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Comparative Evaluation Of Different Chelating Agents And Their Effect On Push-Out Bond Strength Of Three Different Root Canal Sealers To Root Dentin- An Invitro Study

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Abstract
Aim: *To assess and compare the effect of different chelating agents on the push out bond strength of a three different root canal sealer to root dentin using Universal Testing Machine.*
Methodology: *Ninety single-rooted teeth were randomly divided into 3 groups (n=30) and 3 sub-groups (n_1, n_2, n_3=10) on basis of sealers and chelating agents respectively. Group I: [Bio-ceramic sealer]; Group II: [Resin-based sealer]; Group III: [Silicone-based sealer] divided in further sub-groups into A- 10% Citric acid (n_1=10); B- 17% EDTA (n_2=10); C- 7% Maleic acid (n_3=10). NaOCl was used in irrigation procedures, and then the appropriate chelating agents were added. After preparation, canals were obturated with GP and respective sealers be it Bio-C sealer, Meta adseal plus and Guttaflow'2. A universal testing equipment was utilized to measure the strength of the push-out bond.*
Results: *Intergroup comparison of POBS with 10% Citric Acid, 17% EDTA and 7% Maleic Acid resulted with Meta adseal plus exhibited highest bond strength followed by Bio-C sealer and lowest bond strength was conclusive with Guttaflow'2 (p = 0.001). Intragroup comparison of push out bond showed significant differences unlike in 10% Citric Acid Group II maintained uniform bond whereas Group I and Group III showed progressive increase in bond strength.*
Conclusion: *Meta Adseal Plus showed the strongest adhesion in root canal sealing, penetrating deeper into the dentinal tubules. Bio-C sealer showed a moderate bond strength, while Guttaflow'2 showed the weakest adhesion, which made it less effective in preserving the long-lasting bonds within the root canal system.*
Keywords: *Bio-C Sealer, Meta Adseal Plus, Guttaflow'2, Citric Acid, Maleic Acid, EDTA, Protaper Gold, Push-out bond strength.*

INTRODUCTION: The main objective of an endodontic treatment is to eradicate any chance of reinfection by completely or maximally removing the germs from the teeth's root canals and establishing a full hermetic obturation.[1] In order to preserve the integrity of the root canal seal that interfaces during mechanical forces brought on by tooth flexure and during the preparation of post-space or surgical treatments, the binding strength of the endodontic sealer to dentin is crucial. In order to preserve sealing and, ultimately, the clinical effectiveness of endodontic therapy, the bond strength of endodontic sealers reduces the possibility of filling separation from dentin during restorative treatments or the masticatory function.[2-3]
Endodontics uses a variety of sealers, including silicone-based, resin-based, and bio-ceramic sealers. Bio-ceramic sealers, which are made of calcium phosphates, zirconia, hydroxyapatite, and bioactive glass, have

been launched recently. [4-5] There are now new endodontic sealers that are ready to use and are based on calcium silicate. A novel premixed bio-ceramic sealer called the *Bio-C Sealer (Angelus, Londrína, PR, Brazil)* was created for permanent filling and sealing during root canal therapy. Tricalcium silicate, dicalcium silicate, tricalcium aluminate, calcium oxide, zirconia oxide, silicon oxide, polyethylene glycol, iron oxide, and dispensing agents make up Bio-C Sealer, which comes in a single syringe. The producer claims that the release of calcium ions, which promotes the development of mineralized tissue, is what gives it its bioactivity. In addition to promoting periapical tissue mineralization, they have outstanding biocompatibility, strong sealing ability, and antibacterial activity.[6] Few studies, nonetheless, have assessed its impact on periapical tissues and associated cells thus far.

A common implant material in medicine is silicone, which is both biocompatible and inert.[7] Silicon-based sealers have recently been developed to counteract the cytotoxic effects of conventional endodontic sealers; one such material is *GuttaFlow'2*, a polydimethylsiloxane-based root canal filling material *(Coltène/Whaledent, Langenau, Germany)*. The firm claims that the GuttaFlow'2 material is an enhancement of the original GuttaFlow material in capsules with comparable qualities. Another cold flowable system, GuttaFlow'2, mixes sealer in its bulk mass with extremely tiny gutta-percha particles in powder form, which have a particle size of less than 30 µm. Additionally, the producer asserts that the material's improved flowability and small expansion during setting (0.2%) result in improved sealing and superior adaptability. It comes in a dual-barrel syringe ready to use.[8] The biocompatibility of the silicone-based root canal sealer GuttaFlow'2 is not well established, despite the fact that silicone is a highly-tolerated implant material that can close flawlessly even in damp settings.[9] The silicone-based sealers GuttaFlow and GuttaFlow'2 are different in that the former contains nano silver while the later contains micro silver.[10]

With its sophisticated formulation and features, *Adseal Plus (Meta Biomed, NY)* Resin-Based Sealer takes root canal therapy to the next level. With improved flowability and radiopacity provided by Adseal Plus, you may enjoy more performance and ease while guaranteeing complete sealing and accurate diagnosis. Users have more control and efficiency while applying due to the two dispensing tip options available, including the optional auto-mix tip. By preventing tooth discolouration, its Zirconium Oxide content raises the bar for aesthetic results. Additionally, Adseal Plus adds calcium phosphate to enhance safety and biocompatibility.

Numerous irrigation methods and schedules have been suggested in an effort to increase the root canal sealers' adhesion to radicular dentin. Chelating solutions can be used to remove the smear layer and expose more dentinal tubules, increasing the contact area and perhaps improving adhesion by making sure the sealer is more suited to the root canal dentin.[25] 17% EDTA is the most often used chelating agent. 10% citric acid and 7% maleic acid are additional chelating agents that are employed. The structure and chemical makeup of dentin is altered by eliminating the smear layer with various chelators. The permeability and microhardness of dentin are also altered, which affects the bonding strength of root canal obturation and the capacity of sealers to pass through dentinal tubules.[11]

Push out bond strength testing is a suitable technique to assess the root canal sealer's adhesion to the core material and canal wall. In order to assess the push-out bond strength of three distinct endodontic sealers—bio-ceramic, silicone-based, and resin-based—to the root dentin, this study was conducted utilizing three distinct endodontic chelating agents: 17% EDTA, 10% citric acid, and 7% maleic acid.

MATERIALS AND METHODOLOGY

The present study was carried out in the Department of Conservative Dentistry and Endodontics, Jaipur Dental College (MVGU), Jaipur in collaboration with ITS Dental College, Greater Noida.

Inclusion Criteria:

- Single rooted single canal teeth with less than 5° root curvature.

Exclusion Criteria:

- Teeth with developmental anomalies.
- Deciduous teeth.
- Endodontically treated teeth.
- Fractured root.
- Root curvature more than 5°.
- Root caries or resorption.

- Cracks.
- Teeth with inadequate root apices.

Sample Collection: Ninety single rooted teeth, freshly extracted within 3 months for periodontal reason were selected for this study. The teeth were stored in 0.1 % thymol solution (Qualigens Pharma, India) till use. The criteria for teeth selected included a single rooted and single canal (confirmed by radio-visiography both labiolingually and mesiodistally), no visible caries and no fracture or cracks on examination under microscope (10x).

Sample Preparation: The Biomechanical preparation was done by using Protaper Gold (Dentsply Tulsa, Germany) upto the size F2 file, using Tri auto mini Endomotor (J-Morita, Japan). All the teeth were randomly divided into 3 groups (n=30) on the basis of sealers used and sub-divided into further 3 sub-groups (n_1, n_2, n_3=10) on the basis of chelating agents;

GROUP I (n=30): Bioceramic Root Canal Sealer {BIO-C SEALER, ANGELUS}

Sub-grouped into;	**A.** 10% Citric Acid **B.** 17% EDTA **C.** 7% Maleic Acid

GROUP II (n=30): Resin-Based Root Canal Sealer {ADSEAL PLUS, META BIOMED}

Sub-grouped into;	**A.** 10% Citric Acid **B.** 17% EDTA **C.** 7% Maleic Acid

GROUP III (n=30): Silicone-Based Root Canal Sealer {GUTTA FLOW'2, COLTENE}

Sub-grouped into;	**A.** 10% Citric Acid **B.** 17% EDTA **C.** 7% Maleic Acid

For Subgroup A, Solution of 10% Citric Acid was prepared by dissolving 10gm of citric acid powder (Qualigens Pharma, India) in 100 ml of distilled water (Vitszee, India) in a triturator.

For Subgroup B, 17% liquid EDTA (Ammdent, Saronno- Italia) was used as it is in its available prepared formed.

For Subgroup C, Solution of 7% Maleic Acid was prepared by dissolving 7gm of Maleic Acid powder (Qualigens Pharma, India) in 100ml of distilled water (Vitszee, India) in a triturator.

The following sequence was followed for the Biomechanical preparation: S_X was introduced into the canal passively, at *300 rpm and 5.1 N/cm torque*, with an outward brushing motion to enlarge the coronal two-thirds of the root canal. After S_X (orange) all the files were taken till working length in one or more passes. S_1 (purple) was used at *250 rpm and 5.1 N/cm torque*, S_2 (white) at *300 rpm and 1.5 N/cm torque*, F_1 (yellow) at *300 rpm and 1.5 N/cm torque*, F_2 (red) at *300 rpm and 3.1N/cm torque* with each file contact period kept for 1min. Then the root canals preparation of all the groups were rinsed with 5ml of Normal saline for 1 min and dried using paper points (Dentsply Tulsa, Germany). Bio-C Sealer (Angelus, Londrína, PR, Brazil), Adseal Plus and GuttaFlow'2 Sealer (Coltene Whaledent, Germany) was applied onto the canal and the F2 gutta-percha cone is placed and is sealed. Radiographs were taken to see the quality of obturation, followed by Temporary sealing (Cavit, Ammdent, Saronno-Italia) of the cavity.

All the specimens were then incubated in 100% humidity at 37°C for 7 days (Digital BOD Incubator SMI-131, India). After 7 days, the specimens were cut horizontally using a water-cooled precision saw. Three 2 ± 0.01-mm-thick horizontal sections were obtained at 12, 6, and 2 mm (coronal, middle, and apical root sections, respectively) distance from the apex (n = 90 slices/group). A digital caliper (Model craft digital, India) with 0.01-mm accuracy used to measure the final thickness of each slice. A Universal testing machine (Asian Microdata Acquisition System, India) at a cross-head speed of 0.5 mm/min used to apply the push-out test. A modified hand spreader with at least 90% of the apical diameter of the canal placed to the universal testing machine. The maximum load at failure was recorded in Newtons and used to calculate debonding values in mega-Pascals by dividing Newtons to the bonding area of root canal filling. The following formula was used to determine the area in each section:

Area = $2\pi r \times h$; Where; **π** = constant value of 3.14, **r** = radius of the intra-radicular area (root canal radius), and **h** = height (the root dentin slice's thickness) in mm.

PUSH- OUT BOND STRENGTH = FORCE (N)/ AREA (mm^2)

Statistical analysis: The data for the present study was entered in the Microsoft Excel 2007 and analysed using the SPSS statistical software 23.0 Version. The descriptive statistics included mean, standard deviation. The inter group comparison was done using One Way ANOVA to find the difference between groups. The level of the significance for the present study was fixed at 5%.

RESULTS: Meta Adseal Plus exhibited the highest bond strength across all three levels, with mean values of 20.5010 MPa at the coronal third, 20.5010 MPa at the middle third, and 25.9840 MPa at the apical third. Bio Ceramic Sealer followed, with 15.8950 MPa at the coronal, 17.9190 MPa at the middle, and 24.5350 MPa at the apical third. GuttaFlow'2 had the lowest bond strength at all levels, with 14.3462 MPa at the coronal, 14.9489 MPa at the middle, and 20.1900 MPa at the apical third (Table 1).
Overall, the apical third consistently showed the highest bond strength across all groups, with statistically significant differences compared to the middle and coronal thirds. Group II (Meta Adseal Plus) maintained uniform bond strength at the coronal and middle thirds, while Groups I and III showed progressive increases in bond strength from coronal to apical (Table 2).
Meta Adseal Plus demonstrated the highest bond strength across all regions, with mean values of 19.617 MPa at the coronal third, 21.433 MPa at the middle third, and 26.735 MPa at the apical third. Bio Ceramic Sealer followed, exhibiting 17.026 MPa at the coronal, 19.066 MPa at the middle, and 26.500 MPa at the apical third. GuttaFlow'2 showed the lowest bond strength, measuring 15.087 MPa at the coronal, 16.258 MPa at the middle, and 18.433 MPa at the apical third (Table 3).
Post-hoc analysis confirmed that in all three groups, bond strength increased from the coronal to the apical region, with statistically significant differences at each level. The largest difference was observed between the coronal and apical thirds, particularly in Group I (-9.474 MPa, $p < 0.001$) and Group II (-7.118 MPa, $p < 0.001$) as shown in Table 4.
Meta Adseal Plus consistently exhibited the highest bond strength across all three thirds, with mean values of 19.080 MPa at the coronal third, 19.250 MPa at the middle third, and 25.906 MPa at the apical third. Bio-Ceramic Sealer followed, showing 17.218 MPa at the coronal third, 16.955 MPa at the middle third, and 23.141 MPa at the apical third. Gutta Flow 2 had the lowest bond strength in all regions, with values of 14.884 MPa at the coronal third, 15.058 MPa at the middle third, and 21.356 MPa at the apical third (Table 5).
Overall, 7% Maleic Acid treatment resulted in significantly greater bond strength in the apical third compared to the middle and coronal regions across all groups, suggesting that it enhances sealer bonding in deeper root canal regions. However, unlike other chelating agents, the coronal and middle thirds did not show statistically significant differences in bond strength (Table 6).

Table 1: Intergroup comparison of push out bond strength between the groups at coronal third using 10% Citric acid

		Mean	SD	Std Error	Minimum	Maximum	F value	P value
Coronal	Group I	15.8950	0.4541	0.1436	15.29	16.73	212.445	0.001 (Sig)
	Group II	20.5010	0.8678	0.2744	19.53	21.95		
	Group III	14.3462	0.4070	0.1439	14.27	15.44		
Middle	Group I	17.9190	0.7745	0.2449	16.75	19.21	232.693	0.001 (Sig)
	Group II	20.5010	0.6916	0.2187	19.31	21.61		
	Group III	14.9489	0.3151	0.1050	13.83	14.72		
Apical	Group I	24.5350	1.4745	0.4663	22.38	26.84	32.586	0.001 (Sig)
	Group II	25.9840	2.1670	0.6852	22.59	28.39		
	Group III	20.1900	1.2084	0.3821	18.48	21.75		

Intergroup Comparison	**Coronal**	**Middle**	**Apical**

		Mean Difference	P value	Mean Difference	P value	Mean Difference	P value
Group I	Group II	-4.606	0.001(Sig)	-2.582	0.001(Sig)	-1.449	0.042(Sig)
Group I	Group III	0.948	0.001(Sig)	3.570	0.001(Sig)	4.345	0.001(Sig)
Group II	Group III	5.554	0.001(Sig)	6.152	0.001(Sig)	5.794	0.001(Sig)

Table 2: Intragroup comparison between coronal, middle and apical third in the groups with use of 10% Citric acid

	Coronal		**Middle**		**Apical**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Group I	15.8950	0.4541	17.9190	0.7745	24.5350	1.4745
Group II	20.5010	0.8678	20.5010	0.6916	25.9840	2.1670
Group III	14.348	0.4070	14.948	0.3151	20.1900	1.2084

Intergroup Comparison		**Group 1**		**Group 2**		**Group 3**	
		Mean Difference	**P value**	**Mean Difference**	**P value**	**Mean Difference**	**P value**
Coronal	Middle	-2.024	0.001(Sig)	0	1.000	0.5973	0.102
Coronal	Apical	-8.64	0.001(Sig)	-5.483	0.001(Sig)	-5.2438	0.001(Sig)
Middle	Apical	-6.616	0.001(Sig)	-5.483	0.001(Sig)	-5.8411	0.001(Sig)

Table 3: Intergroup comparison of push out bond strength between the groups at coronal third using 17% EDTA

		Mean	Std Deviation	Std Error	Minimum	Maximum	F value	P value
Coronal	Group I	17.026	0.480	0.160	16.24	17.74	220.685	0.001 (Sig)
	Group II	19.617	0.291	0.110	19.22	20.12		
	Group III	15.087	0.430	0.152	14.36	15.82		
Middle	Group I	19.066	0.340	0.113	18.63	19.63	395.032	0.001 (Sig)
	Group II	21.433	0.279	0.088	20.91	21.78		
	Group III	16.258	0.556	0.175	15.25	16.87		
Apical	Group I	26.500	0.995	0.314	24.93	28.03	329.114	0.001(Sig)
	Group II	26.735	0.766	0.255	25.72	28.18		
	Group III	18.433	1.311	0.463	12.83	16.47		

	Coronal	**Middle**	**Apical**

Intergroup Comparison		Mean Difference	P value	Mean Difference	P value	Mean Difference	P value
Group I	Group II	-2.59048*	0.001(Sig)	-2.36633*	0.001(Sig)	-.23556	0.625
Group I	Group III	1.93917*	0.001(Sig)	2.80867*	0.001(Sig)	8.06625*	0.001(Sig)
Group II	Group III	4.52964*	0.001(Sig)	5.17500*	0.001(Sig)	8.30181*	0.001(Sig)

Table 4: Intragroup comparison between coronal, middle and apical third in the groups with use of 17% EDTA

	Coronal		Middle		Apical	
	Mean	SD	Mean	SD	Mean	SD
Group 1	17.026	0.480	19.066	0.340	26.500	0.995
Group 2	19.617	0.291	21.433	0.279	26.735	0.766
Group 3	15.087	0.430	16.258	0.556	18.433	1.311

Intergroup Comparison		Group 1		Group 2		Group 3	
		Mean Difference	P value	Mean Difference	P value	Mean Difference	P value
Coronal	Middle	-2.04	0.001(Sig)	-1.816	0.001(Sig)	-1.171	0.001(Sig)
Coronal	Apical	-9.474	0.001(Sig)	-7.118	0.001(Sig)	-3.346	0.001(Sig)
Middle	Apical	-7.434	0.001(Sig)	-5.302	0.001(Sig)	-2.175	0.001(Sig)

Table 5: Intergroup comparison of push out bond strength between the groups at coronal third using 7% Maleic acid

		Mean	Std Deviation	Std Error	Minimum	Maximum	F value	P value
Coronal	Group I	17.218	0.418	0.132	16.44	17.75	410.659	0.001(Sig)
	Group II	19.080	0.237	0.079	18.61	19.49		
	Group III	14.884	0.265	0.083	14.39	15.18		
Middle	Group I	16.955	0.422	0.149	16.32	17.55	260.301	0.001(Sig)
	Group II	19.250	0.209	0.069	18.93	19.55		
	Group III	15.058	0.487	0.162	14.36	15.94		
Apical	Group I	23.141	0.624	0.208	22.12	24.17	52.056	0.001(Sig)
	Group II	25.906	0.790	0.263	24.46	27.12		
	Group III	21.356	1.318	0.416	19.43	23.29		

Intergroup Comparison	Coronal	Middle	Apical

		Mean Difference	P value	Mean Difference	P value	Mean Difference	P value
Group I	Group II	-1.862	0.001(Sig)	-2.295	0.001(Sig)	-2.765	0.001(Sig)
Group I	Group III	2.334	0.001(Sig)	1.896	0.001(Sig)	1.785	0.001(Sig)
Group II	Group III	4.196	0.001(Sig)	4.191	0.001(Sig)	4.550	0.001(Sig)

Table 6: Intragroup comparison between coronal, middle and apical third in the groups with use of 7% Maleic acid

	Coronal		Middle		Apical	
	Mean	**Std Deviation**	**Mean**	**Std Deviation**	**Mean**	**Std Deviation**
Group 1	17.218	0.418	16.955	0.422	23.141	0.624
Group 2	19.080	0.237	19.250	0.209	25.906	0.790
Group 3	14.884	0.265	15.058	0.487	21.356	1.318

Intergroup Comparison		**Group 1**		**Group 2**		**Group 3**	
		Mean Difference	**P value**	**Mean Difference**	**P value**	**Mean Difference**	**P value**
Coronal	Middle	0.263	0.124	-0.170	0.293	-0.174	0.293
Coronal	Apical	-5.923	0.001(Sig)	-6.826	0.001(Sig)	-6.472	0.001(Sig)
Middle	Apical	-6.186	0.001(Sig)	-6.656	0.001(Sig)	-6.298	0.001(Sig)

DISCUSSION

Both organic and inorganic components make up the smear layer. In addition to its ability to dissolve tissue, NaOCl eliminates the organic component of the smear layer. In order to promote sealant penetration and eliminate the smear layer from the inorganic component, several chelating agents are utilized in combination with NaOCl. The alternating use of sodium hypochlorite and 17% EDTA for irrigation is usually the recommended technique.[12] In endodontic operations, 10% citric acid (CA) and 7% maleic acid (MA) can be utilized as substitutes for 17% EDTA. Both agents boost the bond strength and create bigger openings in the dentin tubules, which increases the area of contact between the root canal dentin and endodontic cement and strengthens the binding between the dentin and the root canal filling material.[13]

To efficiently remove the smear layer, root canal irrigation with chelating agents like EDTA, MA, and CA is advised.[14-17] In sclerotic root canals, MA has been demonstrated to have a superior smear layer-removal capacity and to be more biocompatible than EDTA[18]. In this investigation,[19] CA was used at the indicated dosage of 10% since Haznedaroqlu F. discovered that lesser concentrations of citric acid (5%–10%) did not cause erosion, but 25% and 50% concentrations caused dentinal tubules to be destroyed.[20] It was discovered that 10% CA had a decalcifying effect that was at least twice as strong as 1% CA.[17] 10% citric acid is more biocompatible than 17% EDTA, a research conducted by Maggioni A. R. et al.[21]

With mean values of 20.5010 MPa at the coronal third, 20.5010 MPa at the middle third, and 25.9840 MPa at the apical third, Meta Adseal Plus (Group II) demonstrated the highest bond strength across all three levels when we tested the pushout bond strength between Bio-ceramic sealer, Meta Adseal Plus, and GuttaFlow'2 with 10% citric acid. Group I and Group III came next. For root canal sealing, Meta Adseal Plus (Resin-Based Sealer) offered the best adherence. GuttaFlow'2 showed the poorest adhesion, making it the least successful in preserving a long-lasting link inside the root canal system, whereas Bio-Ceramic Sealer showed a moderate bond strength.

The sealer used and the interaction between the sealer and irrigation solution have a significant impact on the bonding strength, according to Ilkgelen D et al.[22] (2024). Epoxy resin sealer had a stronger bond than bio-ceramic sealer. In terms of bond strength, epoxy resin-based sealers were favoured over bio-ceramic sealers when irrigation solutions containing 17% EDTA or 10% citric acid were utilized. However, Carvalho N.K. et al.[23] (2016) found that the push-out bond strength of endodontic sealers was unaffected by the use of chelating agents like 17% EDTA, 2.25% peracetic acid, and 10% citric acid. Only the sealers were affected by push-out bond strength; the chelating agents were not. Thus, Meta Adseal Plus (Group II), a novel epoxy resin-based sealer, was employed in our investigation and demonstrated better bond strength with 10% citric acid than Group I and Group III. In contrast to 17% EDTA, Rifaat et al.[24] (2023) found that the epoxy-resin based sealer demonstrated a stronger bond when employed with 7% maleic acid as a final irrigant.

Group II showed the strongest adhesion, especially in the coronal and middle thirds (19.617 MPa & 21.433 MPa) and the highest at the apical third (26.735 MPa), according to the mean values of all the sealers with 17% EDTA-POBS at all three levels. In comparison, Group I Bio-ceramic sealer showed results that were comparable to Group II in terms of bond strength, particularly at the apical thirds. Group III was the least successful in preserving a long-lasting link inside the root canal system because it showed the poorest bond strength. These results demonstrated the improved bonding capabilities of bio-ceramic and resin-based sealers, especially when combined with 17% EDTA as an irrigant. Veeramachaneni (2022)[25] claims that the setting reaction of the bio-ceramic sealer, which uses the moisture in the medium to make calcium silicate hydrate gel, produced a stronger binding between the sealer and the root dentin than epoxy resin-based sealers.[26] Additionally, it demonstrated a high flow rate[27], which facilitates the sealer's greater penetration into the root canal's small imperfections.[28] By encouraging the development of a mineral infiltration zone, it demonstrates chemical adherence to dentin.[29] Its bioactivity resulted from the production of hydroxyapatite on the surface of calcium silicate sealers pon contact with phosphate.[30]

The low POBS of GuttaFlow'2 is correlated with a greater percentage of adhesive failures in the current investigation. The POBS of the bio-ceramic sealer was adversely affected by EDTA. The development of the "mineral infiltration zone" proposed by Atmeh et al.[29] may be impeded by a decrease in calcium at the sealer–dentin contact or a breakdown of the calcium silicate component in the sealer. As a result, there was less contact between the sealer and the root canal wall. Compared to GuttaFlow'2 and bio-ceramic sealer, resin sealer had a greater POBS. EDTA and NaOCl had a favorable effect on the resin-based sealer's POBS. EDTA has a somewhat detrimental influence on the bio-ceramic sealer's POBS. In contrast, the irrigation solutions had no effect on GuttaFlow'2 POBS.

We observed another noteworthy discovery when we analysed all of the intra-groups among the varous chelating agents: with regard to POBS, the values showed a substantial difference, i.e., they decreased from apical to coronal third or equivalent in middle-coronal third. This might be because apical dentine contains more solid inter-tubular dentin and fewer patent tubules than coronal dentine, which results in a stronger connection to dentin than to tubules. Additionally, a smaller apical third results in greater adaptation and reduced stress from polymerization shrinkage on the bonding material, which raises the POBS. Last but not least, the conical form and smaller size provide increased frictional resistance, allowing for a bigger POBS at the apical third. This is in accordance with research by Khoury S. et al. (2023), which found that the push-out bond strength was strongest for the apical part of samples that were obturated with a bio-ceramic sealer.[31] These results are probably connected to the gutta-percha cone's improved apical adaption, which can provide greater hydraulic pressures and enhance material adaptation to the canal walls, leading to a thinner sealer layer in this region.[32]

Therefore, our analysis revealed that the final irrigation with 7% MA produced the best POBS in the apical third, 17% EDTA in the middle third, and no discernible difference in the coronal third of all the groups. These findings emphasize the significance of choosing the appropriate sealer and chelating agent in tandem to improve the lifespan and efficacy of root canal treatment from a clinical standpoint. In order to stop microleakage, bacterial reinfection, and endodontic failure, a sealer's binding strength is essential. According to this study, EDTA is still the best way to get the best adhesion possible for silicone-based, epoxy-resin-based, and bio-ceramic sealers, especially in the coronal, middle, and even apical thirds of the root canal system. A substitute, nevertheless, may be 7% maleic acid, particularly for improved bonding in the coronal and apical third. When using 10% citric acid, clinicians should use caution as it may adversely affect sealer retention and therapy results in general.

CONCLUSION

Within the limitation of this study, it can be concluded that:

1. There is a significant influence of different chelating agents on the push-out bond strength of three different sealers be it bio-ceramic, epoxy-resin based and silicone-based root canal sealer to root dentin.
2. Among the tested agents, 17% EDTA exhibited the highest bond strength in majority of the results be it in coronal, middle and apical thirds, followed by 7% Maleic Acid majorly in coronal and apical thirds, while 10% Citric Acid demonstrated the highest value in coronal third for a single group but lowest values across all root thirds.
3. These findings highlight the superior efficacy of 17% EDTA in enhancing sealer adhesion, making it the preferred choice for optimizing root canal obturation. Additionally, bond strength was consistently highest from coronal to apical third, reaffirming the clinical challenge of achieving optimal adhesion in the apical region.
4. Among the tested sealer, Meta Adseal Plus (Group II) exhibited the highest bond strength when compared with all the agents providing the strongest adhesion in root canal sealing penetrating deeper into the dentinal tubules, followed by Bio-C sealer (Group I) demonstrating moderate bond strength and Guttaflow'2 (Group III) exhibiting the weakest adhesion, making it less effective in maintaining the durable bonds within the root canal system.

Clinical significance: The findings of the present study highlight the superior bonding of resin-based sealers with root canal system, showcasing the monobloc concept from one dentinal wall to another, making a preferred choice for obturation.

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