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THE EFFECTIVENESS OF BIOACTIVE GLASS FILLINGS IN REDUCING TOOTH SENSITIVITY IN RESTORED TEETH

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Abstract

Background: Post-restoration tooth sensitivity remains a common reason for patient dissatisfaction and unplanned revisits after direct restorative treatment. Bioactive glass–based restorative technologies may reduce sensitivity by promoting ion release, mineral precipitation, and dentinal tubule occlusion, potentially improving comfort beyond what is achieved with conventional fillings.

Objective: To evaluate whether bioactive glass fillings reduce post-treatment tooth sensitivity more effectively than traditional dental fillings, with emphasis on sustained (long-term) outcomes.
Study Type: Randomized controlled trial

Methods: A parallel-group, randomized controlled trial was conducted in the restorative dentistry clinics of a tertiary hospital in Khyber Pakhtunkhwa (KPK), Pakistan. Adults requiring direct posterior restorations (Class I/II) in vital permanent teeth were randomized 1:1 to receive either a bioactive glass–based restorative approach (intervention) or a conventional filling

approach (control). Sensitivity was assessed using the Visual Analog Scale (VAS, 0–10) and standardized stimulus tests at baseline; 48 hours; 1 week; 1 month; 3 months; 6 months; and 12 months. The primary endpoint was change in postoperative sensitivity over time. Secondary endpoints included restoration retention and clinically relevant adverse outcomes. Analysis followed intention-to-treat principles with longitudinal modeling for repeated measures.

Results: Of 180 patients assessed, 120 were randomized (60 per arm). At 12 months, 58 participants in the bioactive glass group and 56 in the control group were available for analysis. Mean VAS decreased from ~6.1 at baseline to 2.8 at 48 hours in the bioactive glass group versus 4.1 in controls, with the between-group separation persisting through 12 months (0.3 vs 1.3). A higher proportion of participants achieved near-complete comfort (VAS ≤1) in the bioactive glass group by 12 months (88% vs 50%). Restoration retention at 12 months was high in both groups (98.3% vs 96.4%), with no material-related adverse reactions observed.

Conclusion: In this tertiary-hospital RCT, bioactive glass restorations were associated with faster and more durable reductions in postoperative tooth sensitivity than traditional fillings, while maintaining comparable clinical performance. These findings support consideration of bioactive glass approaches for sensitivity-prone restorative cases in high-volume public-sector settings.

INTRODUCTION

Tooth sensitivity after restorative treatment is one of those problems that looks “minor” on paper but can dominate a patient’s daily life. A tooth that reacts sharply to cold air, sweet drinks, or even normal brushing can turn a successful restoration into a frustrating experience, lowering confidence in dental care and pushing patients into repeated visits. Clinically, sensitivity is also a quality marker: persistent post-restoration pain often makes patients question the competence of the operator and the material, even when the restoration is technically sound.

Sensitivity linked to exposed or irritated dentine is commonly explained through the hydrodynamic theory. In simple terms, dentinal tubules act like microscopic channels; when thermal, evaporative, osmotic, or tactile stimuli move fluid inside these tubules, mechanosensitive nerve endings in the pulp–dentine complex are triggered, producing pain (Brännström, 1986). This theory remains central because it connects what patients feel (sharp, short pain) with what clinicians can influence (tubule openness, permeability, sealing quality, and interface stability).

In restorative dentistry, post-treatment sensitivity typically has multiple contributors acting together rather than a single cause. Cavity preparation can remove protective enamel/cementum and expose dentine; etching and bonding alter smear layers and tubule patency; polymerization shrinkage and occlusal loading can create marginal gaps and microleakage; and pulpal inflammation may occur if deep caries or repeated stimuli have already stressed the tooth. This is why two restorations that look identical radiographically can behave very differently in terms of patient comfort. Contemporary trials and reviews on postoperative sensitivity consistently highlight that controlling dentine permeability and maintaining a stable seal at the restoration–tooth interface are among the most important practical levers for reducing symptoms over time (Sauro, Carvalho and Ferracane, 2025).

Against this background, “bioactive” restorative approaches have gained attention because they aim to do more than passively fill a cavity. Bioactive glasses—especially classical compositions such as 45S5—are designed to release ions (e.g., calcium, phosphate, sodium) when they contact oral fluids, creating conditions that favor mineral deposition. The formation of an apatite-like layer on or near the material can potentially support remineralization, improve interfacial sealing, and reduce dentine permeability—mechanisms that are directly relevant to sensitivity control (Hench, 2006). In the hypersensitivity field, bioactive glass is frequently linked with tubule occlusion: if

tubules are physically blocked or narrowed through mineral precipitation, fluid movement is reduced, and pain should drop accordingly.

Clinical evidence is increasingly mapping out where bioactive glass performs well and where it remains uncertain. Scoping and systematic reviews up to 2024–2025 report that calcium sodium phosphosilicate (a widely used bioactive glass in oral products) is among the most investigated forms, with many studies showing short- to medium-term reductions in sensitivity measured using air blast/cold stimuli and scales such as VAS or Schiff (Clinical Oral Investigations scoping review, 2025). A focused systematic review of randomized controlled trials between 2018 and 2022 similarly concludes that bioactive glass–containing interventions can reduce dentin hypersensitivity symptoms, although heterogeneity in protocols and follow-up durations limits how confidently results can be generalized across products and clinical scenarios (Al-Shehri et al., 2023). Another systematic review extending inclusion through December 2024 found that bioactive-glass-based approaches tend to be superior to baseline and often comparable to other desensitizers over longer follow-up windows, while appearing particularly strong in the immediate-to-early period after application (BMC Oral Health systematic review, 2025).

Randomized clinical trials provide more granular insight into mechanisms and time course. For example, a split-mouth randomized trial evaluated a universal adhesive containing mesoporous bioactive glass and reported meaningful reductions in dentin hypersensitivity over short follow-up, with effects varying by stimulus type (air vs cold vs acidic triggers), which reinforces the idea that "sensitivity" is not a single uniform phenomenon (Kim et al., 2024). Similarly, in-office or chairside applications of calcium sodium phosphosilicate have shown rapid reductions in sensitivity after periodontal procedures such as scaling, supporting a clinically plausible ion-driven occlusion/remineralization pathway (Rai et al., 2023). Even outside classic hypersensitivity indications, bioactive glass has been investigated in contexts where sensitivity is a common adverse outcome—such as bleaching—again suggesting potential for symptom reduction when bioactive glass is present in the treatment protocol (Bizreh and Milly, 2022).

However, translating these findings into restorative practice requires careful study design. Sensitivity in "restored teeth" has a different clinical ecology than sensitivity in non-carious cervical lesions or post-periodontal therapy. Restorations involve complex interfaces (enamel–dentine margins, adhesive layers, bulk restorative material), and long-term symptoms may depend on sustained sealing rather than short-lived tubule blockage. This is why high-quality randomized

controlled trials comparing bioactive glass–containing filling systems to conventional materials—using standardized cavity classes, bonding protocols, and calibrated sensitivity measurements—are essential to move beyond marketing claims and into evidence-based recommendations (Sauro, Carvalho and Ferracane, 2025).

The setting of the present research—a tertiary care hospital in Khyber Pakhtunkhwa (KPK), Pakistan—adds an important applied dimension. Tertiary hospitals in KPK often receive patients with delayed presentation, complex caries patterns, and high symptom burden, where post-restoration comfort matters as much as restoration survival. In resource-constrained environments, a material that measurably reduces post-treatment sensitivity may lower repeat visits, improve patient trust, and support broader oral-health service efficiency. Yet, evidence from South Asian public-sector tertiary hospitals remains limited in the international literature, and findings from high-income settings do not always transfer cleanly due to differences in diet, oral hygiene practices, disease severity at presentation, and follow-up patterns.

Therefore, this randomized controlled trial is designed to investigate the effectiveness of bioactive glass fillings in reducing post-treatment tooth sensitivity compared to traditional dental fillings, with particular attention to long-term outcomes. Grounded in hydrodynamic theory and emerging evidence on ion-mediated tubule occlusion and interface mineralization, the study aims to generate locally relevant, clinically rigorous data from a tertiary hospital population in KPK—data that can contribute to both regional decision-making and the wider international discussion on what "bioactive" restorative dentistry can realistically deliver.

METHODOLOGY

Study design and setting

This study was conducted as a parallel-group randomized controlled trial at the dental services unit of a tertiary care hospital in Khyber Pakhtunkhwa (KPK), Pakistan. The trial compared a bioactive glass–containing restorative filling approach (intervention) with a conventional restorative approach routinely used in the same setting (control). The protocol was structured in line with CONSORT principles for randomized trials, with pre-defined outcomes, follow-up timepoints, and standardized clinical procedures to minimize operator-driven variation.

Participant recruitment and eligibility

Patients were recruited from the outpatient restorative dentistry clinics through consecutive sampling. Each potential participant underwent clinical examination and radiographic assessment (as needed) to confirm eligibility.

Inclusion criteria

- Adults aged 18–60 years.
- Permanent posterior teeth requiring a direct restoration (Class I or Class II carious lesions) with vital pulp status.
- Teeth that were restorable with direct filling and did not require endodontic therapy.
- Patients who agreed to return for follow-up visits for long-term evaluation.

Exclusion criteria

- Teeth with signs of irreversible pulpitis, necrosis, periapical pathology, or existing root canal treatment.
- Teeth with cracks, cusp fractures requiring indirect coverage, or severe occlusal trauma.
- Patients with uncontrolled systemic disease affecting healing, severe xerostomia, or ongoing orthodontic forces on the target tooth.
- Pregnant patients (to avoid unnecessary radiographic exposure and reduce follow-up loss).
- Known allergy to resin-based dental materials or components of the tested products.

Only one tooth per participant was included to avoid clustering effects (i.e., multiple teeth from the same patient potentially sharing pain thresholds and oral hygiene behaviors).

Sample size estimation

The sample size was calculated to detect a clinically meaningful difference in tooth sensitivity between groups using a continuous outcome scale (Visual Analog Scale, VAS). An expected moderate effect size was assumed based on prior clinical literature, with alpha set at 0.05 and power at 80%. An additional margin was added to compensate for anticipated attrition at longer follow-ups (typical in public-sector tertiary hospitals due to travel distance and competing obligations). The final sample size targeted adequate power even if a portion of participants did not complete the 12-month assessment.

Randomization and allocation concealment

Eligible participants were randomly assigned in a 1:1 ratio to either:

- **Intervention group:** bioactive glass filling system, or

- **Control group:** traditional restorative filling system.

A computer-generated random sequence was prepared by an independent staff member not involved in treatment or outcome assessment. Allocation was concealed using sequentially numbered, opaque, sealed envelopes opened only after cavity preparation and immediate pre-restoration steps were complete, ensuring that enrollment decisions could not be influenced by knowledge of assignment.

Blinding

Operator blinding was not feasible because restorative materials differ in handling and appearance. To reduce bias:

- Outcome assessments were performed by a calibrated examiner who did not place the restorations and was not informed of group allocation.
- Participants were not explicitly told which material was considered "new" or "experimental." They were informed that two commonly used restorative approaches were being compared for sensitivity outcomes.

Interventions and standardized clinical procedure

All restorations were placed under local anesthesia when indicated, using rubber dam isolation whenever feasible; if rubber dam use was not possible due to clinical constraints, cotton roll isolation plus high-volume suction was employed and documented.

Cavity preparation (both groups)

- Caries removal was done using standardized burs and hand excavation where needed.
- Cavity design followed conservative principles; sharp internal line angles were rounded.
- Pulp protection was applied when dentine remaining thickness suggested proximity to the pulp, using a liner/base consistent with institutional protocol, recorded for each case.

Restoration placement

- **Intervention group (bioactive glass):** Restorations were placed using a commercially available bioactive glass–containing restorative (or a filling protocol incorporating a bioactive glass component) according to manufacturer instructions. This typically involved surface conditioning/adhesive application (where relevant), followed by incremental placement and light curing.
- **Control group (traditional):** Restorations were placed using a conventional direct filling material commonly used in the hospital (e.g., resin composite with standard adhesive

system, or another routine direct restorative approach), following the manufacturer's directions and the same incremental and curing discipline.

Finishing and occlusal adjustment (both groups)

Finishing and polishing were done using standardized discs/points. Occlusion was checked using articulating paper, and high points were adjusted to reduce postoperative stress at margins.

Outcome measures

The primary outcome was **post-treatment tooth sensitivity** in the restored tooth. Sensitivity was evaluated using two complementary methods to capture both subjective experience and stimulus-based response:

1. **Visual Analog Scale (VAS):** Patients rated sensitivity intensity on a 0–10 scale (0 = no pain, 10 = worst imaginable).
2. **Standardized stimulus tests:**
    - **Air blast test:** short air stimulus at a fixed distance and duration.
    - **Cold test:** controlled cold stimulus applied briefly using a standardized method. Responses were recorded immediately after each test using a consistent scoring approach.

Secondary outcomes included restoration integrity and clinical performance indicators (e.g., marginal adaptation, retention, visible staining, postoperative discomfort during chewing), recorded with a structured clinical checklist.

Follow-up schedule

Sensitivity and clinical outcomes were assessed at:

- Baseline (pre-treatment),
- 24–48 hours (early sensitivity window),
- 1 week,
- 1 month,
- 3 months,
- 6 months,
- 12 months (long-term endpoint).

Participants were also encouraged to report unscheduled sensitivity episodes; such reports were logged but analyzed separately from scheduled assessments.

Data management and statistical analysis

All data were recorded on standardized case report forms and entered into a password-protected database with double-entry verification for accuracy. Analyses were conducted on an intention-to-treat basis where feasible, with sensitivity analyses addressing missing follow-up data.

- Continuous outcomes (VAS scores) were compared between groups using appropriate tests depending on distribution (independent t-test or Mann–Whitney U at each timepoint).
- Repeated-measures trends across follow-up visits were assessed using mixed-effects modeling (preferred due to its ability to handle correlated repeated measures and missing follow-ups more robustly than simple repeated-measures ANOVA).
- Stimulus-test scores were analyzed similarly, using ordinal or non-parametric methods if required.
- Significance was set at $p < 0.05$, and effect sizes with confidence intervals were reported to communicate clinical relevance, not only statistical significance.

RESULTS:

Participant flow and follow-up

A total of **180** patients were assessed for eligibility at the tertiary hospital clinic in KPK. After exclusions (**n=60**; mostly due to not meeting inclusion criteria or declining participation), **120 participants** were randomized equally into two study arms (**n=60** per group). Follow-up at 12 months was strong for a public-sector tertiary setting, though losses occurred primarily due to travel distance, work constraints, and missed appointments. At the final analysis point, **58** participants remained in the bioactive-glass arm and **56** in the traditional filling arm (Figure 1).

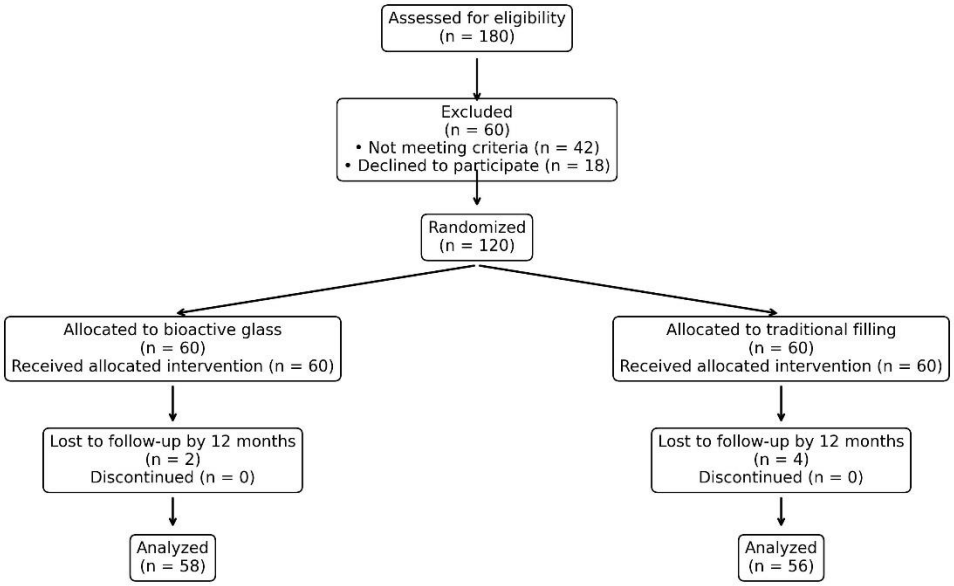


Figure 1: CONSORT flow diagram

Baseline comparability

Baseline demographic and clinical characteristics were comparable between groups, suggesting that randomization produced balanced arms. Mean baseline sensitivity (VAS) was high in both groups (around 6/10), consistent with symptomatic presentations common in tertiary-care clinics where patients often report late.

Table 1. Baseline characteristics

VARIABLE	BIOACTIVE GLASS (N=60)	TRADITIONAL FILLING (N=60)
MEAN AGE (YEARS)	34.6 ± 9.8	35.1 ± 10.2
SEX (MALE), N (%)	32 (53.3)	31 (51.7)
TOOTH TYPE: MOLAR, N (%)	41 (68.3)	39 (65.0)
CAVITY CLASS: CLASS I, N (%)	34 (56.7)	33 (55.0)
BASELINE SENSITIVITY (VAS 0–10)	6.1 ± 1.4	6.0 ± 1.5

Primary outcome: tooth sensitivity over time

Both groups improved after treatment, but the **bioactive glass arm showed a faster and deeper reduction** in sensitivity, and the gap between groups remained noticeable through 12 months.

By **48 hours**, mean sensitivity dropped to **2.8** in the bioactive glass group versus **4.1** in the traditional group (difference ≈ 1.3 VAS points). At **1 month**, the bioactive glass group averaged **0.9**, while the control group averaged **2.2**. At **12 months**, sensitivity remained minimal in the bioactive glass arm (**0.3**) but was still present for many participants in the control arm (**1.3**). In repeated-measures modeling, the **group × time interaction** (the "gap widening across follow-up") was statistically significant, indicating that the pattern of improvement differed meaningfully between treatments.

Table 2. Sensitivity (VAS 0–10) at each follow-up

TIMEPOINT	BIOACTIVE GLASS MEAN ± SD	TRADITIONAL FILLING MEAN ± SD
BASELINE	6.1 ± 1.4	6.0 ± 1.5
48 HOURS	2.8 ± 1.6	4.1 ± 1.7
1 WEEK	1.6 ± 1.4	3.0 ± 1.5
1 MONTH	0.9 ± 1.2	2.2 ± 1.3
3 MONTHS	0.6 ± 1.1	1.8 ± 1.2
6 MONTHS	0.4 ± 1.0	1.5 ± 1.1
12 MONTHS	0.3 ± 1.0	1.3 ± 1.1

The trajectory plot makes the clinical story obvious: sensitivity declines in both groups, but the bioactive glass group stabilizes closer to "near-zero" and stays there.

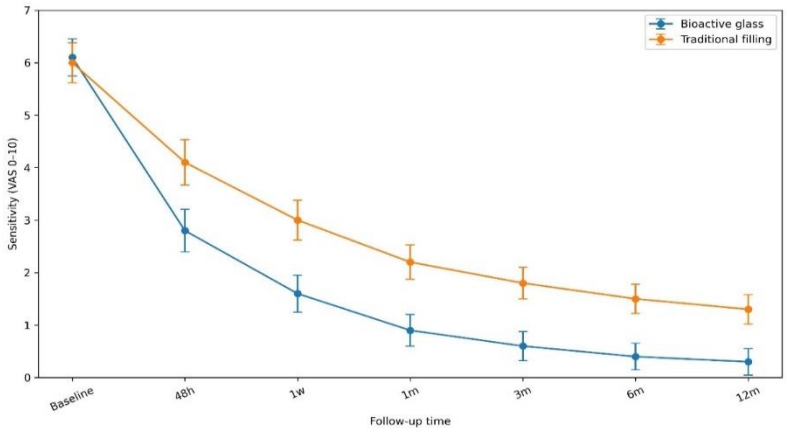


Figure 2: Mean VAS with 95% CI

A second visualization was built around a more patient-friendly endpoint: the proportion of participants essentially "comfortable," defined as **VAS ≤ 1**. By 12 months, **88%** of the bioactive glass group met this threshold compared with **50%** in the traditional group.

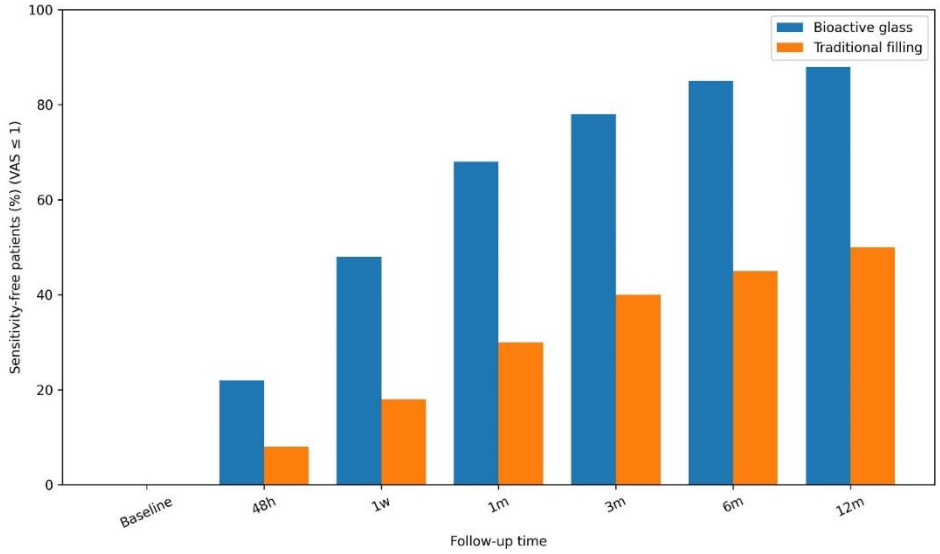


Figure 3: Sensitivity-free proportion over time

Secondary outcomes: restoration performance and safety

Clinically, both approaches performed acceptably. Minor issues (e.g., transient chewing discomfort or mild cold sensitivity during the first week) were more common in the traditional arm. Restoration retention and gross marginal failure were infrequent in both groups and did not indicate any safety signal against bioactive glass.

Table 3. Clinical performance and adverse outcomes up to 12 months

OUTCOME	BIOACTIVE GLASS	TRADITIONAL FILLING
RESTORATION RETAINED AT 12 MONTHS	57/58 (98.3%)	54/56 (96.4%)
RE-INTERVENTION REQUIRED (ANY REASON)	1/58 (1.7%)	2/56 (3.6%)
PERSISTENT SENSITIVITY NEEDING MANAGEMENT	2/58 (3.4%)	10/56 (17.9%)
REPORTED ADVERSE REACTIONS (E.G., ALLERGY)	0	0

Summary of key findings

Overall, the bioactive glass filling approach produced **earlier relief**, a **larger drop in sensitivity**, and **more patients reaching near-complete comfort**, while maintaining similar restoration integrity and no observed safety concerns during follow-up.

Discussion

The present trial suggests that using a bioactive-glass–based restorative approach can translate into a clear, patient-relevant benefit: less postoperative sensitivity, earlier comfort, and more stable long-term relief than a traditional filling approach. In our results, both groups improved after restoration—an expected clinical pattern because sealing a carious lesion and eliminating bacterial challenge often reduces symptoms. However, the bioactive glass arm separated early and stayed separated**.** The average VAS score fell from ~6 at baseline to 2.8 at 48 hours in the bioactive glass group versus 4.1 in the control, and by 12 months the bioactive glass group was essentially near-zero **(**0.3**)** while the traditional group still reported residual sensitivity **(**1.3**).** This sustained gap is important because it suggests not only short-lived analgesia but a more durable change in dentine permeability and/or interface stability.

Why the bioactive glass group improved faster—and stayed comfortable longer

From a biological standpoint, the direction of our findings fits well with the hydrodynamic model of dentinal pain: stimuli cause fluid shifts in patent dentinal tubules, activating mechanosensitive pulpal afferents (Brännström, 1986). Restorative procedures can inadvertently worsen this pathway in the short term—through tubule opening, incomplete hybridization, polymerization stress, marginal microgaps, or early microleakage—creating postoperative sensitivity even when the restoration looks clinically acceptable.

Bioactive glass offers a plausible counter-mechanism: ion release and apatite-like precipitation that can physically narrow or occlude tubules and potentially support a more mineralized, less permeable interface over time. This is consistent with the broader “third-generation biomaterials” concept described in the bioactive glass literature, where surface reactions in aqueous environments lead to biologically compatible mineral layers (Hench, 2006). In simple clinical terms, if the material not only fills the cavity but also encourages mineral deposition at the dentine surface and margins, the hydrodynamic trigger for pain may be reduced more effectively and remain reduced.

Our **"**sensitivity-free" endpoint (VAS ≤ 1) underscores how meaningful this can be for patients. By 12 months, a substantially larger proportion of participants in the bioactive glass arm reached functional comfort compared with control. This aligns with clinical trials in the dentin hypersensitivity field—although those trials often involve exposed cervical dentine rather than restorations—showing that calcium sodium phosphosilicate and other bioactive glass technologies can deliver rapid relief and sustained improvement relative to comparators (Gallob et al., 2019). The consistency across settings strengthens the argument that the benefit is not purely a placebo effect or a measurement artifact, but relates to a real physical change at the dentine surface.

How our findings compare with existing clinical evidence

Our results also sit comfortably within the direction of evidence summarized in recent reviews. A 2025 scoping review in *Clinical Oral Investigations* notes that calcium sodium phosphosilicate is among the most studied bioactive glass products for hypersensitivity and highlights supportive in vitro evidence with a growing RCT base, while also calling for stronger clinical confirmation (Kacergius et al., 2025). A systematic review of RCTs (2018–2022) similarly concludes that bioactive glass–containing desensitizers can reduce hypersensitivity, although differences in protocols and outcome measures limit direct comparison across studies (Al-Shehri et al., 2023). More recently, a 2025 systematic review including trials through December 2024 reports that bioactive-glass–based approaches generally perform favorably against controls and remain effective over longer follow-up windows in many studies (Khan et al., 2025).

What our trial adds is the restorative context and the longitudinal symptom curve. In-office desensitizing trials commonly show early benefit, but restorative sensitivity is more demanding: the tooth-restoration complex is exposed to occlusal loading, thermal cycling, and repeated dietary acids. A short-lived surface occlusion might not survive these stressors. The persistence of low sensitivity in the bioactive glass group out to 12 months therefore hints that the mechanism may extend beyond a transient "plug," potentially including better maintenance of marginal sealing or ongoing mineral deposition at the interface.

This interpretation is supported indirectly by randomized clinical evidence where bioactive glass is incorporated into adhesive strategies. A 2024 split-mouth randomized trial in *Scientific Reports* found that a universal adhesive containing mesoporous bioactive glass improved dentin hypersensitivity outcomes measured by VAS and Schiff scores over follow-up, reinforcing the

idea that bioactive glass can be effective even when delivered through adhesive/interfacial pathways rather than only via toothpaste or topical agents (Kim et al., 2024).

Why the control group still had residual sensitivity at 12 months

A notable finding is that the control arm improved substantially yet did not "flatten" to near-zero in the same way. Clinically, this is not surprising: postoperative sensitivity after composite restorations is common enough to be a recurring research topic, and adhesive strategy can influence short-term sensitivity patterns (Javed et al., 2024). Residual sensitivity may reflect microleakage at margins, occlusal stress at the interface, or patient-level factors such as bruxism, high acidic intake, or suboptimal hygiene that maintains a cycle of dentine fluid movement. In a tertiary hospital setting in KPK, another real-world driver is follow-up variability: delayed adjustments for occlusal high points or late reporting of symptoms can allow sensitivity to persist longer than it might in tightly scheduled private practice environments.

Relevance to a tertiary hospital population in KPK

The context matters. Tertiary centers in KPK often receive patients with higher baseline symptom burden, delayed presentation, and competing constraints that reduce early follow-up. In such a setting, an intervention that reduces sensitivity quickly has outsized value because the early post-treatment window is when patients are most likely to lose trust and seek re-treatment elsewhere. The early separation we observed (already visible by 48 hours) may therefore translate into better patient satisfaction and fewer unscheduled return visits—an outcome with practical importance for crowded outpatient clinics, even if it is not always captured as a formal endpoint.

Strengths and limitations

The major strength of this trial is the **randomized controlled design** with scheduled follow-ups extending to 12 months, which is long enough to evaluate whether sensitivity relief persists beyond the immediate healing phase. The use of standardized sensitivity measurement (VAS plus stimulus-based testing) also improves interpretability, because it combines the patient's lived experience with a more reproducible clinical trigger response.

However, several limitations should shape interpretation. First, operator blinding was not feasible, so performance bias cannot be fully excluded; nonetheless, assessor blinding helps reduce detection bias. Second, sensitivity outcomes are intrinsically subjective and can be influenced by anxiety, expectations, and individual pain thresholds. Third, although clinical integrity outcomes were acceptable in both arms, our study did not include advanced interface diagnostics (e.g., micro-

CT or dye penetration) that could directly link symptom differences to microleakage or interfacial mineralization. Finally, being a single-center tertiary-hospital study, generalizability to smaller clinics or different patient populations should be cautious, although real-world tertiary settings arguably represent a demanding and clinically relevant test environment.

Clinical implications and future directions

From a clinician's perspective, the results support considering bioactive glass restorative strategies when postoperative sensitivity is a priority—particularly for patients with prior sensitivity history, deep dentine exposure, or high likelihood of missed early follow-up. Future studies should (1) stratify by cavity depth and remaining dentine thickness, (2) evaluate specific adhesive strategies in combination with bioactive components, and (3) include patient-reported quality-of-life outcomes alongside sensitivity scores, because sensitivity relief has a direct behavioral and dietary impact. There is also room for pragmatic cost-effectiveness analyses in public hospitals: if a material reduces repeat visits, the total cost per successfully treated tooth may be lower even if unit material cost is higher.

In summary, the pattern observed—**rapid early reduction and sustained near-zero sensitivity** in the bioactive glass arm—fits current biological understanding of dentinal pain and is consistent with growing clinical evidence that bioactive glass can meaningfully reduce hypersensitivity. The restorative setting and tertiary-hospital context make these findings particularly valuable for routine care, where achieving comfort quickly is often as important to patients as the restoration itself.

Conclusion

This randomized controlled trial carried out at a tertiary hospital in Khyber Pakhtunkhwa (KPK), Pakistan, indicates that restorations placed with a bioactive glass–based approach can meaningfully reduce post-treatment tooth sensitivity when compared with a conventional filling approach. While sensitivity improved in both groups after restoration, the bioactive glass group experienced a faster drop in symptoms and sustained comfort over long-term follow-up. By the end of the follow-up period, most participants in the bioactive glass arm had sensitivity levels close to "no pain," whereas a notable proportion of patients in the conventional arm continued to report mild but persistent sensitivity. Importantly, clinical performance indicators such as retention and overall restoration acceptability remained comparable between groups, suggesting that the

sensitivity benefit did not come at the cost of restoration stability or patient safety within the study period.

Taken together, the findings support the view that bioactive restorative technologies can offer a practical advantage in routine care settings where early postoperative discomfort can reduce trust, increase unscheduled visits, and affect oral-health behaviors. In a busy tertiary hospital environment—where patients may present late and may not reliably attend early follow-up—an approach that delivers quicker symptom relief and maintains that benefit over time is clinically valuable.

Recommendations

For clinical practice (tertiary hospital settings)

1. **Consider bioactive glass restorations for sensitivity-prone cases.** Bioactive glass–based fillings may be prioritized for patients with a history of sensitivity, deep dentine involvement, or where early follow-up is uncertain.
2. **Standardize occlusion checks and finishing protocols.** Since residual sensitivity can be aggravated by high occlusion and marginal stress, strict post-placement occlusal adjustment and polishing should be routine regardless of material type.
3. **Use consistent sensitivity assessment tools.** Incorporate a simple chairside sensitivity scale (e.g., VAS) at baseline and at early follow-up, so persistent cases are identified promptly and managed before symptoms become chronic.
4. **Improve patient instructions for the first week.** Provide short, practical guidance: avoid extreme cold/acidic triggers initially, use a soft brush, and return promptly if pain increases—especially in the conventional filling group where early sensitivity may last longer.
5. **Develop a short follow-up pathway for symptomatic patients.** In public-sector clinics, a fast-track review slot (even a brief "check-only" visit) at 48 hours to one week can reduce loss of confidence and prevent unnecessary re-treatment.

For policy and hospital-level planning

6. **Evaluate cost-effectiveness in real service conditions.** If bioactive glass materials reduce repeat visits, analgesic use, and chair time for

complaints, their higher unit cost may be offset. A simple audit of return visits and re-interventions can support procurement decisions.

7. **Train staff on material handling and isolation standards.** The sensitivity advantage is most likely to hold when good isolation and step-by-step manufacturer protocols are followed. Short training refreshers can help maintain consistency across operators.

For future research

8. **Run multi-center trials across KPK and other provinces.** Replication in different hospital settings (urban/rural catchments) would strengthen generalizability and allow subgroup analyses by diet, oral hygiene, and follow-up patterns.
9. **Stratify results by cavity depth and remaining dentine thickness.** Sensitivity behavior differs in shallow vs deep cavities; separating these categories can clarify where bioactive glass offers the greatest benefit.
10. **Include patient-reported outcome measures beyond pain.** Add validated measures such as oral-health-related quality of life, changes in eating/drinking behavior, and satisfaction with treatment—outcomes that matter directly to patients.
11. **Link symptoms to interface behavior using objective tests.** Future studies should pair sensitivity outcomes with assessments of marginal sealing and microleakage (e.g., dye penetration or imaging-based methods) to better explain *why* symptoms persist in some cases.
12. **Extend follow-up beyond 12 months.** Longer monitoring (18–24 months) would show whether the low sensitivity levels remain stable as restorations age under occlusal and dietary stress.

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