

An ex vivo comparison of bond strength measured by the push-out test between AH Plus and Endosequence BC sealer Hiflow

Thayane da Costa Pinheiro¹ , Carlos E da Silveira Bueno¹ , Alexandre Sigrist De Martin¹ , Carolina Pessoa Stringheta¹ , Carlos E Fontana² , Rina A Pelegrine¹ , Ana G Limoeiro³ , Wayne M Nascimento¹ , Marilia Fagury Videira Marceliano-Alves^{5,6,7} , Thais Machado de Carvalho Coutinho⁵ , Cesar A Perini Rosas⁸ , Daniel G Pedro Rocha⁴ 

1. Faculdade São Leopoldo Mandic, Instituto de Pesquisa São Leopoldo Mandic, Departamento de Endodontia, Campinas, SP, Brasil.

2. Pontifícia Universidade Católica de Campinas, Centro de Ciências da Vida, Programa de Pós-Graduação em Ciências da Saúde, Campinas, SP, Brasil.

3. Universidade de São Paulo, Faculdade de Odontologia de Bauru, Departamento de Dentística, Endodontia e Materiais Dentários, Bauru, SP, Brasil.

4. Pontifícia Universidade Católica de Campinas, Departamento de Endodontia, Campinas, São Paulo, Brazil

5. Universidade Iguacu, Programa de Pós-Graduação em Odontologia, Nova Iguacu, Brasil.

6. Centro Universitário Maurício de Nassau, Rio de Janeiro, Brasil.

7. Department of Dental Research Cell, Dr. D. Y. Patil Dental College and Hospital, Dr. D. Y. Patil Vidyapeeth, Pune 411018, India.

8. Universidade Estadual do Norte do Paraná, Campus de Jacarezinho, Paraná, Brasil

ABSTRACT

Endodontic obturation is fundamental to treatment success, with the bond strength of sealer cements to dentin being a crucial parameter for evaluating their effectiveness. **Aim:** To evaluate the bond strength between root canal dentin walls and the obturation materials AH Plus and Endosequence BC Sealer HiFlow using the push-out test. **Material and Method:** Twenty single-rooted mandibular premolars were divided into two groups (n=10) according to the sealer used: Group AH (AH Plus Sealer) and Group HF (Endosequence BC Sealer HiFlow). The canals were instrumented with Wave One Gold Large, using 20 mL of 2.5% sodium hypochlorite as irrigation solution. The teeth were cut into 1 mm thick slices in the cervical and middle third regions to perform the push-out test. The failure mode was observed under a stereomicroscope at 40x magnification. The results were subjected to Tukey's test and ANOVA with a 5% significance level. **Results:** In the push-out bond strength test, there was no statistically significant difference between AH Plus and Endosequence BC Sealer HiFlow cements (p=0.1952). Similarly, the failure modes showed no significant difference between the cements, in both the cervical and middle thirds (p=0.5703). **Conclusion:** AH Plus and Endosequence BC Sealer HiFlow demonstrated similar behavior in terms of bond strength and failure mode in root canal dentin walls.

Keywords: dentine - bond strength - root canal sealers

To cite: da Costa Pinheiro T, da Silveira Bueno CE, Sigrist De Martin A, Pessoa Stringheta C, Fontana CE, Pelegrine RA, Limoeiro AG, Nascimento WM, Videira Marceliano-Alves MF, de Carvalho Coutinho TM, Perini Rosas CA, Pedro Rocha DG. An ex vivo comparison of bond strength measured by the push-out test between AH Plus and Endosequence BC sealer Hiflow. Acta Odontol Latinoam. 2025 Dec 30;38(3):210-215. <https://doi.org/10.54589/aol.38/3/210>

Corresponding Author:

Ana Grasiela Limoeiro
grasielalimoeiro@gmail.com

Received: February 2025.

Accepted: November 2025.



This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Comparação ex vivo da resistência de união do teste de push-out entre os cimentos AH Plus e o Endosequence BC Hiflow

RESUMO

A obturação endodôntica é fundamental para o sucesso do tratamento, sendo a resistência de adesão dos cimentos seladores à dentina um parâmetro crucial para avaliar sua eficácia. **Objetivo:** Avaliar a resistência de adesão das paredes de dentina do canal radicular e a obturação com AH Plus e Endosequence BC Sealer HiFlow pelo teste de push-out. **Materiais e Método:** Vinte pré-molares mandibulares de raiz única foram divididos em dois grupos (n=10) de acordo com o cimento utilizado: Grupo AH (Cimento AH Plus) e Grupo HF (Endosequence BC Sealer HiFlow). Os canais foram instrumentados com Wave One Gold Large, utilizando um total de 20 mL de hipoclorito de sódio a 2,5% como solução irrigante. Os dentes foram cortados em fatias de 1 mm de espessura nas regiões do terço cervical e médio para realizar o teste de push-out. O modo de falha foi observado sob um estereomicroscópio com aumento de 40x. Os resultados foram submetidos ao teste de Tukey e ANOVA com nível de significância de 5%. **Resultados:** No teste de resistência de adesão (push-out), não houve diferença estatisticamente significativa entre os cimentos AH Plus e Endosequence BC Sealer HiFlow (p=0.1952). Similarmente, os modos de falha não apresentaram diferença significativa entre os cimentos, tanto no terço cervical quanto no médio (p=0.5703). **Conclusão:** Os cimentos AH Plus e Endosequence BC Sealer HiFlow demonstraram um comportamento semelhante em termos de resistência de adesão e modo de falha nas paredes de dentina do canal radicular.

Palavras-chave: dentina - resistência de adesão - selante de canal radicular

INTRODUCTION

Endodontic obturation is an essential step to seal the root canal system and prevent future bacterial contamination or recontamination¹. Endodontic sealers can interact with dentin both physically and chemically. Physical interaction occurs when the material penetrates the dentinal tubules, creating mechanical retention, while chemical interaction is characterized by the formation of tags along the cement-dentin interface². In addition to bond strength to dentin, some obturation materials show a biological response at the material-dentin interface that provides support, improving the sealing quality³. Leakage and filling material bond strength have been used to evaluate the effectiveness of root canal fillings⁴. The push-out test is commonly used to assess the bond strength between cement and canal walls⁵.

AH Plus (AHP - Dentsply Maillefer, Tulsa, OK, USA) is an epoxy resin-based endodontic cement that is considered the gold standard due to its good adaptation and bond strength compared to other materials⁶. It also has a long-term sealing function, short setting time, and better flowability than other cements⁷.

Bioceramic sealers are promising materials to improve the filling quality and thus the long-term success of endodontic treatment⁸. Endosequence BC Sealer HiFlow (HF -Brasseler, Savannah, GA) is a bioceramic sealer in premixed syringe form that has sufficient biological properties to be safely used as a root canal filling material⁹. Its composition is similar to that of the standard Endosequence BC Sealer (BC), with a base of calcium silicate, monobasic calcium phosphate, calcium hydroxide, zirconium oxide and thickeners¹⁰, and it has antimicrobial activity, high pH, hydrophilicity, and diffusion of calcium hydroxide¹¹.

The aim of this study was to compare AHP and HF by performing an *in vitro* evaluation of bond strength between the endodontic sealers and root canal dentin walls using the push-out test. The null hypothesis is that the tested groups have equivalent results in terms of the analyzed parameters.

MATERIALS AND METHOD

Specimen selection and preparation:

This study was approved by the Human Research Ethics Committee of the São Leopoldo Dental College Research Center (CAAE: 38675120.0.0000.5374). Twenty freshly extracted permanent single-rooted

human mandibular premolars were donated by patients who had an indication for extraction for various reasons, with each patient having signed an informed consent form. The inclusion criteria were fully formed single-rooted teeth with a single root canal, without fractures, calcifications, cracks or previous endodontic treatment. The teeth were divided into 2 groups (n=10 per group) according to the sample calculation (G Power 3.1.9.4, Franz Faul, College of Kiel, Germany) with a type "a" error of 0.05 and a type "b" error of 0.80. Specimens were preserved in 0.1% thymol solution.

Periapical radiographs were acquired in the mesiodistal and buccolingual directions to confirm the presence of a single straight circular canal using the New Ida digital sensor (Dabi-Atlante Ltda, Ribeirão Preto, Brazil). These specimens were also examined with an optical surgical microscope (Alliance, São Carlos, Brazil) at 16× magnification to confirm the absence of cracks, fractures and external apical resorption on the entire surface of each root. The teeth were cleaned with periodontal curettes (Duflex- SS White Artigos Dental Ltda., Rio de Janeiro, Brazil), ultrasound (Schuster Equipamentos Odontologicos, Santa Maria, Brazil) and water. After cleaning, the coronal part of each tooth was cut with a double-sided diamond disc (KG Sorensen, Barueri, Brazil) to standardize root length to 15 mm.

The teeth were placed in a container of impression compound with condensation silicone (Panasil, Indaiatuba, SP, Brazil) for stabilization. Apices were sealed with wax (Wilson Polidental Ind. e Com. Ltda., Cotia, Brazil). Subsequently, all endodontic treatments were performed by a specialist in endodontics.

Odontometry was determined visually with a size 10 K-file (Maillefer Corp, Ballaigues, Switzerland) inserted into each canal to verify that it was in the apical foramen based on a periapical radiograph. The working length (WL) was determined at the apical foramen (0,0). Then the canals were preflared in the cervical third with the Orifice Shaper (17/.08) rotary file (MK Life, Porto Alegre, Brazil). Instrumentation was performed with 15/.02, 20/.02, 25/.02 Flexofile hand files and Wave One Gold Large (45/.05) reciprocal file (Dentsply Sirona, Ballaigues, Switzerland) connected to the VDW Silver endodontic motor (VDW, Munich, Germany) in WaveOne ALL mode.

During root canal cleaning and shaping, a 5-mL irrigation syringe (Ultradent Products, Indaiatuba, Brazil) was used to irrigate with 2.5% NaOCl (Asfer Ind. Química Ltda. São Caetano do Sul, Brazil), for a total of 20 mL of solution per tooth. A final ultrasonic irrigation was performed with an Irrisonic E1 insert (Helse Ultrasonic, Santa Rosa de Viterbo, Brazil), stirring the rinse solution for 20 seconds with 17% ethylenediaminetetraacetic acid (EDTA) (Biodinamica, Ibiporã, Brazil) in 3 cycles (1 mL per cycle); 3 additional cycles (2 mL per cycle) for 20 seconds with 2.5% NaOCl, and finally with 5 mL of distilled water. Then, the canals were dried using a capillary tip (Ultradent Products, Indaiatuba, Brazil) and absorbent paper points (MK Life, Porto Alegre, Brazil).

Subsequently, the samples were randomly (www.random.org) divided into 2 groups of 10 samples:

- Group AHP: AH Plus Sealer
- Group HF: Endosequence BC Sealer HiFlow

The obturation was performed using a VDW single cone (Dentsply Ind. e Com. Ltda, São Paulo, Brazil) compatible with the canal diameter. After root canal filling, the teeth were kept in an incubator at 100% humidity and 37°C for 1 week to allow the sealers to set completely. All the bond strength tests were conducted by a blinded operator who did not know the experimental groups.

Bond strength evaluation

The roots were cut into 1mm thick slices in a slicer (Isomet 1000 Precision Saw, Buehler, Canada) with a disk (EXTEC Dia. wafering blade) and placed in containers of distilled water to hydrate, separated by group and number of specimens. They were then subjected to the push-out test using the universal testing machine EMIC, model DL2000, to assess the bond strength between the filling material and the dentin. The specimens were placed individually on the metal surface of the machine. Shortly thereafter, a cylindrical plunger with a diameter of 1 mm for the coronal specimens and 0.6 mm diameter plunger for the middle specimens was inserted, applying pressure in the canal to displace the filling material. The force in Newtons was then converted into tensile strength (in MPa).

Analysis of fault modes

The specimens were evaluated under a stereomicroscope (Stemi 508; Carl Zeiss, Jena,

Germany) at 40× magnification to determine the nature of the gap between the dentin walls of the canal and the filling material based on the following scores: 1) adhesive to dentin; 2) adhesive to obturation material; 3) mixed; 4) cohesive in dentin; 5) cohesive in filling material.

Statistical analysis

The results were analyzed using the Biostat 5.3 program and subjected to the Shapiro-Wilk normality test. The sample showed normal behavior, and the parametric ANOVA test was performed with a significance of 5%.

RESULTS

There was no statistically significant difference between the AHP and HF bonding tests in the cervical and middle thirds ($p=0.1952$), or between the cervical and middle thirds in comparison with the same sealer ($p=0.1952$) (Table 1).

In terms of failure, there was no statistically significant difference in failure modes between AHP and HF sealers in the cervical and middle thirds ($p=0.5703$), or between the cervical and middle thirds when comparisons were made with the same sealer ($p=0.5703$) (Table 2). Types of failure that occurred in this work: adhesive to dentin (Fig. 1A), mixed (Fig. 1B) and cohesive to dentin (Fig. 1C).

Table 1. Arithmetic means, standard deviations, and ANOVA statistical test of bond strength using the push-out test (kgf).

	Coronal	Middle	(p)
AHP	3.37 (1.95) ^A	4.65 (1.21) ^A	0.1952
HF	3.79 (2.11) ^A	4.26 (1.43) ^A	
(p)	0.1952		

Same capital letters in horizontal and vertical directions: no statistically significant difference.

Table 2. Medians, interquartile deviations, and Kruskal-Wallis statistical test for the failure modes of the sample groups.

	Coronal	Middle	(p)
AHP	3.50 (1.00) ^A	3.00 (0.00) ^A	0.5703
HF	3.50 (1.00) ^A	4.00 (3.00) ^A	
(p)	0.5703		

Same capital letters in horizontal and vertical directions: no statistically significant difference.

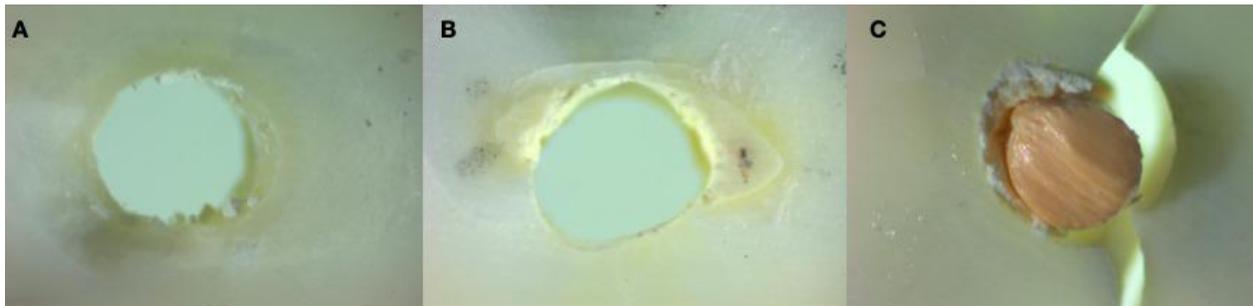


Fig. 1: A) Adhesive failure to dentin, B) Mixed failure and C) Cohesive failure in dentin.

DISCUSSION

In this study, the adhesion between the filling material and the canal walls was evaluated using the push-out test. The AHP and HF sealers showed equivalent results in terms of the parameters analyzed. There was no statistically significant difference in the tests performed, so the null hypothesis was accepted.

The type of movement (rotary or reciprocating) used for canal instrumentation may influence bond strength, as it may create debris that prevents the filling material from bonding to the dentin¹². In this study, the reciprocating WaveOne Gold instrument was used, and the smear layer was removed from the dentin wall with 17% EDTA. However, Shokouhinejad et al. reported that the presence of a smear layer had no effect on the bond strength of Endosequence BC Sealer and AHP sealers 7 days after root canal filling¹³.

The moisture condition of the canal may also affect the bond strength, influence the curing time, and negatively affect the microhardness of the sealer after curing¹⁴. In the current study, the curing time was 7 days in an oven at 37°C and 100% humidity, and the canals were completely dry, resulting in adequate curing. It may be beneficial to leave the canals slightly moist before filling with bioceramics; however, Nagas et al.¹⁵ found that AHP showed similar results with or without moisture. Srivastava et al.¹⁶ reports that irrigation protocols influenced the push-out bond strength of BioRoot RCS and AHP, while Gibby et al.¹⁷ found that the moisture remaining in the dentinal tubules after canal irrigation could vary greatly even after drying the canals with paper points. As with AHP, such moisture would also reduce monomer conversion, resulting in incomplete polymerization of the resin and lower bond strength to dentin¹⁸.

Bond strength may vary depending on the type of sealer and the root canal filling technique¹⁹. In contrast

to the current study, Hammar et al.²⁰ reported that the use of AHP with the single cone technique showed a lower bond strength, which could be related to the fact that the high sealer volume reduces the quality of the obturation seal compared to other techniques. However, in another study by Belsare et al. using the lateral condensation technique, AHP showed better bond strength than BC, which was even better when the thermocompaction technique (continuous wave technique) was used²¹.

In oval canals, the canal instrumentation and cleaning method and the materials used for obturation can both influence bond strength³. Pawar et al.³ reported that the lowest bond strength was measured in canals instrumented with WaveOne and filled with gutta-percha and AHP. The shear bond strength of dentin to calcium silicate-based sealer was significantly higher than that of AHP. Banphakarn et al.¹⁰ observed residues of calcium silicate sealer adhering to impregnated gutta-percha in most of the tested samples.

In the current study, adhesion failure was mostly cohesive in both groups. This result agrees with Shokouhinejad et al.¹³, who investigated AHP and BC sealers. However, in the study by DeLong et al.²², most failures were mixed when BC was used with the single-cone or continuous wave technique. Al-Hiyasat et al.¹⁹ found that for TotalFill and AHP, the mixed failure mode was the most common, followed by cohesive failure and adhesive failure. This discrepancy in failure modes may be due to the different types of obturation techniques used in the studies.

The limitation of the present study is that it is an *ex vivo* study, which is slightly different from an *in vivo* study where the tooth is seated in its socket and the periodontal ligament is at body temperature, which may affect sealer properties. Although the bond strength test cannot predict the clinical behavior of

materials, the push-out test is still one of the best measurements of bond strength currently available²³. Factors such as sample thickness, plunger diameter, and specimen orientation influence the value of the push-out bond strength²⁴. All these factors were considered in this study. No other study has yet been conducted to test the bond strength of Endosequence BC Sealer HiFlow, so further research is required on this topic.

CONFLICT OF INTERESTS

The authors declare no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

REFERENCES

- Peng L, Ye L, Tan H, Zhou X. Outcome of root canal obturation by warm gutta-percha versus cold lateral condensation: a meta-analysis. *J Endod.* 2007 Feb;33(2):106-9. <https://doi.org/10.1016/j.joen.2006.09.010>. Epub 2006 Dec 22. PMID: 17258624.
- Haragushiku GA, Teixeira CS, Furuse AY, Sousa YT, De Sousa Neto MD, Silva RG. Analysis of the interface and bond strength of resin-based endodontic cements to root dentin. *Microsc Res Tech.* 2012 May;75(5):655-61. <https://doi.org/10.1002/jemt.21107>. Epub 2011 Nov 7. PMID: 22505186.
- Han L, Okiji T. Bioactivity evaluation of three calcium silicate-based endodontic materials. *Int Endod J.* 2013 Sep;46(9):808-14. <https://doi.org/10.1111/iej.12062>. Epub 2013 Feb 12. PMID: 23402321.
- Pawar AM, Pawar S, Kfir A, Pawar M, Kokate S. Push-out bond strength of root fillings made with C-Point and BC sealer versus gutta-percha and AH Plus after the instrumentation of oval canals with the Self-Adjusting File versus WaveOne. *Int Endod J.* 2016 Apr;49(4):374-81. <https://doi.org/10.1111/iej.12455>. Epub 2015 Apr 16. PMID: 25827240.
- Madhuri GV, Varri S, Bolla N, Mandava P, Akkala LS, Shaik J. Comparison of bond strength of different endodontic sealers to root dentin: An in vitro push-out test. *J Conserv Dent.* 2016 Sep-Oct;19(5):461-4. <https://doi.org/10.4103/0972-0707.190012>. PMID: 27656067; PMCID: PMC5026108.
- Belli S, Cobankara FK, Ozcopur B, Eliguzeloglu E, Eskitascioglu G. An alternative adhesive strategy to optimize bonding to root dentin. *J Endod.* 2011 Oct;37(10):1427-32. <https://doi.org/10.1016/j.joen.2011.06.014>. Epub 2011 Aug 15. PMID: 21924196.
- Nawal RR, Parande M, Sehgal R, Naik A, Rao NR. A comparative evaluation of antimicrobial efficacy and flow properties for Epiphany, Guttaflow and AH-Plus sealer. *Int*

CONCLUSION

Based on comprehensive ex vivo evaluation, this study concluded that AH Plus and Endosequence BC Sealer HiFlow had comparable performance. No statistically significant difference was observed in terms of push-out bond strength or failure modes between these two endodontic sealers for either cervical or middle root thirds, thus supporting the null hypothesis. These findings suggest that both materials offer similar bonding capabilities to root canal dentin walls after a seven-day curing period.

ACKNOWLEDGMENTS

This study was supported by grants from Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ - E26/200.184/2023) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - 200280/2022-8), Brazilian Government Institutions.

- Endod J. 2011 Apr;44(4):307-13. <https://doi.org/10.1111/j.1365-2591.2010.01829.x>. Epub 2011 Jan 10. PMID: 21219358.
- Roizenblit RN, Soares FO, Lopes RT, Dos Santos BC, Gusman H. Root canal filling quality of mandibular molars with EndoSequence BC and AH Plus sealers: A micro-CT study. *Aust Endod J.* 2020 Apr;46(1):82-87. <https://doi.org/10.1111/aej.12373>. Epub 2019 Sep 26. PMID: 31556201.
- Rodríguez-Lozano FJ, López-García S, García-Bernal D, Tomás-Catalá CJ, Santos JM, Llena C, Lozano A, Murcia L, Forner L. Chemical composition and bioactivity potential of the new Endosequence BC Sealer formulation HiFlow. *Int Endod J.* 2020 Sep;53(9):1216-1228. <https://doi.org/10.1111/iej.13327>. Epub 2020 Jun 18. PMID: 32412113.
- Banphakarn N, Yanpiset K, Banomyong D. Shear bond strengths of calcium silicate-based sealer to dentin and calcium silicate-impregnated gutta-percha. *J Investig Clin Dent.* 2019 Nov;10(4):e12444. <https://doi.org/10.1111/jicd.12444>. Epub 2019 Jul 27. PMID: 31350871.
- Zhou HM, Shen Y, Wang ZJ, Li L, Zheng YF, Häkkinen L, Haapasalo M. In vitro cytotoxicity evaluation of a novel root repair material. *J Endod.* 2013 Apr;39(4):478-83. <https://doi.org/10.1016/j.joen.2012.11.026>. Epub 2013 Jan 11. PMID: 23522540.
- Paqué F, Boessler C, Zehnder M. Accumulated hard tissue debris levels in mesial roots of mandibular molars after sequential irrigation steps. *Int Endod J.* 2011 Feb;44(2):148-53. <https://doi.org/10.1111/j.1365-2591.2010.01823.x>. Epub 2010 Nov 17. PMID: 21083577.
- Shokouhinejad N, Gorjestani H, Nasseh AA, Hoseini A, Mohammadi M, Shamschiri AR. Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. *Aust Endod J.* 2013 Dec;39(3):102-6. <https://doi.org/10.1111/j.1747-4477.2011.00310.x>. Epub 2011 May 29. PMID: 24279654.

14. Loushine BA, Bryan TE, Looney SW, Gillen BM, Loushine RJ, Weller RN, Pashley DH, Tay FR. Setting properties and cytotoxicity evaluation of a premixed bioceramic root canal sealer. *J Endod.* 2011 May;37(5):673-7. <https://doi.org/10.1016/j.joen.2011.01.003>. Epub 2011 Mar 3. PMID: 21496669.
15. Nagas E, Uyanik MO, Eymirli A, Cehreli ZC, Vallittu PK, Lassila LV, Durmaz V. Dentin moisture conditions affect the adhesion of root canal sealers. *J Endod.* 2012 Feb;38(2):240-4. <https://doi.org/10.1016/j.joen.2011.09.027>. Epub 2011 Nov 13. PMID: 22244645.
16. Srivastava A, Yadav DS, Rao M, Rao HM, Arun A, Siddique R. Evaluation of push-out bond strength of BioRoot RCS and AH Plus after using different irrigants: An in vitro study. *J Conserv Dent.* 2020 Jan-Feb;23(1):26-31. https://doi.org/10.4103/JCD.JCD_223_20. Epub 2020 Oct 10. PMID: 33223637; PMCID: PMC7657418.
17. Gibby SG, Wong Y, Kulild JC, Williams KB, Yao X, Walker MP. Novel methodology to evaluate the effect of residual moisture on epoxy resin sealer/dentine interface: a pilot study. *Int Endod J.* 2011 Mar;44(3):236-44. <https://doi.org/10.1111/j.1365-2591.2010.01806.x>. Epub 2010 Oct 11. PMID: 21039628.
18. Aguiar TR, Di Francescantonio M, Ambrosano GM, Giannini M. Effect of curing mode on bond strength of self-adhesive resin luting cements to dentin. *J Biomed Mater Res B Appl Biomater.* 2010 Apr;93(1):122-7. <https://doi.org/10.1002/jbm.b.31566>. PMID: 20091904.
19. Al-Hiyasat AS, Alfirjani SA. The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer. *J Dent.* 2019 Oct;89:103169. <https://doi.org/10.1016/j.jdent.2019.07.007>. Epub 2019 Jul 18. PMID: 31326527.
20. Hammad M, Qualtrough A, Silikas N. Evaluation of root canal obturation: a three-dimensional in vitro study. *J Endod.* 2009 Apr;35(4):541-4. <https://doi.org/10.1016/j.joen.2008.12.021>. Epub 2009 Feb 26. PMID: 19345801.
21. Gade VJ, Belsare LD, Patil S, Bhede R, Gade JR. Evaluation of push-out bond strength of endosequence BC sealer with lateral condensation and thermoplasticized technique: An in vitro study. *J Conserv Dent.* 2015 Mar-Apr;18(2):124-7. <https://doi.org/10.4103/0972-0707.153075>. PMID: 25829690; PMCID: PMC4379651.
22. DeLong C, He J, Woodmansey KF. The effect of obturation technique on the push-out bond strength of calcium silicate sealers. *J Endod.* 2015 Mar;41(3):385-8. <https://doi.org/10.1016/j.joen.2014.11.002>. Epub 2015 Jan 6. PMID: 25576202.
23. Pane ES, Palamara JE, Messer HH. Critical evaluation of the push-out test for root canal filling materials. *J Endod.* 2013 May;39(5):669-73. <https://doi.org/10.1016/j.joen.2012.12.032>. Epub 2013 Feb 12. PMID: 23611388.
24. Chen B, Haapasalo M, Mobuchon C, Li X, Ma J, Shen Y. Cytotoxicity and the Effect of Temperature on Physical Properties and Chemical Composition of a New Calcium Silicate-based Root Canal Sealer. *J Endod.* 2020 Apr;46(4):531-538. <https://doi.org/10.1016/j.joen.2019.12.009>. Epub 2020 Feb 18. PMID: 32081458.