CEM, a calcium-based cement with faster setting and better flow than MTA, benefits from smear layer (SL) removal. Mehrad et al., [13] showed that SL removal significantly increases CEM's bond strength by opening dentinal tubules, facilitating hydroxyapatite interfacial layer formation and tag-like structures. These structures enhance contact with dentinal walls, improving retention via interlocking. In contrast, preserving the SL blocks tubules, preventing hydroxyapatite layer formation and reducing adhesion [58].

CONCLUSION

The effect of the smear layer (SL) on the adhesion of bioceramic-based sealers is complex and debated in endodontics. Some studies suggest the SL enhances bonding, especially with MTA-based sealers, by improving the mechanical and chemical interaction with dentin. However, other research shows that the SL can hinder sealer adaptation, leading to microleakage and compromised treatment success. This inconsistency suggests that the SL's role may depend on factors like sealer type and removal techniques. More research is needed to clarify these interactions and develop evidence-based protocols.

LIMITATIONS

The experimental nature of the studies limits their applicability to clinical settings, as external factors are not considered, reducing the practical relevance of the review. Nonetheless, the research advances understanding of dentin adhesion in calcium silicate-based materials and paves the way for future studies. Despite limitations, clinicians can still glean insights into material differences and the smear layer's impact on adhesion. The modified CONSORT checklist by Faggion *et al*., was used for quality assessment, revealing high checklist adherence across studies, indicating low bias. The studies' heterogeneity made quantitative or qualitative synthesis difficult, highlighting the need for further research to confirm findings and draw specific conclusions.

REFERENCES

1. Shamsy, E., Nassani, M. Z., Habib, A. A., & Doumani, M. (2019). Evaluation of the Apical Seal of Mineral Trioxide Aggregate in the Absence and Presence of Smear Layer. *The Journal of Contemporary Dental Practice*, *20*(3), 298-303.
2. Bolbolian, M., Hamzei, A., Mohammadi, N., & Tofangchiha, M. (2022). Evaluation of dentin penetration of three different endodontic sealers in the presence and absence of the smear layer. *Folia Medica*, *64*(6), 953-960.
3. Al-Haddad, A., & Che Ab Aziz, Z. A. (2016). Bioceramic-based root canal sealers: a review. *International journal of biomaterials*, *2016*(1), 9753210.
4. De Pinho Quintão, C., Costa, S. T. P., Lacerda, M. F. L. S., Girelli, C. F. M., & Oliveira, C. (2020). Adhesion capacity of bioceramic and resin-based root canal sealer to root dentin: An integrative review. *Rev. Bras. Odontol*, *77*, e1758.
5. Paulson, L., Ballal, N. V., & Bhagat, A. (2018). Effect of root dentin conditioning on the pushout bond strength of biodentine. *Journal of endodontics*, *44*(7), 1186-1190.
6. Özata, M. Y., Kaya, S., Yolcu, E. N., Okumuş, T. B., & Falakaloglu, S. (2023). Effect of smear layer removal using different chelators on push-out bond strength of bioceramic sealer. *Giornale Italiano di Endodonzia*, *37*(1).
7. Carvalho, N. K., Prado, M. C., Senna, P. M., Neves, A. A., Souza, E. M., Fidel, S. R., ... & Silva, E. J. N. L. (2017). Do smear-layer removal agents affect the push-out bond strength of calcium silicate-based endodontic sealers?. *International endodontic journal*, *50*(6), 612-619.
8. Al-Hiyasat, A. S., & Yousef, W. A. A. (2022). Push-Out Bond Strength of Calcium Silicate-Based Cements in the Presence or Absence of a Smear Layer. *International Journal of Dentistry*, *2022*(1), 7724384.
9. Attash, I., & Wiaam, A. A. (2022). The Effect of Smear Layer on the Push-out Bond Strength of Silicone-based Root Canal Sealers. *Al-Rafidain Dental Journal*, *22*(2), 313-322.
10. Shokouhinejad, N., Gorjestani, H., Nasseh, A. A., Hoseini, A., Mohammadi, M., & Shamshiri, A. R. (2013). Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. *Australian Endodontic Journal*, *39*(3), 102-106.
11. Paulson, L., Ballal, N. V., & Bhagat, A. (2018). Effect of root dentin conditioning on the pushout bond strength of biodentine. *Journal of endodontics*, *44*(7), 1186-1190.
12. Shokouhinejad, N., Hoseini, A., Gorjestani, H., &

Shamshiri, A. R. (2013). The effect of different irrigation protocols for smear layer removal on bond strength of a new bioceramic sealer. *Iranian endodontic journal*, *8*(1), 10.
13. Lotfi, M., Ghasemi, N., Rahimi, S., Bahari, M., Vosoughhosseini, S., Saghiri, M. A., & Zand, V. (2014). Effect of smear layer on the push-out bond strength of two endodontic biomaterials to radicular dentin. *Iranian endodontic journal*, *9*(1), 41.
14. Reyhani, M. F., Ghasemi, N., Rahimi, S., Milani, A. S., Mokhtari, H., Shakouie, S., & Safarvand, H. (2014). Push-out bond strength of Dorifill, Epiphany and MTA-Fillapex sealers to root canal dentin with and without smear layer. *Iranian endodontic journal*, *9*(4), 246.
15. El-Ma'aita, A. M., Qualtrough, A. J., & Watts, D. C. (2013). The effect of smear layer on the push-out bond strength of root canal calcium silicate cements. *Dental Materials*, *29*(7), 797-803.
16. Bidar, M., Sadeghalhoseini, N., Forghani, M., & Attaran, N. (2014). Effect of the smear layer on apical seals produced by two calcium silicate-based endodontic sealers. *Journal of oral science*, *56*(3), 215-219.
17. Hamid, H. A., & Abdul-kareem, J. (2013). The effect of smear layer on push-out bond strength to dentin of Bioceramic sealer (In vitro study). *Journal of baghdad college of dentistry*, *25*(4), 5-11.
18. Türker, S. A., Uzunoğlu, E., & Purali, N. (2018). Evaluation of dentinal tubule penetration depth and push-out bond strength of AH 26, BioRoot RCS, and MTA Plus root canal sealers in presence or absence of smear layer. *Journal of dental research, dental clinics, dental prospects*, *12*(4), 294.
19. Kuçi, A., Alaçam, T., Yavaş, Ö., Ergul-Ulger, Z., & Kayaoglu, G. (2014). Sealer penetration into dentinal tubules in the presence or absence of smear layer: a confocal laser scanning microscopic study. *Journal of endodontics*, *40*(10), 1627-1631.
20. Faggion Jr, C. M. (2012). Guidelines for reporting pre-clinical in vitro studies on dental materials. *Journal of Evidence Based Dental Practice*, *12*(4), 182-189.
21. Daghustani, M., Alhammadi, A., Merdad, K., Ohlin, J., Erhardt, F., & Ahlquist, M. (2011). Comparison between high concentration EDTA (24%) and low concentration EDTA (3%) with surfactant upon removal of smear layer after rotary instrumentation: a SEM study. *Swedish dental journal*, *35*(1), 9-15.
22. Coneglian, P. Z. A., Orosco, F. A., Bramante, C. M., Moraes, I. G. D., Garcia, R. B., & Bernardineli, N. (2007). In vitro sealing ability of white and gray mineral trioxide aggregate (MTA) and white Portland cement used as apical plugs. *Journal of Applied Oral Science*, *15*, 181-185.
23. Duarte, M. A. H., de Oliveira Demarchi, A. C. C., Yamashita, J. C., Kuga, M. C., & de Campos Fraga, S. (2003). pH and calcium ion release of 2 root-end filling materials. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *95*(3), 345-347.
24. Tanomaru Filho, M., Figueiredo, F. A., & Tanomaru, J. M. G. (2005). Effect of different dye solutions on the evaluation of the sealing ability of mineral trioxide aggregate. *Brazilian oral research*, *19*, 119-122.
25. Escobar, C., Michanowicz, A. E., Czonstkowsky, M., & Miklos, F. L. (1986). A comparative study between injectable low-temperature (70 degrees C) gutta-percha and silver amalgam as a retroseal. Oral Surgery, Oral Medicine, and Oral Pathology, 61(5), 504-507.
26. Kontakiotis, E. G., Tzanetakis, G. N., & Loizides, A. L. (2007). A l2-month longitudinal in vitro leakage study on a new silicon-based root canal filling material (Gutta-Flow). *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *103*(6), 854-859.
27. Paradella, T. C., & Bottino, M. A. (2012). Scanning Electron Microscopy in modern dentistry research. *Brazilian Dental Science*, *15*(2), 43-48.
28. Yolcu, E. N., Tartuk, G. A., Kaya, S., & Eskibağlar, M. (2021). The use of confocal laser scanning microscopy in endodontics: A literature review. *Turk. Endod. J*, *6*, 55-60.
29. Alamoudi, R. A. (2019). The smear layer in endodontic: To keep or remove–an updated overview. *Saudi Endodontic Journal*, *9*(2), 71-81.
30. Camilleri, J. (2014). Color stability of white mineral trioxide aggregate in contact with hypochlorite solution. *Journal of endodontics*, *40*(3), 436-440.
31. Mohammadi, Z., & Abbott, P. V. (2009). The properties and applications of chlorhexidine in endodontics. *International endodontic journal*, *42*(4), 288-302.
32. Basrani, B., Santos, J. M., Tjäderhane, L., Grad, H., Gorduysus, O., Huang, J., ... & Friedman, S. (2002). Substantive antimicrobial activity in chlorhexidine-treated human root dentin. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *94*(2), 240-245.
33. Mohammadi, Z. (2008). An update on the antibiotic-based root canal irrigation solutions. *Iranian endodontic journal*, *3*(2), 1.
34. Calt, S., & Serper, A. (2002). Time-dependent effects of EDTA on dentin structures. *Journal of endodontics*, *28*(1), 17-19.
35. Özata, M. Y., Kaya, S., Yolcu, E. N., Okumuş, T. B., & Falakaloglu, S. (2023). Effect of smear layer removal using different chelators on push-out bond strength of bioceramic sealer. *Giornale Italiano di Endodonzia*, *37*(1).
36. Kaya, S., Yiğit-Özer, S., & Adigüzel, Ö. (2011). Evaluation of radicular dentin erosion and smear layer removal capacity of Self-Adjusting File using different concentrations of sodium hypochlorite as an initial irrigant. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *112*(4), 524-530.
37. Cecchin, D., Farina, A. P., Vidal, C. M., & Bedran-

Russo, A. K. (2018). A novel enamel and dentin etching protocol using α-hydroxy glycolic acid: surface property, etching pattern, and bond strength studies. *Operative dentistry*, *43*(1), 101-110.
38. Dal Bello, Y., Farina, A. P., Souza, M. A., & Cecchin, D. (2020). Glycolic acid: Characterization of a new final irrigant and effects on flexural strength and structural integrity of dentin. *Materials Science and Engineering: C*, *106*, 110283.
39. Baumgartner, J. C., & Mader, C. L. (1987). A scanning electron microscopic evaluation of four root canal irrigation regimens. *Journal of endodontics*, *13*(4), 147-157.
40. Lottanti, S., Gautschi, H., Sener, B., & Zehnder, M. (2009). Effects of ethylenediaminetetraacetic, etidronic and peracetic acid irrigation on human root dentine and the smear layer. *International endodontic journal*, *42*(4), 335-343.
41. Ari, H., & Erdemir, A. (2005). Effects of endodontic irrigation solutions on mineral content of root canal dentin using ICP-AES technique. *Journal of Endodontics*, *31*(3), 187-189.
42. Neelakantan, P., Nandagopal, M., Shemesh, H., & Wesselink, P. (2015). The effect of root dentin conditioning protocols on the push-out bond strength of three calcium silicate sealers. *International Journal of Adhesion and Adhesives*, *60*, 104-108.
43. Sarkar, N. K., Saunders, B., Moiseyeva, R., Berzins, D. W., & Kawashima, I. (2002, March). Interaction of mineral trioside aggregate (MTA) with a synthetic tissue fluid. In *Journal of Dental Research* (Vol. 81, pp. A391-A391). 1619 DUKE ST, ALEXANDRIA, VA 22314-3406 USA: INT AMER ASSOC DENTAL RESEARCHI ADR/AADR.
44. Reyes-Carmona, J. F., Felippe, M. S., & Felippe, W. T. (2009). Biomineralization ability and interaction of mineral trioxide aggregate and white portland cement with dentin in a phosphate-containing fluid. *Journal of endodontics*, *35*(5), 731-736.
45. Camilleri, J. (2007). Hydration mechanisms of mineral trioxide aggregate. *International endodontic journal*, *40*(6), 462-470.
46. Garberoglio, R., & Brännström, M. (1976). Scanning electron microscopic investigation of human dentinal tubules. *Archives of oral biology*, *21*(6), 355-362.
47. Bird, D. C., Komabayashi, T., Guo, L., Opperman, L. A., & Spears, R. (2012). In vitro evaluation of dentinal tubule penetration and biomineralization ability of a new root-end filling material. *Journal of Endodontics*, *38*(8), 1093-1096.
48. Ersahan, S., & Aydin, C. (2010). Dislocation resistance of iRoot SP, a calcium silicate–based sealer, from radicular dentine. *Journal of endodontics*, *36*(12), 2000-2002.
49. Camilleri, J., Sorrentino, F., & Damidot, D. (2013). Investigation of the hydration and bioactivity of radiopacified tricalcium silicate cement, Biodentine and MTA Angelus. *Dental materials*, *29*(5), 580-593.
50. Atmeh, A. R., Chong, E. Z., Richard, G., Festy, F., & Watson, T. F. (2012). Dentin-cement interfacial interaction: calcium silicates and polyalkenoates. *Journal of dental research*, *91*(5), 454-459.
51. Camilleri, J., Formosa, L., & Damidot, D. (2013). The setting characteristics of MTA Plus in different environmental conditions. *International Endodontic Journal*, *46*(9), 831-840.
52. Han, L., Kodama, S., & Okiji, T. (2015). Evaluation of calcium-releasing and apatite-forming abilities of fast-setting calcium silicate-based endodontic materials. *International endodontic journal*, *48*(2), 124-130.
53. Han, L., & Okiji, T. (2013). Bioactivity evaluation of three calcium silicate-based endodontic materials. *International endodontic journal*, *46*(9), 808-814.
54. Kokubo, T., & Takadama, H. (2006). How useful is SBF in predicting in vivo bone bioactivity?. *Biomaterials*, *27*(15), 2907-2915.
55. Ruiz-Linares, M., Baca, P., Arias-Moliz, M. T., Ternero, F. J., Rodríguez, J., & Ferrer-Luque, C. M. (2019). Antibacterial and antibiofilm activity over time of GuttaFlow Bioseal and AH Plus. *Dental materials journal*, *38*(5), 701-706.
56. Akcay, M., Arslan, H., Durmus, N., Mese, M., & Capar, I. D. (2016). Dentinal tubule penetration of AH Plus, iRoot SP, MTA fillapex, and guttaflow bioseal root canal sealers after different final irrigation procedures: A confocal microscopic study. *Lasers in surgery and medicine*, *48*(1), 70-76.
57. Gandolfi, M. G., Siboni, F., Botero, T., Bossù, M., Riccitiello, F., & Prati, C. (2015). Calcium silicate and calcium hydroxide materials for pulp capping: biointeractivity, porosity, solubility and bioactivity of current formulations. *Journal of applied biomaterials & functional materials*, *13*(1), 43-60.
58. Asgary, S., Eghbal, M. J., Parirokh, M., & Ghoddusi, J. (2009). Effect of two storage solutions on surface topography of two root-end fillings. *Australian Endodontic Journal*, *35*(3), 147-152.

Cite This Article: Emna Garouachi, Amira Kikly, Sabra Jaafoura, Neila Zokkar, Nabiha Douki (2024). The Effect of the Smear Layer on the Adhesion Capacity of Bioceramic Sealers to Root Dentin: A Systematic Review of the Literature. *EAS J Dent Oral Med*, *6*(6), 133-145.