ejpmr, 2024, 11(11), 273-282

SJIF Impact Factor 7.065

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

Research Article

ISSN 2394-3211

EJPMR

EFFECTS OF ENDODONTIC SEALERS AND IRRIGATION SYSTEMS ON SMEAR LAYER REMOVAL AFTER POST SPACE PREPARATION EVALUATED AND STUDIED UNDER A SCANNING ELECTRON MICROSOCOPE

[1*]Dr. Sameer Mohideen Gani S., [2]Dr. Ananthakrishna S., [3]Dr. Pradeep P. R., [4]Dr. Yuva Rani P. and [5]Dr. Akshata M. H.

[1]Post-Graduate Student, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

[2]Professor and HOD, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

[3]Principal and Professor, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

[4]Postgraduate Student, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

[5]Postgraduate Student, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

***Corresponding Author: Dr. Sameer Mohideen Gani S.**

Post-Graduate Student, Department of Conservative Dentistry and Endodontics, M. R. Ambedkar Dental College and Hospital, Bangalore.

Article Received on 07/09/2024 Article Revised on 27/09/2024 Article Accepted on 17/10/2024

ABSTRACT

Objective: This study aimed to evaluate the effectiveness of five different endodontic sealers with three irrigation methods for smear layer removal after post space preparation, using scanning electron microscopy (SEM). **Materials and Methods:** Seventy-five single-rooted extracted teeth were standardized to 15 mm in length. After canal preparation with F5 Pro Taper instruments and 5.25% NaOCl irrigation, the canals were flushed with 17% EDTA. Teeth were divided into five groups based on the sealers used:

1. AH Plus (Epoxy resin-based)
2. Sealapex (Calcium hydroxide-based)
3. Gutta Flow 2
4. MTA Fill apex
5. Metaceraseal (Bioceramic-based)

After obturation, 10 mm of gutta-percha was removed, leaving 5 mm apically intact. Each group was subdivided based on irrigation methods:

- Passive Ultrasonic Irrigation (PUI)
- Endovac system (EV)
- Regular Rinse (RR) with 17% EDTA and 2% CHX.

SEM analysis at 1000x magnification evaluated smear layer removal at the middle third of the canals.

Results: AH Plus had the least smear layer residue, making it the easiest to remove, while Metaceraseal had the most remnants. MTA Fillapex, Sealapex, and Gutta Flow performed moderately. PUI was the most effective irrigation method, followed by Endovac, with Regular Rinse being the least effective. **Conclusion:** The combination of AH Plus sealer and PUI irrigation was the most effective for smear layer removal. AH Plus offers good flow and easy retrieval, while PUI enhances cleaning through acoustic streaming, making it the optimal protocol for post space preparation.

INTRODUCTION

The success of root canal treatment depends equally on effective root canal therapy and the subsequent restoration of the tooth to ensure its long-term functionality.[1] The root canal procedure involves filling the root canal space with a biocompatible material to prevent microleakage and recontamination. High-quality obturation is essential to seal the canals completely and prevent microorganism entry, which is crucial for the treatment's success.

Post-endodontic restoration is vital for the function and longevity of a treated tooth. For teeth with significant structural loss, intraradicular posts, especially fiberreinforced composite posts, are commonly used for added retention. The post space preparation involves removing part of the root canal filling to fit the post, and care must be taken to preserve the apical seal to avoid compromising the treatment.[2]

Common failures in adhesive fiber posts often result from bond deficiencies. Successful bonding depends on the hybridization of the demineralized surface and formation of resin tags. The smear layer, a barrier formed during canal preparation, can impede optimal bonding. Proper irrigation techniques are needed to remove residual debris, necrotic tissue, bacteria, and the smear layer.[3]

Ideal irrigants should have antimicrobial properties, dissolve necrotic tissues, flush debris, serve as a lubricant, remove the smear layer, and have low surface tension. Sodium Hypochlorite (NaOCl) is the most commonly used for its tissue-dissolving and antimicrobial properties. Ethylenediaminetetraacetic acid (EDTA) is used for its chelating properties, which help remove the smear layer.[2,4]

Endodontic filling materials, including gutta-percha and sealers, play a critical role in ensuring a fluid-tight seal. Sealers fill gaps between the core material and dentinal walls and exhibit antimicrobial properties without causing inflammation. Various sealers are available, such as AH Plus (epoxy resin), calcium hydroxide-based sealers, and bioceramic-based sealers like Meta Ceraseal. Newer sealers, including Mineral Trioxide Aggregate (MTA) and Gutta Flow, are also in use.[5]

Passive Ultrasonic Irrigation (PUI) enhances irrigation effectiveness by disrupting biofilm and facilitating better irrigant penetration. The EndoVac Irrigation system (EV) is a device that uses apical negative pressure to drain irrigating solution at the apical third of the canal system and to remove the debris using a negative pressure mechanism.[2] The EV system tends to extrude less irrigant in the periapical tissues, reducing the accidental extrusion of the NaOCl.[6] The Regular Rinse (RR) group uses 17% EDTA and NaOCl.

This study aims to evaluate the effectiveness of different endodontic sealers and irrigation systems in removing the smear layer after post space preparation, using scanning electron microscopy for assessment.

MATERIALS AND METHODS

SOURCE OF DATA

Study design: An in-vitro study was performed in 75 single-rooted teeth.

Source: Seventy-five single-rooted extracted teeth either for orthodontic or periodontic reasons, were collected from the Department of Oral and Maxillofacial Surgery at M. R. Ambedkar Dental College and Hospital after obtaining consent from the patient. The OSHA Guidelines were followed in the collection and storage of the samples.

METHOD OF COLLECTION OF DATA

Sampling technique: Samples were randomly selected depending on the inclusion and exclusion criteria till the desired sample size of 75 was obtained.

Sample size: The sample size was estimated using the G Power software v. 3.1.9.4 [(Franz Faul, Universität Kiel, Germany) considering the effect size to be measured (f) at 42%, power of the study at 80% and the alpha error at 5%, the sample size needed is 75. Each group will comprise of 15 samples. The samples in each group will be further sub-divided into 5 samples each based on 3 different post- dowel irrigation methods. [5 samples x 3 Irrigations systems x 5 sealers = 75 samples].

Sample selection: Samples were selected according to inclusion and exclusion criteria.

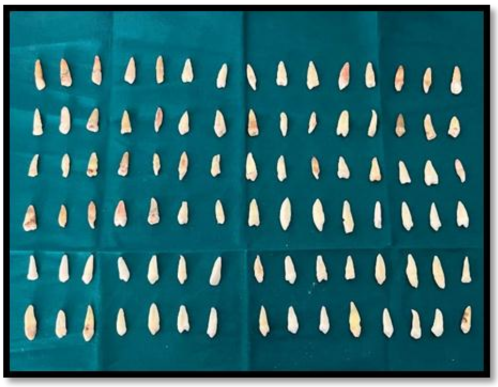
CRITERIA FOR SELECTION

Inclusion criteria

Teeth that were caries free.
Teeth with single root.
Teeth with single canal and mature apex.

Exclusion criteria

Fractured or restored teeth.
Carious teeth.
Severely attrited/abraded teeth.
Root canal treated teeth.
Incompletely formed apex.
Curved canals
Teeth with internal or external resorption.
Teeth with calcified canals.



ARMAMENTARIUM

Mouth mirror.
Explorer/ straight probe.
Tweezers.
Airotor Hand piece.
Stainless Steel Hand Files # 10-40.
0.9% Saline.
RVJ Carestream Digital Radiography System.
Endoaccess Bur.

Ultrasonic Scaler (Satelec, Acteon, U.K)
Diamond Round Burs.
Protaper Next Rotary File System.
Gutta Percha (Dentsply Maillefer; Ballaigues, Switzerland)
Apex Loactor.
Protaper Paper Points (Dentsply Maillefer; Ballaigues, Switzerland)
AH Plus Sealant
Calcium Hydroxide Sealer.
Gutta Flow.
Mineral Trioxide Aggregate (MTA).
Bioceramic Sealer (Meta CeraSeal).
Endovac Irrigation system.
Ultrasonic Irrigation system.
Regular rinse irrigation (NaOCl, 17% EDTA)
Peso reamers #5
Scanning electron microscope.
Spiral spreader.

METHODOLOGY

All the procedures performed in this study were in adherence with the ethical standards of the institutional research ethics committee.

The study is single-blinded.

Seventy-five human-extracted single-rooted teeth were selected from the Department of Oral and Maxillofacial Surgery.

These single-rooted teeth underwent decoronation to standardize the root length to 15mm.

After coronal access preparation, the canals were manually enlarged up to #40 file size and then instrumented up to F5 Pro Taper Universal Rotary Instrument.

During instrumentation, 5.25% of NaOCl is used as an irrigant. Before obturation, each canal was flushed with 10 ml 17% EDTA.

Distribution of participants

Group	Type of Sealers	Number of Teeth
Group I	AH Plus sealer	15
Group II	Calcium Hydroxide based sealer	15
Group III	Gutaa Flow	15
Group IV	Mineral Trioxide Aggregate (MTA) based sealer	15
Group V	Bioceramic Sealer (Meta CeraSeal)	15

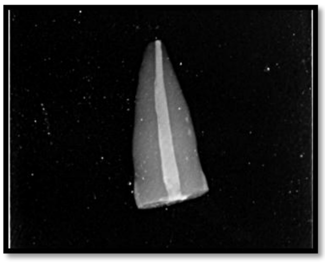
The root canal sealers were delivered into the canal using a spiral spreader.

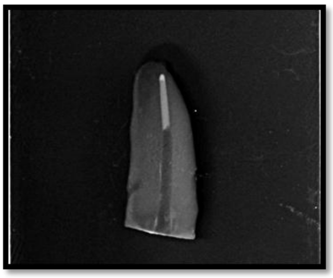
A main gutta percha point with a tip diameter of 0.5mm and a taper of 0.6 was inserted into the canal.

Additional gutta percha points, were introduced into the apical 5 mm of the canal using a #25 lateral condensation plugger to reach an adequate apical sealing, thus completing the obturation.

After obturation, a Peso reamer was used to remove the 10 mm of gutta percha leaving 5mm of the apical sealing untouched.

Post-space preparation was completed with a #3 drill, resulting in post-space with a 1.9 mm diameter at the coronal level.



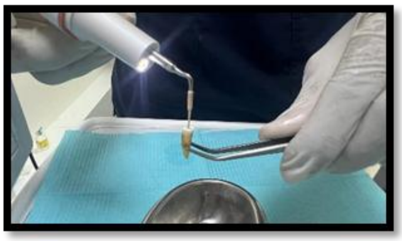


After the post-space preparation, the specimens within each group were randomly divided into three subgroups according to the irrigation system used.

Subgroup	Type of Irrigation system used
Subgroup A	Regular Rinse
Subgroup B	Endovac
Subgroup C	Passive Ultrasonic

A sample size of 5 teeth randomly selected from each sealant group (main group) was used for each irrigation system (Subgroup) to remove the smear layer.

After irrigation is done, longitudinal grooves along the buccolingual direction were prepared in each specimen, without penetrating the post space. The dissected halves were dried in a desiccator for 24 hours and were mounted on metallic stubs, sputter coated with gold, and evaluated at the middle third under a Scanning electron microscope at 1000 X.



The number of debris was scored from 0 to 2 as follows
No debris or the remnant particles covered with <25% of the canal walls.

Few debris particles covering an evident area of 25-50% of the canal surface.

Large number of debris particles covering an area >50%.

RESULTS

Comparison of mean Micro leakage (in mm) b/w 3 groups at Immediate time interval using One-way ANOVA Test

Groups	N	Mean	SD	Min	Max	p-value
Seal Apex	5	0.544	0.223	0.25	0.81	<0.001*
MTA Fillapex	5	0.526	0.117	0.38	0.67	
Ceraseal	5	1.030	0.015	1.01	1.05	

* - Statistically Significant

Multiple comparison of mean diff. in mean Micro leakage b/w 3 groups at Immediate time interval using Tukey's Post hoc Test

(I) Groups	(J) Groups	Mean Diff.(I-J)	95% CI for the Diff		p-value
			Lower	Upper	
Sealapex	MTA Fillapex	0.017	-0.228	0.263	0.98
	Ceraseal	-0.486	-0.732	-0.241	0.001*
MTA Fillapex	Ceraseal	-0.504	-0.749	-0.258	<0.001*

* - Statistically Significant

The mean Microleakage in Seal Apex group was 0.544±0.223, in MTA Fill apex group was 0.526±0.117 and in Ceraseal group was 1.030±0.015. This difference in the mean Microleakage between 3 sealer groups at Immediate time interval was statistically significant at p<0.001. [Graph no. 1]

Multiple comparison of mean differences between groups revealed that the Ceraseal group showed significantly increased mean Microleakage as compared to Seal apex and MTA Fill apex group and the mean differences were statistically significant at p=0.001 & p<0.001 respectively. However, no significant difference was observed in the mean Micro leakage between Seal apex and MTA Fill apex group [p=0.98]. This infers that the mean Microleakage at Immediate time interval was significantly higher in Ceraseal group and lesser in Seal Apex and MTA Fill apex groups. [Graph no. 2]

Comparison of mean Micro leakage (in mm) b/w 3 groups after 1-week time interval using One-way ANOVA Test

Groups	N	Mean	SD	Min	Max	p-value
Seal Apex	5	0.911	0.422	0.58	1.47	<0.001*
MTA Fill apex	5	0.808	0.170	0.53	0.97	
Ceraseal	5	1.475	0.265	1.03	1.71	

* - Statistically Significant

Multiple comparison of mean diff. in mean Micro leakage b/w 3 groups after 1-week time interval using Tukey's Post hoc Test

(I) Groups	(J) Groups	Mean Diff.(I-J)	95% CI for the Diff		p-value
			Lower	Upper	
Sealapex	MTA Fillapex	0.103	-0.410	0.616	0.86
	Ceraseal	-0.564	-1.077	-0.051	0.03*
MTA Fillapex	Ceraseal	-0.667	-1.180	-0.154	0.01*

* - Statistically Significant

The mean Micro leakage in Seal Apex group was 0.911±0.422, in MTA Fill apex group was 0.808±0.170 and in Ceraseal group was 1.475±0.265. This difference in the mean Microleakage between 3 sealer groups after 1-week time interval was statistically significant at p<0.001. [Graph no. 3]

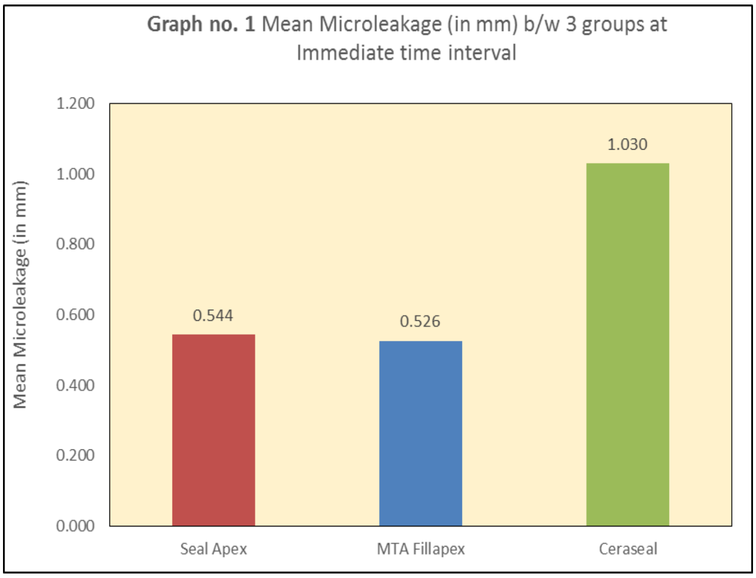
Multiple comparison of mean differences between groups revealed that the Ceraseal group showed significantly increased mean Microleakage as compared to Seal apex and MTA Fill apex group and the mean differences were statistically significant at p=0.03 & p=0.01 respectively. However, no significant difference was observed in the mean Micro leakage between Seal apex and MTA Fill apex group [p=0.86] This infers that the mean Microleakage at 1-week time interval was significantly higher in Ceraseal group and lesser in Seal Apex and MTA Fill apex groups. [Graph no. 4]

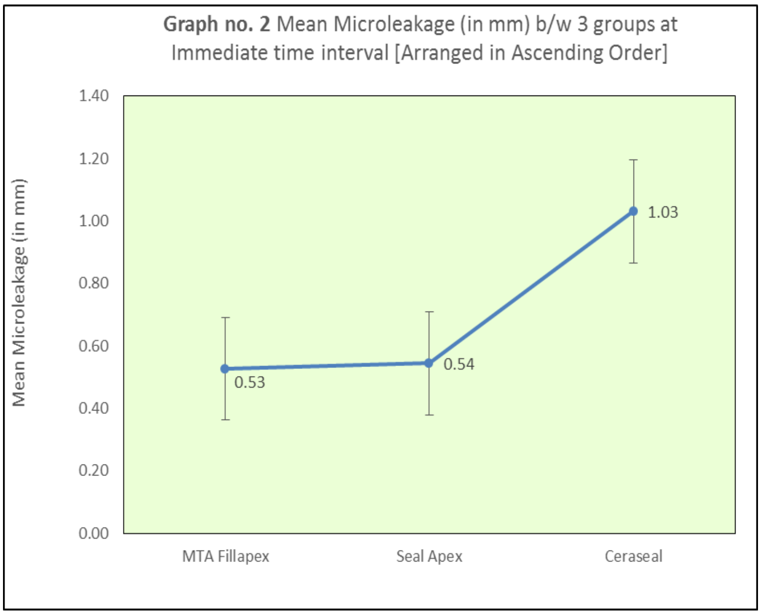
Comparison of mean Micro leakage (in mm) b/w Immediate & after 1-week time interval in each group using Student Paired t Test

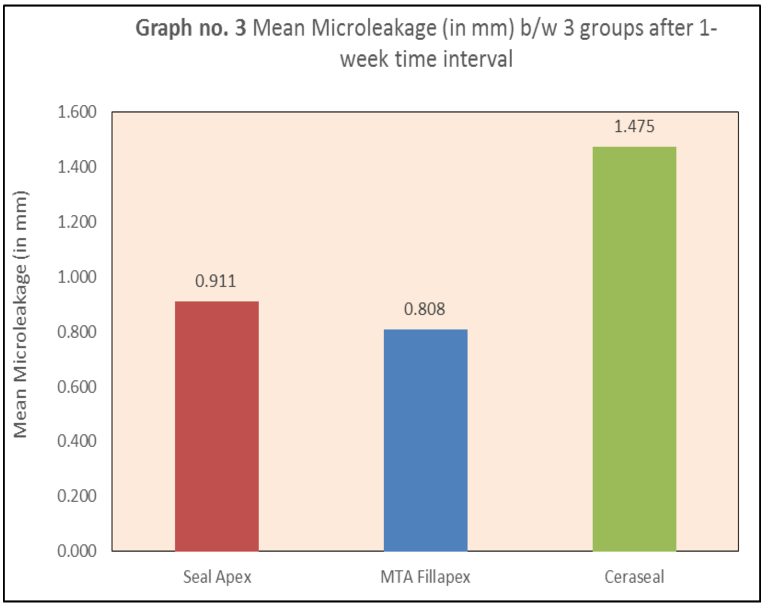
Groups	Time	N	Mean	SD	Mean Diff	p-value
Seal Apex	Immediate	5	0.544	0.223	-0.367	0.04*
	1 Week	5	0.911	0.422		
MTA Fillapex	Immediate	5	0.526	0.117	-0.281	0.05#
	1 Week	5	0.808	0.170		
Ceraseal	Immediate	5	1.030	0.015	-0.445	0.02*
	1 Week	5	1.475	0.265		

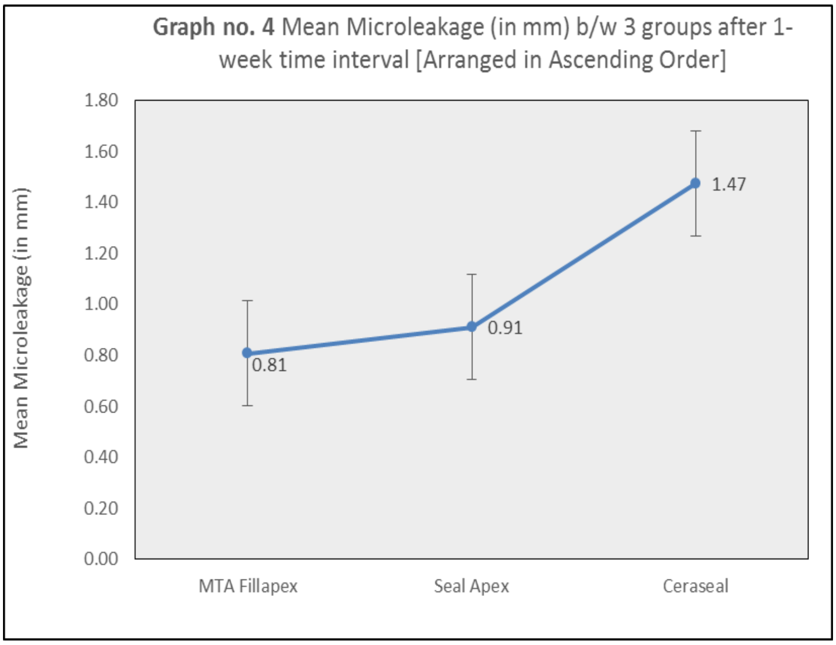
* - Statistically Significant

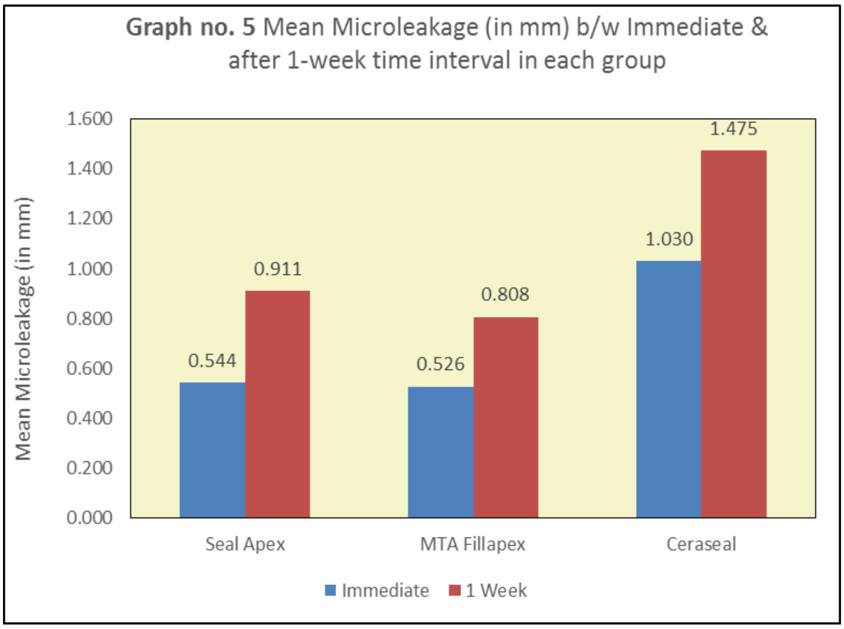
In Seal Apex and Ceraseal group, the mean Microleakage significantly increased at 1-week time interval [0.911±0.422 & 1.475±0.265] as compared to Immediate time-interval [0.544±0.223 & 1.030±0.015] and the mean differences between 2 time intervals was statistically significant at p=0.04 & p=0.02 respectively. In MTA Fill apex group, the mean Microleakage relatively increased at 1-week time interval [0.808 ± 0.170] as compared to Immediate time-interval [0.526±0.117] and the mean difference between 2 time intervals showed a borderline significance at p=0.05. This infers that the mean Microleakage in all the 3 groups showed significant increase at 1-week time interval as compared to Immediate time period. [Refer Graph no. 5]


Graph no. 1 Mean Microleakage (in mm) b/w 3 groups at Immediate time interval
Mean Microleakage (in mm)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.544
0.526
1.030
Seal Apex
MTA Fillapex
Ceraseal


Graph no. 2 Mean Microleakage (in mm) b/w 3 groups at Immediate time interval [Arranged in Ascending Order]
Mean Microleakage (in mm)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.53
0.54
1.03
MTA Fillapex
Seal Apex
Ceraseal


Graph no. 3 Mean Microleakage (in mm) b/w 3 groups after 1-week time interval
Mean Microleakage (in mm)
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.911
0.808
1.475
Seal Apex
MTA Fillapex
Ceraseal





DISCUSSION

The primary aim of root canal treatment is to completely remove both vital and non-vital tissues from the canal space. This involves filling the canal with a biocompatible material to seal it entirely, preventing microleakage and recontamination.[7] The effectiveness of this obturation is critical, as it ensures that the canals are sealed completely, preventing the entry of microorganisms that could cause treatment failure.

Gutta-percha is considered the gold standard for root canal filling due to its favorable properties, but it cannot achieve a perfect three-dimensional seal on its own. To address this limitation, endodontic sealers are used in conjunction with gutta-percha.[8] Sealers play a crucial role by sealing the canal more effectively, entombing any remaining microorganisms, and filling inaccessible areas within the canal walls. Advances in sealer technology have improved their ability to penetrate dentinal tubules and adhere to both dentine and core materials, enhancing the overall seal.[9]

During root canal treatment, a layer of organic and inorganic material called the smear layer forms on the canal walls. This smear layer, consisting of particles ranging from less than 0.5–15 µm, has an irregular structure and can hinder the penetration of irrigants and sealants into dentinal tubules.[10] Removing the smear layer is essential for thorough cleaning of the canal walls and promoting the adhesion of sealants.

Several factors influence the extent to which a sealer can penetrate dentinal tubules, including the smear layer, the viscosity and surface activity of the sealer, particle size, and the size and number of dentinal tubules. Age-related changes in dentin, such as decreased tubule density and increased peritubular dentin, can also affect sealer penetration.[11,12] A sealer with low surface activity or sufficient surface-active agents can enhance penetration into dentinal tubules. Other factors like sealer thickness, working time, and hardening also play important roles.[13]

Post root canal treatment, restoring the tooth to its normal function and appearance is crucial. Due to the potential lack of adequate tooth structure, post-space preparation is often necessary to create space for a post that supports permanent restoration. Historically, cast posts and cores, post-retained amalgam, and composite cores were used. Today, fiber posts are preferred for their dentin-like characteristics, biocompatibility, corrosion resistance, and improved aesthetics. Fiber posts are bonded using adhesives and composite resins to ensure strong retention and enhance fracture resistance.[14,15]

Post-space preparation involves creating space within the canal for the post by removing a portion of the root canal filling.[16] Typically, 3-5 mm of the root canal filling material is retained in the apical third, while the remaining material is removed using various reamers. The depth of preparation depends on the root's length and morphology, with longer posts generally providing better retention.[17,18]

Effective removal of the smear layer is crucial for proper sealing and is commonly achieved using irrigants like sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA). NaOCl, used as an initial rinse, removes organic components, while EDTA, used as a final rinse, removes inorganic components of the smear layer. This method effectively cleans the coronal and middle thirds of the canal but may be less effective in the apical third due to the intricate anatomy and vapor lock effect.[19,20]

Traditional syringe irrigation typically uses a 5 ml, 23-gauge needle and is limited to 1.5-2 mm beyond the needle tip, mainly covering the coronal and middle thirds. To address this, intracanal activation methods, including manual agitation and machine-assisted devices, can enhance irrigant penetration throughout the canal space.[3]

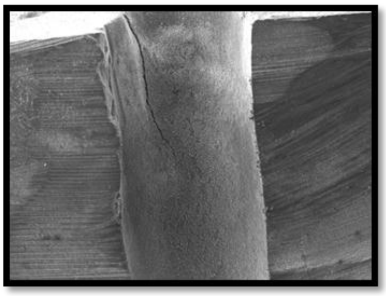
The Endovac irrigation system utilizes apical negative pressure (ANP) to deliver irrigation solutions to the apical third while removing debris via suction. This method achieves superior debridement and minimal risk of irrigant extrusion compared to traditional needle irrigation.[21]

Passive Ultrasonic Irrigation (PUI) is another effective method that enhances cleaning by using ultrasonic energy to disrupt the biofilm and improve irrigant penetration. PUI has been shown to remove debris from canals and isthmus more effectively than syringe irrigation. Factors like acoustic streaming and cavitation contribute to its efficacy.[22]

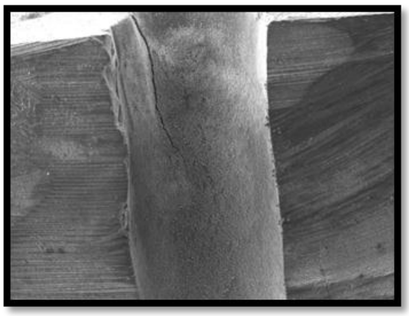
In the present study, the effectiveness of different irrigation systems in removing the smear layer was evaluated using gutta-percha and five different sealers. AH Plus, an epoxy resin sealer known for its low shrinkage, low leakage, and good biocompatibility, was the most effective in smear layer removal when used with PUI. MTA Fillapex, a tricalcium silicate-based sealer, also performed well with PUI. Sealapex, a calcium hydroxide-based sealer, and Gutta Flow, a polyvinyl siloxane-based sealer, showed intermediate results, while Metaceraseal, a bioceramic sealer, had the most smear layer remnants.[23]

These findings align with previous studies. For example, research by Xuan Chen et al. and Oltra E et al. demonstrated that AH Plus consistently showed better results in smear layer removal compared to other sealers. Similarly, studies by Mavishna MV et al. and Tandon J et al. confirmed the superior efficacy of PUI over traditional methods and other irrigation systems in removing gutta-percha and sealers.[24]

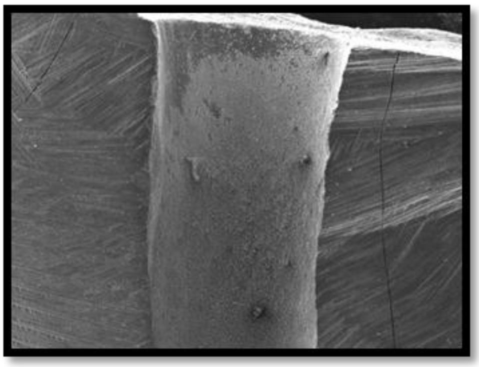
In conclusion, the study supports the superior effectiveness of PUI in removing the smear layer compared to other irrigation systems. AH Plus sealer, in particular, demonstrated the best performance in smear layer removal, followed by MTA Fillapex, Sealapex, and Gutta Flow. The results highlight the importance of choosing the right irrigation and sealer systems to achieve optimal cleaning and sealing in endodontic treatments.



SEM ANALYSIS OF AH PLUS WITH PUI.



SEM ANALYSIS OF AH PLUS WITH ENDOVAC IRRIGANT



SEM ANALYSIS OF AH PLUS WITH REGULAR RINSE IRRIGATION

CONCLUSION

The current study assessed the effectiveness of five endodontic sealers and three irrigation systems in removing the smear layer after post-space preparation, using scanning electron microscopy.

The results showed that the AH Plus sealer combined with the Passive Ultrasonic Irrigation (PUI) system was the most effective, with the least amount of smear layer remnants. This was followed by MTA Fillapex with PUI and AH Plus with Endovac (EV). Other effective combinations included Sealapex with PUI and Gutta Flow 2 with PUI. In contrast, Metaceraseal with Regular Rinse (RR) had the highest amount of smear layer remnants.

Overall, AH Plus emerged as the best sealer for smear layer removal, especially when used with PUI. Metaceraseal, however, was the least effective. Among the irrigation systems, PUI was superior in removing the smear layer, followed by Endovac. The Regular Rinse system was the least effective.

In summary, regardless of the sealer used, the PUI system was the most efficient for smear layer removal, followed by Endovac, with Regular Rinse showing the least effectiveness. AH Plus proved to be the most effective sealer, while Metaceraseal was the least effective in this regard.

REFERENCE

1. Grossman, V. Gopikrishna. Shaping and cleaning of the radicular space. Grossman 14th edition, 265-280.
2. Grossman, V. Gopikrishna. Cleaning and shaping of Root Canals. Grossman 13th edition, 219-232.
3. Xuan Chen, Haixia Liu, MA, Yuanli He, Tao Luo and Ling Zou. Effects of Endodontic Sealers and Irrigation Systems on Smear Layer Removal after Post Space Preparation. J. Endod, 2018; 44(8): 1293-7.
4. Vitória MS, de Almeida ENM, Barros APO, de Oliveira ECG, Costa JLSG, Dantas AAR, Kuga MC. Evaluation of different mechanical cleaning protocols associated with 2.5% sodium hypochlorite in the removal of residues from the post space. J Conserv Dent Endod, 2024; 27(3): 274-9.
5. De Assis DF, do Prado M, Simão RA. Evaluation of the interaction between endodontic sealers and dentin treated with different irrigant solutions. J. Endod, 2011; 37(11): 1550-2.
6. Altmann AS, Leitune VC, Collares FM. Influence of eugenol-based sealers on push-out bond strength of fiber post luted with resin cement: systematic review and meta-analysis. J. Endod, 2015; 41(9): 1418-23.
7. Topbas C, Adiguzel O. Endodontic Irrigation Solutions: A review. Int. Dent. Res; 2017; 7(3): 54-61.
8. Orstavik D. Materials used for root canal obturation: Technical, biological and clinical testing. Endod Topics, 2005; 12: 25‑38.
9. Sonu KR, Girish TN, Ponnappa KC, Kishan KV, Thameem PK. “Comparative evaluation of dentinal penetration of three different endodontic sealers with and without smear layer removal”-Scanning electron microscopic study. Saudi Endod. J; 2016; 6(1): 16-20.
10. Alamoudi RA. The smear layer in endodontic: To keep or remove - an updated overview. Saudi Endod J; 2019; 9(2): 71-81
11. Kokkas AB, Boutsioukis AC, Vassiliadis LP, Stavrianos CK. The influence of the smear layer on dentinal tubule penetration depth by three different root canal sealers: An in vitro study. J Endod, 2004; 30(2): 100‑2.
12. Mamootil K, Messer HH. Penetration of dentinal tubules by endodontic sealer cements in extracted teeth and in vivo. Int Endod J; 2007; 40(11): 873‑81.
13. Okşan T, Aktener BO, Sen BH, Tezel H. The penetration of root canal sealers into dentinal tubules. A scanning electron microscopic study. Int Endod J; 1993; 26(5): 301‑5.
14. Perdigão, J, Geraldeli, S, Lee, I.K. Push-out bond strengths of tooth-colored posts bonded with different adhesive systems. Am. J. Dent, 2004; 17: 422–6.
15. Hayashi, M.; Takahashi, Y.; Hirai, M.; Iwami, Y; Imazato, S. Ebisu, S. Effect of endodontic irrigation on bonding of resin cement to radicular dentin. Eur. J. Oral Sci; 2005; 113: 70–6.
16. Caputo, A.A.; Standlee, J.P. Pins and posts—Why, when and how. Dent. Clin. N. Am; 1976; 20: 299–311.
17. Kremeier K, Fasen L, Klaiber B, Hofmann N. Influence of endodontic post type (glass fiber, quartz fiber or gold) and luting material on push-out bond strength to dentin in vitro. Dent. Mater, 2008; 24(5): 660-6.
18. Özkurt-Kayahan Z, Barut G, Ulusoy Z, Oruçoğlu H, Kayahan MB, Kazazoğlu E, Haznedaroğlu F. Influence of Post Space Preparation on the Apical Leakage of Calamus, Single-Cone and Cold Lateral Condensation Obturation Techniques: A Computerized Fluid Filtration Study. J. Prosthodont, 2019; 28(5): 587-91.

19. Andrabi SM, Kumar A, Zia A, Iftekhar H, Alam S, Siddiqui S. Effect of passive ultrasonic irrigation and manual dynamic irrigation on smear layer removal from root canals in a closed apex in vitro model. J Investig Clin Dent. 2014; 5(3): 188-93.
20. Zehnder M. Root canal irrigants. J Endod, 2006; 32: 389–98.
21. Schoeffel GJ. The EndoVac method of endodontic irrigation, part 2--efficacy. Dentistry today, 2008; 27(1): 82-4.
22. Pashley DH, Tay FR. Review of contemporary irrigant agitation techniques and devices. J Endod, 2009; 35(6): 791–804.
23. Tandon J, Yadav RK, Tikku AP, Shakya VK, Singh SK. Comparative evaluation of different irrigating and irrigant activation system in removal of gutta-percha/sealer during retreatment: An in vitro Micro-CT study. J Oral Biol Craniofac Res; 2022; 12(4): 444-8.
24. Mavishna MV, Venkatesh KV. Comparative evaluation of retreatability of calcium silicate-based root canal sealers and epoxy resin-based root canal sealers in curved canals-An In-Vitro micro-CT analysis. Indian J Dent Res; 2021; 32(1): 79-86.