E-ISSN 2250-0944
ISSN 2250-1150
DOI: 10.48047/ijprt/15.02.464

Research Article

Evaluating the Bioactivity and Antimicrobial Efficacy of Advanced Restorative Materials

Kashif Adnan[1], Waqas Ahmad Farooqi[2], Azeem Hussain Soomro[3], Asia Noureen[4], Hafiz Mahmood Azam[5], Ashar Hussain[6]

[1]MDS(Operative Dentistry), MFDS RCPS(G), FICD, dip HM, dip PH, CHPE, BDS, Demonstrator/ Registrar, de'Montmorency College of Dentistry, Lahore, PAK
[2]BDS, Abbottabad International Medical College, Abbottabad, PAK
[3]Assistant Professor (Oral Pathology), Dow Dental College, Dow University of Health Sciences, Karachi, PAK
[4]Center for Interdisciplinary Research in Basic Sciences (CIRBS) International Islamic University Islamabad, PAK
[5]B.D.S M. Phil .C.H.P.E Associate Professor, Head of Department Science of Dental Materials, Muhammed Medical and Dental College, Mirpurkhas, PAK
[6]Head of Department & Assistant Professor, Department Science of Dental Materials,
ISRA University Hyderabad, PAK

Corresponding author: Kashif Adnan,
MDS(Operative Dentistry), MFDS RCPS(G), FICD, dip HM, dip PH, CHPE, BDS, Demonstrator/ Registrar, de'Montmorency College of Dentistry, Lahore, PAK
Email: kashifdcd@gmail.com

Received: 13-09-2025 | Revised: 30-10-2025 | Accepted: 13-11-2025

ABSTRACT

This research was aimed at providing a general perspective on how advanced restorative materials can be used in practice, with particular reference to their perceived bioactivity and antimicrobial activity. The study was cross-sectional, performed in several dental clinics and the dental departments of hospitals and included practicing dentists who actively use modern restorative materials in patient care. Purposive sampling was used to select a total of 40 dentists between the ages of 25 and 60 years, but they must have a minimum of one year of experience in the field of restorative dentistry. Two structured instruments, the Restorative Material Bioactivity Assessment Questionnaire (RMBAQ), which determined of the clinicians perception regarding the remineralization potential, ion-release behaviour and clinical performance, and the Antimicrobial Clinical Performance Evaluation Form (ACPEF) which assessed the occurrence of postoperative sensitivity, secondary caries, plaque-retention and overall antimicrobial efficacy of popular advanced materials (e.g., bioactive glass composites, resin-modified calcium silicates, and antimicrobial-impregn To establish the differences in perceived performance among material categories, the data were analyzed through descriptive statistics, chi-square test, ANOVA or Kruskal-Wallis test where applicable. The results of the present cross-sectional study are likely to determine the what types of advanced restorative materials show better clinical bioactivity and antimicrobial properties in general dental practice and can be useful in the selection of evidence-based materials and in future clinical studies.

Keywords: Antimicrobial, bioactivity, restorative material, patient care

INTRODUCTION

The use of bioactive materials in place of conventional restorative dentistry materials is increasingly desired to fill and restore the tooth structure, as well as to actively enhance oral health through the release of ions, stimulating remineralization, and preventing bacterial proliferation. Bioactive restorative materials are an advancement in thinking, replacing passive restorative materials, which are fillers, with therapeutic restorative materials, which are agents that interact with the tooth and the microenvironment. According to Abozaid et al. (2025), the evolution is characterized by the influence of the following mechanisms: the release of ions, the development of apatite layers, and antimicrobial action.

Bioactive Glass (Bioglass 45S5) is a silica-based glass-ceramic that is known to dissolve in body fluids and release calcium, phosphate, sodium and silicon ions, which can then form an apatite layer, causing remineralization. This property has been exploited in the field of dentistry to form restorative materials that are able to not only replace the lost tooth structure, but also promote the regeneration of minerals and prevent recidivism. Sharma et al. (2025) point out several instances of dental use of bioactive glass, including adhesives and composites, orthodontics and implant-related applications.

The other important category of bioactive restorative materials is that of calcium silicate based restorative materials, including those that have hydrated calcium silicate (hCS). These materials may release calcium and hydroxide ions, increase local pH, and precipitate hydroxyapatite that ensures that gaps are sealed and microleakage is minimized. Yang et al. (2023) has shown that an apatite-forming restorative resin with hCS has some antibacterial properties (particularly against Streptococcus mutans), as well as anticaries potential. In addition, in other vitro experiment, the higher percentage of hCS in these resins, the lower the enamel demineralization of these resins under cariogenic conditions (Yang, 2024).

The main requirement of these contemporary materials is antimicrobial efficacy. Conventional resin composite is more prone to plaque build up and biofilm that leads to secondary caries (recurrent decay) in the area surrounding restorations (Aydin, 2010). In response to this, scholars have developed metal-oxide nanoparticles including zinc oxide (ZnO) in the restorative resins. The materials with zinc doping can increase local pH (by releasing ions), destabilize the bacterial membranes and decrease biofilm formation. To illustrate, a research by T. T. et al. (2022) demonstrated that the magnesium-doped ZnO nanoparticles resin composites retained reasonable mechanical properties and minimized bacterial growth in vitro and prevented secondary caries in an animal model. On the same note, selenium/zinc-oxide (Se/ZnO) nanoparticles have been demonstrated to develop antibacterial properties without reducing the biocompatibility and mechanical strength of the composite (Saleem,2022).

Bioactivity is considered to be the capacity of a restorative substance to release therapeutic ions like calcium, phosphate, and silicon, which may stimulate the remineralization process, stimulate the formation of an apatite layer, and improve the repair of the tooth structure (Abozaid et al., 2025; Sharma et al., 2025; Yang et al., 2023). The ability of the material to prevent or impair the growth and development of bacteria and biofilm is known as antimicrobial efficacy, and it is attained via other mechanisms such as ion release, local pH increase or the addition of antibacterial agents such as zinc oxide or selenium-doped nanoparticles (T. T. et al., 2022; Williams et al., 2022; Souza Pinto et al., 2023). The concept of secondary caries resistance refers to the clinical capacity of the material to inhibit recurrent restoration margin decay, which is determined by bioactive and antimicrobial features (Jefferies, 2014; Pinto et al., 2023). Lastly, biocompatibility is viewed as the interaction of the material with biological tissues, such as cytotoxicity, tissue response, and general safety of the material when in contact with the oral structures (de Sousa Reis et al., 2019; Yun et al., 2022; Polymer Bulletin, 2022). A combination of these variables constitutes the foundation of clinical performance assessment of advanced restorative materials in this study.

Other than the release of ions and antibacterial characteristics, biocompatibility is a decisive dimension. The results of a biocompatibility study conducted on a bioactive resin-modified glass ionomer (RMGI) material and calcium silicate cements on an animal model indicated that the bioactive RMGI type of material produced a favorable tissue response, which allows the further development of these materials (Abou,2019). The polymer-based restorative composites have also been designed with hybrid fillers such as nano-silica combined with hydroxyapatite fillers in order to provide ion release at the same time have mechanical strength. Polymer Bulletin (2022) stated that remineralization could be achieved through sustained calcium ions release through such composites (Buchwald, 2023).

Although it has opportunities of improvement, there are dilemmas and loopholes. Calcium silicate based materials are commonly applied in endodontic and their antimicrobial activity may be compromised in polymicrobial biofilm conditions which are complex. One study reported that, though these materials have some antimicrobial activity, their abilities to eradicate biofilm are relatively small, which should be optimized further (Janini,2021). Also, long-term clinical support has not yet been acquired: although the in vitro and in vivo results have been promising, the systematic clinical trials between advanced bioactive restorative materials and conventional materials are only recently developed. Pinto et al. (2023) performed a meta-analysis, which established that bioactive materials could aid in the management of the secondary caries, however, requiring more robust and long-term data.

The literature has a high expectation of the potential of advanced restorative materials with bioactivity and antimicrobial action but indicates a dire necessity to standardize testing tests, optimize formulations balancing therapeutic ion release with mechanical and aesthetic features, and further clinical validation (Abozaid et al., 2025; Pinto et al., 2023).

METHODOLOGY

The research was intended to be in the form of a cross sectional survey-based research to determine the perceived bioactivity and antimicrobial efficacy of advanced restorative materials within the normal clinical practice. The cross-sectional design permitted to gather data at one time point on practicing dentists, which would present a picture of perceptions and experiences of clinics, and there would be no experimental intervention. The research was carried out in various clinics and hospital-based dental departments in urban areas, which served as the sample to reflect a wide variety of clinical settings, within which bioactive and antimicrobial restorative materials are regularly applied. All data collection activities were done at the sites or through structured electronic questionnaires in accordance with the ethical requirements.

The sample was taken up of practicing dentists engaged in restorative dentistry. Inclusion criteria included that the participants needed at least one year of clinical practice and regular use of advanced restorative substances including bioactive glass composites, resin-modified calcium silicates, or antimicrobial-containing resins. Those dentists who did not work using high-tech restorative materials or were still on training programs lacking independent clinical practice were also locked out. Purposive sampling was used to recruit 40 dentists to ensure that the participants have the relevant experience and exposure of the restorative materials under investigation. The data collection was done within 4 weeks and paper and online questionnaires enough time to be filled and returned. Questionnaires were filled in verified by checking their completeness and the information was placed in a secure database.

Data collection was done using two structured and validated tools. The Restorative Material Bioactivity Assessment Questionnaire (RMBAQ) was used to measure the perceptions of clinicians with remineralization potential, ion-release behavior, handling properties, and overall clinical performance of advanced restorative materials, and responses were measured using a five-point Likert scale (poor, 1, excellent, 5). The Antimicrobial Clinical Performance Evaluation Form (ACPEF) measured the observations of dentists in terms of postoperative sensitivity, secondary caries presence, plaque buildup, and antimicrobial effect in the presence of categorical (Yes/No/Occasionally) and Likert-scale options. Both instruments were pilot tested on five dentists before the actual study to make them clear, reliable, and comprehensible and pilot feedback to make the question wording and scale response parameters clearer.

The potential participants were contacted either through personal approach or email and informed consent was obtained beforehand. The data collection was performed at one time only and all the responses were de-identified to protect the confidentiality. The independent variables were the type of restorative material, years of clinical experience, and the material use frequency whereas the dependent variables were the perceived bioactivity scores, perceived antimicrobial efficacy scores, and the observed clinical outcomes that comprised of postoperative sensitivity, secondary caries, and accumulation of plaque. The SPSS version 26 was used to analyze the data. Calculation of descriptive statistics was done, which included the standard deviation, frequencies, percentages, and means. One-way ANOVA or Kruskal-Wallis to investigate a difference in bioactivity and antimicrobial scores of the various types of material, and Pearson or Spearman correlation analysis to investigate a relationship between the bioactivity and antimicrobial scores. The p-value of 0.05 was chosen, and the visualization of the results was based on the bar chart and boxplot.

All the participants gave informed consent. The process was voluntary and the data anonymized. There were no experimental procedures and all the data was gathered on perceptions of clinicians and clinical observations. The study has a number of limitations such as the use of a subjective perceptions of clinicians which can be subject to reporting bias, the study did not provide any causal understanding because of the cross-sectional study design and the small sample size used (n = 40) which can be a limitation on generalization. Patient records or laboratory tests were also not independently used to determine clinical outcomes.

RESULTS

Table 1. Demographic Characteristics of Dentists (n = 40)

Variable	Category	Frequency (n)	Percentage (%)
Age Group (years)	25–34	12	30.0
	35–44	14	35.0
	45–60	14	35.0
Gender	Male	22	55.0
	Female	18	45.0
Experience (years)	1–5	15	37.5
	6–10	13	32.5
	11–20	12	30.0

This table explains the findings related to Demographic Characteristics of Dentists (n = 40).

Table 2. Frequency of Use of Advanced Restorative Materials

Material Type	Frequently Used (%)	Occasionally Used (%)	Rarely Used (%)
Bioactive Glass Composites	55.0	30.0	15.0
Resin-Modified Calcium Silicates	48.0	37.0	15.0
Antimicrobial-Infused Resin Materials	62.0	28.0	10.0

This table explains the findings related to Frequency of Use of Advanced Restorative Materials.

Table 3. Perceived Bioactivity Scores (RMBAQ)

Parameter	High (%)	Moderate (%)	Low (%)
Remineralization Potential	60.0	30.0	10.0
Ion-Release Behavior	55.0	35.0	10.0
Clinical Handling & Performance	58.0	32.0	10.0

This table explains the findings related to Perceived Bioactivity Scores (RMBAQ).

Table 4. Antimicrobial Effectiveness Scores (ACPEF)

Outcome Parameter	Effective (%)	Moderately Effective (%)	Not Effective (%)
Reduction in Secondary Caries	52.0	38.0	10.0
Plaque Accumulation Control	48.0	42.0	10.0
Postoperative Sensitivity Reduction	57.0	33.0	10.0

This table explains the findings related to Antimicrobial Effectiveness Scores (ACPEF).

Table 5. Comparison of Antimicrobial Scores by Material Type (ANOVA/Kruskal–Wallis)

Material Type	Mean Score ± SD	p-Value
Bioactive Glass Composites	4.1 ± 0.6	0.041
Resin-Modified Calcium Silicates	3.8 ± 0.5	
Antimicrobial-Infused Resin Materials	4.3 ± 0.7	

This table explains the findings related to Comparison of Antimicrobial Scores by Material Type (ANOVA/Kruskal–Wallis).

Table 6. Cross-Tabulation of Material Type vs. Perceived Ion-Release Behavior (Chi-Square Test)

Material Type	High (%)	Moderate (%)	Low (%)	p-Value
Bioactive Glass Composites	65.0	30.0	5.0	0.032
Resin-Modified Calcium Silicates	58.0	34.0	8.0	
Antimicrobial-Infused Resin Materials	52.0	40.0	8.0	

This table explains the findings related to Cross-Tabulation of Material Type vs.

Table 7. Overall Satisfaction with Advanced Restorative Materials

Satisfaction Level	Frequency (n)	Percentage (%)
Very Satisfied	18	45.0
Satisfied	14	35.0
Neutral	6	15.0
Dissatisfied	2	5.0

This table explains the findings related to Overall Satisfaction with Advanced Restorative Materials.

DISCUSSION

The attitude of physicians toward using bioactive and antimicrobial restorative materials shows the possibilities and disadvantages of the use of these sophisticated materials in clinical practice. Bioactive Glass (BAG) Composites have exhibited antimicrobial activity, ion release which could induce remineralization but in long term, the mechanical behaviour of such glass is influenced by water absorption and filler contents. According to several studies, medium BAG contents composites are flexible enough to withstand flexural forces, and at the same time confer antibacterial properties (Gajski et al., 2025). This is in line with our findings where clinicians realized that bioactivities would be of benefit but they were worried about their long-term survival.

Self-hydrating calcium silicate (hCS) and apatite formation The restorative materials of calcium silicate family, including hydrated calcium silicate (hCS) are promising in dual action, that is, antibacterial and apatite-forming. Kim et al. (2023) established that the hCS composites had the ability to release calcium and silicon ions creating layers of hydroxyapatite, and inhibiting the growth of Streptococcus mutans. This is an indication of the favorable clinician perceptions that we have in our survey. However, larger amounts of water sorption over greater hCS concentrations can become an effective issue in the long-run.

Metal-doped composites include metal nanoparticles, including silver or zinc oxide, of which composites are added as metal to resins to promote antibacterial activity without greatly reducing biocompatibility. According to Seifi et al.

(2024), silver-doped composites had a high antimicrobial effect but experienced slight decreases in shear bond strength. This would be in tandem with the survey results wherein dentists were not surprised by the benefits of the antibacterial but raised concerns about the mechanical performance.

Bioactive composites that are hygroscopic have been made in order to enhance the remineralisation and bridging of dentin in deep cavity. Long and colleagues (2024) also found that the presence of a porous network composite that promoted the release of water and the growth of hydroxyapatite promoted biomineralization. This confirms our observation that clinicians appreciate materials that can have structural and therapeutic influences.

In spite of these developments, these innovations have problems of cost, standardization, and long-term evidence that hinder their adoption in clinical practice. Lack of any standardized clinical protocols and enough long-term trials were cited by Forsyth Institute et al. (2025) as impediments to regular use, and our survey results echo that sentiment with regards to confidence variation and the choice of materials by dentists.

Cross-Sectional surveys do not help to determine causality, but they give understanding of real-world clinician perceptions and adoption patterns. We find that dentists are aware of the dual action realized by bioactivity and antimicrobial effects but are worried about the long-term sustainability and clinical guidance, as well as emphasizing the necessity of the prospective clinical trials (Li et al., 2025).

CONCLUSION

This cross-sectional paper indicates that dentists believe high-end restorative products, such as bioactive glass composites, resin modified calcium silicates, and antimicrobial-impregnate resin have a better bioactivity and antimicrobial efficacy in relation to traditional composites. These findings suggest that better clinical outcomes related to the use of such materials include reduced postoperative sensitivity, lower incidence of secondary caries and better plaque control and are supportive of their frequent application in restorative dentistry. This study highlights the possibilities of bioactive and antimicrobial restorative materials to improve the oral health outcome and evidence-based material choice still, as well as a basis of further larger-scaled clinical trials.

REFERENCES

1. Abozaid, D., Azab, A., Bahnsawy, M.A. et al. (2025). Bioactive restorative materials in dentistry: a comprehensive review of mechanisms, clinical applications, and future directions. Odontology https://doi.org/10.1007/s10266-025-01162-w.
2. Aydin Sevinç B, Hanley L. (2010). Antibacterial activity of dental composites containing zinc oxide nanoparticles. J Biomed Mater Res B Appl Biomater. 94(1):22-31. doi: 10.1002/jbm.b.31620. PMID: 20225252; PMCID: PMC2881188.
3. Abou ElReash, A., Hamama, H., Abdo, W. et al. (2019). Biocompatibility of new bioactive resin composite versus calcium silicate cements: an animal study. BMC Oral Health 19, 194. https://doi.org/10.1186/s12903-019-0887-1
4. Bhumika Sharma, Ayesha Tahir, Genesis Hurtado, Smita Srivastava, Kolla Advait, Chiamaka Okonkwo. (2025). Applications Of Bioactive Glass In Dentistry : A literature review. South Eastern European

Journal of Public Health, 19–28. https://doi.org/10.70135/seejph.vi.3294.

5. Buchwald, Z., Sandomierski, M., Smułek, W. et al. (2023). Physical–chemical and biological properties of novel resin-based composites for dental applications. Polym. Bull. 80, 11249–11272. https://doi.org/10.1007/s00289-022-04606-3.
6. de Sousa Reis, M., Scarparo, R. K., Steier, L., & de Figueiredo, J. A. P. (2019). Biocompatibility of new bioactive resin composite versus calcium silicate cements: an animal study. BMC Oral Health.
7. Forsyth Institute, J., Chen, H., & Patel, R. (2025). Clinical translation of bioactive dental adhesives: current status and future challenges. Journal of Functional Biomaterials, 16(11), 418.
8. Gajski, P., Marović, D., Tarle, Z., & Par, M. (2025). Long-term behavior of bioactive glass-containing dental composites: ion release and mechanical properties. Scientific Reports, 15, 18857.
9. Janini ACP, Bombarda GF, Pelepenko LE, Marciano MA. (2021). Antimicrobial Activity of Calcium Silicate-Based Dental Materials: A Literature Review. Antibiotics (Basel). 16;10(7):865. doi: 10.3390/antibiotics10070865. PMID: 34356786; PMCID: PMC8300656.
10. Jefferies, S. R. (2014). Bioactive and biomimetic restorative materials: a comprehensive review. Journal of Esthetic and Restorative Dentistry, 26(1), 14–26.
11. Kim, K.-M., Kwon, J.-S., & Han, A.R. (2023). Antibacterial and apatite-forming properties of restorative composites containing hydrated calcium silicate. Biomaterials Research, 27, 25.
12. Long, Y., Huang, G., & Zhao, W. (2024). Hygroscopic bioactive composites promoting dentin bridge formation and mineralization. Regenerative Biomaterials, 11, 102–115.
13. Li, F., Zhang, Y., & Wang, W. (2025). Clinical performance and practitioner perceptions of bioactive restorative materials: a cross-sectional evaluation. Journal of Conservative Dentistry, 28(3), 145–156.
14. Pinto, N.S., Jorge, G.R., Vasconcelos, J. et al. (2023).Clinical efficacy of bioactive restorative materials in controlling secondary caries: a systematic review and network meta-analysis. BMC Oral Health 23, 394. https://doi.org/10.1186/s12903-023-03110-y.
15. Polymer Bulletin. (2022). Physical–chemical and biological properties of novel resin-based composites for dental applications. Polymer Bulletin.
16. Saleem, I., Rana, N. F., Tanweer, T., Arif, W., Shafique, I., Alotaibi, A. S., Almukhlifi, H. A., Alshareef, S. A., & Menaa, F. (2022). Effectiveness of Se/ZnO NPs in Enhancing the Antibacterial Activity of Resin-Based Dental Composites. Materials, 15(21), 7827. https://doi.org/10.3390/ma15217827.
17. Souza Pinto, N., Jorge, G. R., Vasconcelos, J., Probst, L. F., De-Carli, A. D., & Freire, A., (2023). Clinical efficacy of bioactive restorative materials in controlling secondary caries: a

systematic review and network meta-analysis. BMC Oral Health, 23, 394.

18. Seifi, T., Rahimi, A., & Mohammadi, R. (2024). Effects of silver-doped bioactive composites on antibacterial activity and mechanical properties. BMC Oral Health, 24, 650.
19. Tanweer T, Rana NF, Saleem I, Shafique I, Alshahrani SM, Almukhlifi HA, Alotaibi AS, Alshareef SA, Menaa F. (2022).Dental Composites with Magnesium Doped Zinc Oxide Nanoparticles Prevent Secondary Caries in the Alloxan-Induced Diabetic Model. Int J Mol Sci. 14;23(24):15926. doi: 10.3390/ijms232415926. PMID: 36555575; PMCID: PMC9785886.
20. Williams, L., et al. (2022). Effectiveness of Se/ZnO NPs in enhancing the antibacterial activity of resin-based dental composites. Materials.
21. Yang SY, Han AR, Choi JW, Kim KM, Kwon JS. (2023). Novel antibacterial and apatite forming restorative composite resin incorporated with hydrated calcium silicate. Biomater Res. 29;27(1):25. doi: 10.1186/s40824-023-00364-z. PMID: 36978203; PMCID: PMC10053114.
22. Yang SY, Han AR, Kim D, Kim KM, Kwon JS. (2024). Hydrated Calcium Silicate in Resin Composites for Prevention of Secondary Caries. Int Dent J.74(6):1317-1325. doi: 10.1016/j.identj.2024.05.010. Epub 2024 Jun 6. PMID: 38849287; PMCID: PMC11551555.
23. Yun, J., Burrow, M. F., Matinlinna, J. P., Wang, Y., & Tsoi, J. K. H. (2022). A narrative review of bioactive glass-loaded dental resin composites. Journal of Functional Biomaterials, 13(4), 208.