Research Article

A Comparative Evaluation of Microleakage of Activa^{tm} Bioactive, Smart Dentin Replacement, Cention N and Conventional Glass Ionomer Cement In Class V Cavities – an in Vitro Study

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ABSTRACT

Context: Microleakage at the tooth–restoration interface may cause postoperative sensitivity, recurrent caries, and restoration failure. Newer bioactive restorative materials have been developed to improve marginal sealing.

Aims: To compare the microleakage of ACTIVA™ BioACTIVE, Smart Dentin Replacement (SDR), Cention N, and Conventional Glass Ionomer Cement (GIC) in Class V cavities.

Materials and Methods: Forty-eight extracted human maxillary premolars were randomly divided into four groups (n=12) and restored with Conventional GIC, ACTIVA™ BioACTIVE, SDR, or Cention N. After thermocycling and mechanical loading, specimens were coated with nail varnish, immersed in 2% Rhodamine B dye for 24 hours, sectioned buccolingually, and evaluated under a stereomicroscope at 30× magnification.

Statistical Analysis: Microleakage scores were analyzed using the Kruskal–Wallis test followed by the Dwass–Steel–Critchlow–Fligner post hoc test ($p < 0.05$).

Results: Mean microleakage scores were 2.83 ± 0.39 for Conventional GIC, 0.58 ± 0.67 for ACTIVA™ BioACTIVE, 1.75 ± 0.75 for SDR, and 1.33 ± 0.78 for Cention N. Significant differences were observed among the groups ($p = 0.0005$). ACTIVA™ BioACTIVE exhibited the lowest microleakage, whereas Conventional GIC showed the highest. No significant difference was observed between SDR and Cention N.

Conclusion: ACTIVA™ BioACTIVE exhibited the least microleakage and superior marginal sealing ability among the materials tested.

Keywords: Marginal sealing ability, Polymerisation shrinkage, Stereomicroscopy, Thermocycling

Key Message: ACTIVA™ BioACTIVE demonstrated the least microleakage and superior marginal sealing ability, suggesting its potential as a reliable restorative material for Class V cavities.

INTRODUCTION

The long-term success of restorative materials largely depends on their ability to form an effective marginal seal. Microleakage, defined as the penetration of bacteria, saliva, and ions through microscopic spaces at the tooth–restoration interface, may result from poor marginal adaptation.[1] It can lead to postoperative sensitivity, marginal discolouration, recurrent caries, pulpitis, and restoration failure.[2] The cavity configuration (C-factor) is the ratio of bonded to unbonded surfaces. A high C-factor indicates greater polymerisation stresses, which increase shrinkage stresses. Among the various factors influencing shrinkage stress, the C-factor is particularly significant.[3] Dentin or cementum margins also provide less predictable bonding than enamel. Polymerisation contraction stresses may therefore cause marginal gaps and increase microleakage.[4] Differences in thermal expansion between restorative materials and tooth structure may further compromise marginal integrity. Glass ionomer cement is a bioactive restorative material that provides a mechanical seal while exhibiting anti-cariogenic properties. [6] ACTIVA™ BioACTIVE is a novel, flowable, resin-based composite that is hydrophilic and self-adhesive with improved bond strength. It combines glass ionomer components with a patented rubberized resin that provides shock-absorbing properties.[7] Smart Dentin Replacement is a flowable bulk-fill composite designed with a polymerisation modulator that reduces shrinkage stress and improves internal adaptation when used as a dentin substitute,[8] whereas Cention N is an alkasite restorative material with ion-releasing properties and reduced polymerisation shrinkage.[1]

This study compared the microleakage of these four materials in Class V cavities. The null hypothesis was that restorative material would not significantly influence microleakage scores.

MATERIALS AND METHODS

Ethical approval: The study protocol was approved by the Institutional Human Ethics Committee (xxxxx/IHEC No: 05/Protocol No: 24/2024).

Sample selection: The study comprised forty-eight extracted human permanent maxillary premolars of comparable dimensions and without caries. Using a simple randomisation technique, the selected teeth were assigned to four groups, with 12 specimens in each group.
Samples with caries, restoration, fissure, fracture, or any deformity were excluded from the study. All samples selected for the study were cleaned with the aid of an ultrasonic scaler (Woodpecker UDS-J; Guilin Woodpecker Medical Instrument Co., Ltd., Guilin, China) to remove any remaining soft tissue and calculus deposits. The samples were kept hydrated by storing them in distilled water (High Purity Laboratory Chemicals Pvt Ltd, Mumbai, India).

Cavity preparation: On the buccal aspect of all samples, Cervical Class V cavities were prepared by utilizing cylindrical diamond burs (ISO 012) (MANI Inc., Utsunomiya, Tochigi, Japan) in a high-speed air-driven handpiece (NSK Ltd., Kanuma, Tochigi, Japan). The Class V cavities had a mesiodistal width of three mm, occlusogingival length of two mm, and depth of two mm. While the occlusal wall was made on the level of enamel, the cervical wall was at the junction of dentin-cementum to mimic a clinical Class V cavity. To keep uniformity in cavity preparation, burs were changed after every five sample cavity preparations. A Williams' graduated periodontal probe (Hu-Friedy, Chicago, IL, USA) was used for verification of dimensions of the Class V cavities.[9]

Grouping of samples:
The selected samples were divided into four groups of 12 samples each based on the restorative materials evaluated:
Group 1: Conventional Glass Ionomer Cement (GIC) (GC Corporation, Tokyo, Japan)
Group 2: ACTIVA™ BioACTIVE (Pulpdent Corporation, Watertown, MA, USA)
Group 3: Smart Dentin Replacement (SDR) (Dentsply Sirona, Konstanz, Germany)
Group 4: Cention N (Ivoclar Vivadent, Schaan, Liechtenstein)

Restorative procedures: By the manufacturer's guidelines, all the restorative procedures were done. In group I, the prepared cavity was conditioned with 10% polyacrylic acid for 20 seconds, and restored with conventional GIC. In group II, ACTIVA™ BioACTIVE restorative material was placed in the cavity preparation and then photopolymerised using an LED curing light (Woodpecker, Guilin Woodpecker Medical Instrument Co., Ltd., Guilin, China) for 20 seconds with a power intensity of ≥1000 mW/cm². In group III, Te-Econom Bond (Ivoclar Vivadent AG, Schaan, Liechtenstein) was coated in cavity preparation and subsequently light polymerised according to the manufacturer's instructions. Then the cavity was filled with SDR bulk-fill flowable restorative material and light polymerised for 20 seconds using an LED curing light operating at an intensity level of 1000–1200 mW/cm². In group IV, the cavity was restored with Cention N restorative material, followed by photopolymerisation for 20 seconds using an LED curing unit with an intensity of ≥1000 mW/cm². Using the Shofu Super-Snap Finishing and Polishing Kit (SHOFU Inc., Kyoto, Japan), all restorations were finished and polished. Subsequently, all samples were immersed in distilled water at 37°C for 24 hours.

Thermocycling and mechanical loading: Samples were exposed to 500 temperature cycles between 5°C and 55°C, maintaining a residence interval of 25 s at each temperature in a Thermocycling chamber (Holmarc Opto Mechatronics Ltd, Kochi, India). Subsequently, 10,000 cycles of mechanical loading were performed for another 25 secs.[9]

Microleakage evaluation
Following thermocycling, the apical ends of all specimens were sealed using dental sticky wax (Dental Products of India [DPI], Mumbai, Maharashtra, India). The entire tooth surface, except 1 mm around the restoration margins, was coated with a double layer of nail polish varnish (Galaxy Nail Colour™, Vasai, Maharashtra, India).

The prepared samples were then immersed in 2% Rhodamine B dye solution (Nitin Dye Chem, Valsad, India) for 24 hours. Thereafter, the specimens were thoroughly rinsed under running water and then cleaned in isotonic saline solution (Otsuka Pharmaceutical India Pvt. Ltd., Ahmedabad, Gujarat, India). To obtain cross-sectional views of the tooth-restoration interface, longitudinal sectioning of the samples was performed through the centre of the restoration using a diamond disc (SS White, New Jersey, USA) with water coolant. Sections were then evaluated using a stereomicroscope (SZ61, Olympus America Inc, Centre Valley, PA, USA) at a magnification of 30× to detect the penetration of dye into the restoration-tooth interface.[9] Microleakage scores were assessed independently at both the occlusal and cervical margins according to established scoring criteria. The amount of dye penetration visualized under magnification was considered indicative of marginal leakage.

MICROLEAKAGE SCORING SYSTEM (Silveira de Araújo et al., 2022)

SCORE	CRITERIA
0	No microleakage and no dye penetration
1	Penetration involving half the occlusal/gingival wall
2	Penetration involving more than half the occlusal/gingival wall
3	Penetration involving the axial wall

Statistical Analysis

The obtained data were organized systematically and analyzed using the Statistical Package for the Social Sciences (SPSS) version 25 (IBM Statistics, New York, USA) software package. Intergroup comparison of microleakage scores was carried out using the Kruskal–Wallis test followed by the Dwass–Steel–Critchlow–Fligner post hoc test for analysis of multiple pairwise comparisons. A p-value below 0.05 was considered statistically significant.

RESULTS

The distribution and descriptive statistics of microleakage scores among the four restorative materials are presented in Tables 1- 3.

Considerable variation in microleakage was observed among the study groups, as shown in Table 1. The descriptive statistics and intergroup comparison of microleakage scores are shown in Table 2.

GIC exhibited the highest mean microleakage score (2.83 ± 0.39), indicating the poorest marginal sealing ability among the tested materials. In contrast, ACTIVA™ BioACTIVE demonstrated the lowest mean microleakage score (0.58 ± 0.67), suggesting superior marginal adaptation. SDR and Cention N exhibited intermediate mean microleakage scores of 1.75 ± 0.75 and 1.33 ± 0.78, respectively.

The median microleakage score was highest for Conventional GIC (3.0), whereas the lowest median value was observed for ACTIVA™ BioACTIVE (0.5). The interquartile range (IQR) was 0.0 for Conventional GIC and 1.0 for the remaining groups.

Intergroup comparison using the Kruskal–Wallis test revealed a highly statistically significant difference in microleakage scores among the four restorative materials (χ^2 = 29.3, p = 0.0005), indicating that the type of restorative material significantly influenced marginal microleakage.

To identify the groups responsible for the observed differences, pairwise comparisons were performed using the Dwass–Steel–Critchlow–Fligner test (Table 3). Conventional GIC showed significantly higher microleakage scores than ACTIVA™ BioACTIVE (W = 6.10, p = 0.001), SDR (W = 4.71, p = 0.005), and Cention N (W = 5.72, p = 0.001). Furthermore, ACTIVA™ BioACTIVE exhibited significantly lower microleakage scores than SDR (W = 4.48, p = 0.008).

However, no statistically significant differences were observed between ACTIVA™ BioACTIVE and Cention N (W = 3.21, p = 0.106) or between SDR and Cention N (W = 1.50, p = 0.712).

Overall, ACTIVA™ BioACTIVE demonstrated the lowest microleakage scores, followed by Cention N and SDR, whereas Conventional GIC exhibited the highest degree of microleakage among the evaluated restorative materials.

DISCUSSION

Microleakage was observed in all restorative materials evaluated, indicating that none was able to eliminate marginal leakage in Class V cavities. Marginal integrity remains a key determinant of restorative success because microleakage may lead to postoperative sensitivity, recurrent caries, pulpitis, and restoration failure.[10] The null hypothesis was therefore rejected.

Class V cavities were selected because they present a restorative challenge owing to margins located partly in enamel and partly in dentin or cementum.[11] These preparations have a high C-factor (5:1), which increases polymerisation shrinkage stress and the risk of interfacial gap formation.[12] In addition, adhesion to dentin and cementum is less predictable than to enamel.[13] Thermocycling was performed to simulate thermal changes in the oral environment, where differences in thermal expansion between tooth structure and restorative materials may contribute to bond fatigue and marginal gap formation.[14] Kassim et al. reported that 500 thermocycles correspond to approximately 2–3 weeks of clinical exposure.[15] Rhodamine B dye was selected because of its reproducibility in microleakage assessment and ease of stereomicroscopic visualization.[10]

The higher microleakage observed with Conventional GIC may be attributed to its moisture sensitivity during the initial setting reaction and relatively lower mechanical strength, both of which may compromise marginal integrity. Momin et al. similarly reported greater leakage with GIC than composite and bioactive restorative materials,[2] while Jasrotia et al. reported greater microleakage with GIC than resin-based composite and nano-filled glass ionomer materials.[16]

The superior marginal adaptation of ACTIVA™ BioACTIVE may be related to its bioactive resin matrix, resilient resin component, and reactive glass fillers capable of releasing calcium, phosphate, and fluoride ions, thereby reducing polymerisation stress and improving marginal adaptation. Martínez-Sabio et al. reported favourable marginal adaptation and reduced microleakage with ACTIVA™ BioACTIVE,[17] while Hinduja et al. similarly observed improved marginal sealability.[18]

The favourable performance of Cention N may be explained by its alkasite composition, reduced polymerisation shrinkage stress, ion release, and highly cross-linked polymer structure. Similar findings have been reported by Srikumar et al.,[19] Sardana et al.,[1] Dhivya et al.,[20] Kumari et al.,[21] and Rai et al.,[22] supporting its satisfactory marginal sealing ability.

SDR exhibited moderate microleakage despite its modified urethane dimethacrylate matrix and flowable consistency, which are intended to reduce polymerisation shrinkage stress and improve cavity adaptation. Comparable findings were reported by AlSagob et al.,[23] whereas Kumar et al. observed greater gingival microleakage with SDR.[12] In contrast, Bilgrami et al.[24] and Arya et al.[25] reported favourable marginal sealing associated with SDR.

Clinically, improved marginal adaptation may reduce complications associated with microleakage; however, none of the evaluated materials completely prevented marginal leakage, consistent with the findings of Jasrotia et al. and Bollu et al.[16,26.] The present study is limited by its in vitro design, which cannot fully replicate oral conditions such as saliva, pH fluctuations, masticatory forces, and long-term ageing.[5] Therefore, further well-designed clinical studies are required to validate the long-term in vivo performance of these restorative materials.

TABLES

Table 1: Distribution of Microleakage Scores Among Study Groups

Groups (n=12)	**Microleakage scores**											
1	3	3	3	3	3	3	3	3	3	2	3	2
2	0	1	1	2	0	1	0	0	1	0	1	0

3	1	3	2	1	2	2	3	2	1	2	1	1
4	1	2	0	0	1	2	2	1	2	2	1	2

Table 2: Comparison of microleakage score between groups by Kruskal-Wallis test

Microleakage Score	N	Mean	SD	Median	IQR	KW χ^2-value	p-value
Conventional GIC	12	2.83	0.39	3.0	0.0	29.3	0.0005 **
Activa Bioactive	12	0.58	0.67	0.5	1.0		
Smart Dentin Replacement	12	1.75	0.75	2.0	1.0		
Cention N	12	1.33	0.78	1.5	1.0		
** Highly Statistically Significant at p < 0.01 level							

N = number of samples in each group, SD – standard deviation, IQR - interquartile range, KW- Kruskal-Wallis

Table 3: Pairwise Comparison of Microleakage Scores Between Groups Using Dwass–Steel–Critchlow–Fligner test

		W	p-value
Conventional GIC	Activa Bioactive	6.1	0.001 **
Conventional GIC	Smart Dentin Replacement	4.71	0.005 **
Conventional GIC	Cention N	5.72	0.001 **
Activa Bioactive	Smart Dentin Replacement	4.48	0.008 **
Activa Bioactive	Cention N	3.21	0.106 #
Smart Dentin Replacement	Cention N	1.5	0.712 #
** Highly Statistical Significance at p < 0.01 and # No Statistical Significance at p > 0.05 level			

W – Dwass–Steel–Critchlow–Fligner Test statistic

CONCLUSION

Within the constraints of this in vitro study, all the evaluated restorative materials exhibited varying degrees of microleakage in Class V cavities. ACTIVA™ BioACTIVE demonstrated the least microleakage and superior marginal sealing ability among the tested materials. Cention N and SDR exhibited intermediate performance, whereas Conventional GIC showed the highest microleakage. These findings suggest that ACTIVA™ BioACTIVE may be a promising restorative material for improving marginal sealing in Class V restorations.

Authors' Contributions:

1. Dr. Rajesh Sasidharan Nair: Concepts, Design, Definition of intellectual content, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review
2. Dr. Srihariharan Madhappan*: Design, Literature search, Clinical studies, Experimental studies, Manuscript preparation, Manuscript editing, Manuscript review, Guarantor.
3. Dr. Sarah Renjelina Christopher: Concepts, Design, Literature search, Data acquisition, Data analysis, Statistical analysis, Manuscript review.
4. Dr. Vijay Mathai: Definition of intellectual content, Clinical studies, Experimental studies, Data acquisition, Data analysis, Statistical analysis, Manuscript preparation, Manuscript editing, Manuscript review.
5. Dr. Vijil Vimala Ravi: Design, Literature search, Clinical studies, Manuscript editing, Manuscript review.
6. Dr. Swathi Vasantha Sudersanan: Concept, Experimental studies, Data analysis, Manuscript editing, Manuscript review.

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Definition of intellectual content	√			√		
Literature search		√	√		√	
Clinical studies			√	√	√	
Experimental studies			√	√		√
Data acquisition	√	√		√		
Data analysis		√		√		√
Statistical analysis		√		√		
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Manuscript editing	√		√	√	√	√
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INSTITUTIONAL HUMAN ETHICS COMMITTEE
SREE MOOKAMBIKA INSTITUTE OF DENTAL SCIENCES,
KULASEKHARAM, TAMILNADU

Communication of Decision of the Institutional Human Ethics Committee(IHEC)

SMIDS/IHEC No: 05 / Protocol No: 24/2024

Protocol Title: A comparative evaluation of Microleakage of ACTIVA™ BioACTIVE, Smart Dentin Replacement, Cention N and Conventional Glass Ionomer Cement in Class V cavities - An invitro study

Principal Investigator: Dr. Srihariharan M

Name and Address of Institution: Department of Conservative dentistry and Endodontics Sree Mookambika Institute of Dental Sciences, Kulasekharam

☑ New review ☐ Revised review ☐ Expedited review

Date of review (D/M/Y): 06-12-2024
Date of previous review, if revised application:

Decision of the IHEC:

☑ Recommended ☐ Recommended with suggestions
☐ Revision ☐ Rejected

Suggestions/ Reasons/ Remarks:

Recommended for a period of: One Year

Please Note*

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- Inform IHEC in case of any change of study procedure, site and investigator
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IHEC

Signature of Member Secretary (IHEC)

Reference:

1. Sardana A, Kumar M, Taneja S. Comparative evaluation of microleakage and hardness of newer posterior restorative materials. J Oral Biol Craniofac Res. 2022;12(5):733-736.
2. Momin Z, Maria R. To compare and evaluate the microleakage of four different tooth coloured restorative materials in Class V cavities: a stereomicroscopic study. Acta Sci Dent Sci. 2023;7(2):61-67.
3. Santhosh L, Bashetty K, Nadig G. The influence of different composite placement techniques on microleakage in preparations with high C-factor: an in vitro study. J Conserv Dent. 2008;11(3):112-116.
4. Malempati RR, Konakanchi A, Ganta GK, Vangala RM, Alla RK, Mohammed S. Revisiting microleakage: persistent challenges in restorative dentistry. Int J Dent Mater. 2025;7(1):18-26.
5. Van Ende A, De Munck J, Lise DP, Van Meerbeek B. Bulk-fill composites: a review of the current literature. J Adhes Dent. 2017;19(2):95-109.

6. Basavanna RS, Setia D, Shivanna V. Evaluation of microleakage of glass ionomer sealant in etched and non-etched enamel: a stereomicroscopic study. J Conserv Dent. 2003;6(1):13-17.
7. Paul A, Dubey R, Joshi SB, Patil AC, Narvekar PS. Fracture resistance of postendodontic restoration using self-adhesive bioactive resin and a bulk-fill composite with or without resin-impregnated glass fibers: An in vitro study. J Conserv Dent Endod. 2024;27(9):908-912.
8. Srivastava H, Thanvi C, Jyotiyana MK, Karale AG, Prasad AB, Raisingani D. Incremental versus bulk-fill techniques in Class I restorations using Smart Dentin Replacement Plus and Tetric N-Ceram: a prospective randomized split-mouth clinical trial. J Conserv Dent Endod. 2026;29(7):734-740.
9. Jambagi SR, Totad S, Srinidhi SR, Saraf P, Patil B. Comparative evaluation of marginal microleakage of a bioactive composite resin using three different bonding agents in non-carious cervical lesions: an in vitro study. Saudi J Oral Dent Res. 2023;8(8):270-274.
10. Sooraparaju SG, Kanumuru PK, Nujella SK, Konda KR, Reddy KB, Penigalapati S. A comparative evaluation of microleakage in Class V composite restorations. Int J Dent. 2014;2014:685643.
11. Ataide IDN, Fernandes M, Kumar A. Comparative evaluation of sealing ability of two self-adhesive flowable composites following various restorative techniques in Class V lesions: an in vitro study. J Conserv Dent. 2021;24(5):508-513.
12. S AK, VP VK, KN J, P V, P SK, SA G, Methew M. Comparative evaluation of microleakage of G-aenial Universal Flo, Smart Dentin Replacement and Tetric Evo Ceram bulk-fill resin composite restorations in Class V cavity preparation: an in vitro study. Int Dent J Stud Res. 2018;6(1):7-12.
13. Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerisation shrinkage stress: current techniques for posterior direct resin restorations. J Contemp Dent Pract. 2006;7(4):79-88.
14. Umer F, Naz F, Khan F. An in vitro evaluation of microleakage in Class V preparations restored with hybrid versus silorane composites. J Conserv Dent. 2011;14(2):103-107.
15. Kassim Z, Faiz Anuar M, Ramli S, Ismail I, Angelis N. Thermocycling stain challenge and colour stability of two current zirconium silicate-filled indirect composite restorative materials. Open Dent J. 2023;17:e187421062305020.
16. Jasrotia A, Bhagat K, Bhagat RK. Assessment of the microleakage of CGIC, RMGIC and nano-filled RMGIC in Class V cavities: An in vitro study. Ann Int Med Dent Res. 2021;7(6):111-116.
17. Martínez-Sabio L, Peñate L, Arregui M, Veloso Duran A, Blanco JR, Guinot F. Comparison of shear bond strength and microleakage between Activa™ Bioactive Restorative™ and bulk-fill composites—An in vitro study. Polymers (Basel). 2023;15(13):2840.
18. Hinduja D, Swathi S, Vedavathi B, Pai SV, Ambili C, Geetha V. Comparative evaluation of microleakage in Class V cavities restored with bioactive composite resin with and without a bioactive liner—An in vitro study. J Interdiscip Dent. 2025;15(1):14-18.
19. Srikumar GPV, Patel C, Pati P, Mohanty A, Himagiri S. An in vitro evaluation of microleakage in Class V cavities restored with chemically cured glass ionomer cement, light-cured glass ionomer cement, nanofilled resin-modified glass ionomer cement and Cention N. J Res Adv Dent. 2018;8(2):54-60.
20. Dhivya S, Vasanthakumari A, Arumugam S, Preethi S, AA C. Comparative evaluation of microleakage of three different restorative materials (cention N, zirconomer improved and glass hybrid restorative system) in Class V cavity restoration using stereomicroscope: in vitro study. J Pharma Res Int. 2022;34:34-42.
21. Kumari A, Singh N. A comparative evaluation of microleakage and dentin shear bond strength of three restorative materials. Biomater Investig Dent. 2022;9(1):1-9.
22. Rai N, Shetty S, Gupta R. Comparative evaluation of the microleakage of Cention N and glass ionomer cements in open-sandwich Class II restorations—An in vitro study. J Int Oral Health. 2023;15:113-118.
23. AlSagob EI, Bardwell DN, Ali AO, Khayat SG, Stark PC. Comparison of microleakage between bulk-fill flowable and nanofilled resin-based composites. Interv Med Appl Sci. 2018;10(2):102-109.
24. Bilgrami A, Alam MK, Qazi FUR, Maqsood A, Basha S, Ahmed N, Syed KA, Mustafa M, Shrivastava D, Nagarajappa AK, Srivastava KC. An in vitro evaluation of microleakage in resin-based restorative materials at different time intervals. Polymers (Basel). 2022;14(3):466.
25. Arya A, Gill B, Bishnoi N, Vishwanadulwar D, Lakhani D, Bhatnagar A. Comparative assessment of microleakage in various bulk-fill flowable composites: An in vitro study. J Pharm Bioallied Sci. 2024;16(Suppl 4):S3976-S3978.
26. Bollu IP, Hari A, Thumu J, Velagula LD, Bolla N, Varri S, Kasaraneni S, Nalli SV. Comparative evaluation of microleakage between nano-ionomer, giomer and resin-modified glass ionomer cement in Class V cavities—CLSM study. J Clin Diagn Res. 2016;10(5):ZC66-ZC70.