ECRONICON OPEN ACCESS

EC DENTAL SCIENCE
Research Article

Clinical Efficacy of Nanocoatings and Surface Modification for Mitigating Post-Restorative Hypersensitivity

Salah A Yousief[1]*, Basil Badi Alshammari[2], Abdullah Mohammed S Aljasser[2], Bander Saleh A Albaqi[2], Maram Turki Abbas[2], Wafa Abdulaziz Alhazmi[2] and Osamah Ahmad Katib[2]

[1]Department of Restorative and Prosthetic Dental Sciences, College of Dentistry, Dar Al Uloom University, Riyadh, Saudi Arabia and Department of Crown and Bridge, Faculty of Oral and Dental Medicine, Al Azhar University, Assiut Branch, Egypt
[2]General Dentist, KSA

***Corresponding Author:** Salah A Yousief, Department of Restorative and Prosthetic Dental Sciences, College of Dentistry, Dar Al Uloom University, Riyadh, Saudi Arabia and Department of Crown and Bridge, Faculty of Oral and Dental Medicine, Al Azhar University, Assiut Branch, Egypt.

Received: November 28, 2025; **Published:** December 12, 2025

Abstract

Background: Post-operative or post-restorative dentin hypersensitivity is a common complication following dental restorations, often attributed to open dentinal tubules and microleakage after bonding procedures. Various preventive strategies-ranging from novel nanoparticle-based dentin coatings to laser desensitization-have been proposed, but a definitive gold-standard protocol remains elusive. This systematic review evaluates the efficacy of nanoparticle tubule-occlusive coatings, compares laser-based versus chemical desensitization approaches, and examines the impact of these surface modifications on resin-dentin bond strength.

Methods: Following PRISMA guidelines, an extensive literature search was performed in PubMed, Scopus, Web of Science, and Cochrane Library (up to November 2025) for clinical trials, *in vitro* studies, and reviews related to dentin hypersensitivity after restorations. Key search terms included dentin hypersensitivity, nanoparticles (silver, zinc oxide, hydroxyapatite), laser desensitization (Er:YAG, Nd:YAG, diode), glutaraldehyde, oxalate desensitizer, and bond strength. Studies were screened and selected for inclusion based on relevance to the three predefined research questions. Data on tubule occlusion efficacy, clinical sensitivity outcomes, and bond strength metrics were extracted. A qualitative synthesis was undertaken due to heterogeneity of interventions.

Results: A total of 30 studies (including *in vitro* investigations, randomized clinical trials, and systematic reviews) met the inclusion criteria (Figure 1). Nanoparticle-based coatings (silver, ZnO, calcium phosphate/hydroxyapatite) demonstrated effective dentinal tubule occlusion and significant reductions in hypersensitivity in many reports. Nano-hydroxyapatite additives, in particular, showed superior clinical performance versus conventional fluoride treatments in reducing hypersensitivity. A novel titania nanoparticle-reinforced bonding agent significantly decreased immediate post-restorative sensitivity compared to a standard adhesive ($p < 0.01$). Comparisons of laser desensitization (e.g., low-level diode, Nd:YAG, Er:YAG) with chemical desensitizers (glutaraldehyde/HEMA, oxalate-based agents) revealed that both modalities achieve significant symptom relief. Several trials reported no significant difference between laser and chemical treatments in short- and long-term outcomes. In contrast, others noted enhanced or more sustained relief when combining lasers with chemical agents. Regarding bond strength, glutaraldehyde-based desensitizers were found to preserve or even improve resin-dentin bond durability by collagen cross-linking and MMP inhibition. Oxalate desensitizers, though reducing immediate bond strength by depositing insoluble crystals, mitigated long-term bond degradation. Properly applied laser treatment did not adversely affect bonding; Nd:YAG laser pre-treatment of hypersensitive dentin actually increased microtensile bond strength of a resin adhesive.

Conclusion: Nanoparticle dentin coatings (especially calcium/phosphate-based and metal-oxide nanoparticles) show promising efficacy in occluding tubules and reducing post-restorative sensitivity without deleterious effects on bonding. Laser desensitization methods provide comparable clinical outcomes to gold-standard chemical agents, with potential synergistic benefits when used in combination. Most desensitizing surface modifications can be integrated into the restorative workflow without compromising resin bond strength; in some cases, they confer protective effects on the bond. Owing to variations in study protocols and short follow-up durations, further well-controlled clinical trials are needed to establish optimized, long-lasting strategies for managing post-restorative hypersensitivity.

Keywords: *Post-Restorative Dentin Hypersensitivity; Nanoparticle-Based Coatings; Laser Desensitization; Chemical Desensitizers*

Introduction

Post-restorative dentin hypersensitivity is characterized by sharp pain in a tooth after a restorative procedure (such as placement of a composite filling), typically triggered by thermal, tactile, or osmotic stimuli [1,2]. Unlike pre-existing dentin hypersensitivity on exposed root surfaces, post-operative sensitivity arises in a restored tooth due to factors like polymerization shrinkage gaps, microleakage, cusp flexure under load, or residual dentinal tubule exposure after tooth preparation [3]. Clinically, patients may report discomfort when biting or sensitivity to cold in the weeks following a restoration [4]. The incidence of postoperative hypersensitivity with resin composites has been reported in the range of 10 - 30% of restorations [5], underscoring a need for preventive measures to improve patient comfort and restoration success.

Brännström's hydrodynamic theory classically explains the etiology of dentin hypersensitivity [6]. Stimuli such as cold or air cause rapid fluid movement within open dentinal tubules, deforming odontoblastic processes and triggering nociceptors in the pulp, resulting in pain. Therefore, most desensitization strategies aim to either occlude the dentinal tubules or dampen neural response. In the context of restorative dentistry, additional considerations include preventing bacterial ingress at the tooth-restoration interface and maintaining the integrity of the resin-dentin bond. An ideal approach would reliably reduce hypersensitivity without compromising the bond strength or sealing ability of the restoration.

Nanotechnology in desensitization: Recent advancements leverage nanoparticle coatings to block dentinal tubules or enhance the properties of adhesives physically. Nano-sized particles (e.g. silver, zinc oxide, calcium phosphate compounds) can penetrate deep into tubules and form occlusive plugs or remineralized mineral deposits [7,8]. These nanocoatings often also impart antibacterial effects, potentially reducing pulpal irritation from bacterial toxins [9]. However, it is critical to assess how effectively such nano-modified surfaces reduce hypersensitivity *in vivo*, and whether they impact the resin bonding process.

Laser desensitization vs chemical agents: High-energy lasers (such as Nd:YAG, Er:YAG, or Er,Cr:YSGG) can seal tubules via melting or protein coagulation, while low-level lasers (diode or He-Ne) may modulate nerve transmission or promote secondary dentin formation [10]. Lasers are an attractive chairside option but require specialized equipment and training. Traditional chemical desensitizers, on the other hand, are simple and inexpensive. Glutaraldehyde-based agents (e.g. 5% glutaraldehyde with 35% HEMA, known by the brand Gluma) precipitate proteins within tubules, rapidly reducing permeability [11]. Oxalate compounds (e.g. potassium oxalate) create insoluble calcium oxalate crystals that occlude tubules [12]. Both approaches have shown success, but their comparative efficacy and the longevity of hypersensitivity relief, especially under the conditions of a newly placed restoration, warrant systematic evaluation.

Bond strength considerations: Any dentin pre-treatment before bonding (whether a desensitizing chemical, a nanoparticle slurry, or laser irradiation) can potentially alter the substrate and affect the resin, dentin adhesive interface [13]. A trade-off may exist between aggressively occluding tubules (which might inhibit resin tag formation) and achieving a high bond strength. Notably, glutaraldehyde/HEMA primers have been reported to increase bond strength by cross-linking collagen and inhibiting endogenous collagenase enzymes (MMPs), whereas oxalates can decrease initial bond strength if crystals form a barrier [14]. Laser pre-treatment of dentin has had mixed reports, some studies indicate reduced bond strength due to hyper-mineralized surfaces, while others suggest lasers can create a micro-roughened, clean surface conducive to bonding [15]. Evaluating the net effect of desensitizing protocols on bond integrity is crucial for clinical adoption.

Given these considerations, the purpose of this review is to systematically investigate: (1) the effectiveness of novel nanoparticle coatings (silver, zinc oxide, calcium phosphate-based, etc.) in occluding dentinal tubules and reducing post-restorative hypersensitivity; (2) the comparative clinical outcomes and durability of hypersensitivity relief using laser-based desensitization versus traditional chemical desensitizers applied immediately before bonding; and (3) the impact of these surface modifications on resin-dentin bond strength and restoration longevity. By synthesizing current evidence from *in vitro* experiments, clinical trials, and meta-analyses, we aim to inform best practices for managing postoperative sensitivity while preserving adhesive success.

Methodology

Protocol and search strategy

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The focused questions were defined based on the PICO framework: for patients with dentin exposed during restorative procedures (P), do nanoparticle dentin coatings or laser desensitization methods (I) compared to no desensitization or conventional chemical agents (C), result in reduced post-operative hypersensitivity, and what is their effect on bond strength and long-term outcomes (O)? A review protocol outlining the objectives and inclusion criteria was established a priori.

A comprehensive electronic search was performed in October 2025 and updated through November 14, 2025, using the databases PubMed-MEDLINE, Scopus, Web of Science, and Cochrane Central Register of Controlled Trials (CENTRAL). The search combined keywords and MeSH terms related to dentin hypersensitivity and the interventions of interest. Keywords included variations of: "postoperative hypersensitivity", "dentin sensitivity", "nanoparticle", "nanotechnology", "silver nanoparticle", "zinc oxide", "nano-hydroxyapatite", "laser desensitization", "Er: YAG", "Nd: YAG", "diode laser", "glutaraldehyde desensitizer", "oxalate", and "bond strength." No date or language restrictions were applied initially; non-English articles were translated when necessary. Additionally, reference lists of relevant articles and previous reviews were hand-searched for any studies that the electronic search might have missed.

Study selection

Two reviewers independently screened the titles and abstracts yielded by the search to identify potentially eligible studies. Full-text articles were obtained for all references that appeared to meet the inclusion criteria or where eligibility was uncertain. The inclusion criteria were:

- **Population:** Teeth (human or extracted) prepared for direct restorations (e.g. composite fillings) or with existing restorations, where dentin hypersensitivity or post-op sensitivity was evaluated.
- **Interventions:** Any nanoparticle-based surface treatment (applied to dentin or incorporated in adhesive/restorative materials) intended to reduce hypersensitivity; and/or laser irradiation of dentin for desensitization.
- **Comparators:** Placebo or no treatment, or conventional chemical desensitizing agents (such as glutaraldehyde/HEMA primers, oxalate compounds, fluoride varnishes) applied before or immediately after restoration.
- **Outcomes:** Measures of dentin hypersensitivity (such as pain scores to thermal, air, or tactile stimuli) at specified follow-up times; and/or resin-dentin bond strength measures (shear, tensile, or microtensile bond strength), as well as any relevant secondary outcomes (e.g., SEM analysis of tubule occlusion, degree of microleakage, etc.).
- **Study types:** Randomized or quasi-randomized controlled trials, controlled clinical trials, and laboratory (*in vitro*) studies with appropriate controls. Additionally, systematic reviews and meta-analyses were considered for background and data triangulation. Case reports and small case series were excluded due to the high risk of bias.

Two reviewers then independently assessed the full texts for inclusion, with any disagreements resolved through discussion or consultation with a third reviewer. Exclusion criteria included: studies focusing on hypersensitivity unrelated to restorations (e.g. non-carious cervical lesion trials without restorations), studies without a control or comparison group, and those lacking quantitative outcomes for sensitivity or bond strength. Figure 1 presents the study selection flow diagram.

Data extraction and quality assessment

Data from the included studies were extracted into structured tables. For each study, relevant details were recorded: author/year, study design, sample characteristics (e.g. number of teeth or patients), the intervention and control details (type of nanoparticle or laser, type of chemical desensitizer, application protocol), outcome measures and results (sensitivity scores, % reduction, bond strength values, etc.), and key conclusions. Where provided, results of statistical comparisons (p-values, confidence intervals) were noted.

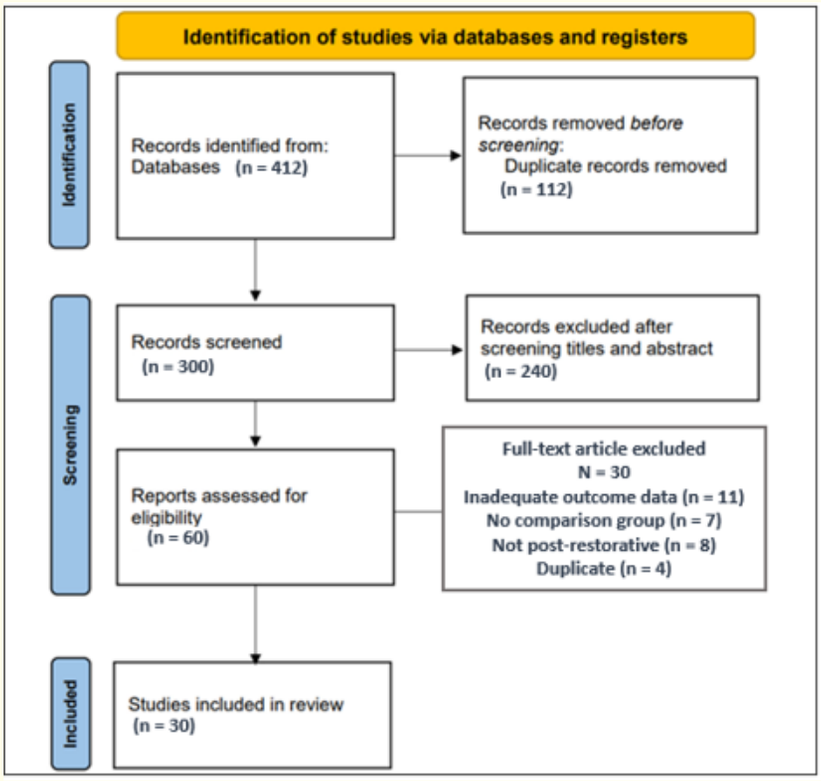

Figure 1: *PRISMA 2020 flow diagram summarizing the literature search and study selection process. A total of 412 records were identified; after removing duplicates and screening for relevance, 60 full-text articles were evaluated. Finally, 30 studies meeting included in the qualitative synthesis.*

Risk of bias was assessed for clinical trials using the Cochrane Risk of Bias tool (RoB 2) for RCTs, evaluating domains such as randomization, blinding, and outcome reporting. *In vitro* studies were appraised with a checklist focusing on sample preparation, randomization of specimens, and completeness of outcome reporting. We did not exclude studies based on quality, but the risk of bias was considered in the data synthesis (e.g. by giving more weight to high-quality RCT evidence). Given heterogeneity in interventions and outcome measures, a meta-analysis was not performed; instead, a descriptive and tabular synthesis is presented.

Results

Overview of included studies

Out of 60 full-text articles assessed, 30 studies fulfilled the inclusion criteria (Figure 1). These comprised 15 randomized controlled trials (11 involving clinical hypersensitivity outcomes, 4 focusing primarily on bond strength or *in vivo* tubule occlusion), 8 laboratory studies (scanning electron microscopy and bond strength evaluations), 4 systematic reviews/meta-analyses, and 3 prospective controlled trials. Key characteristics and findings are summarized in tables and narrative form below, organized by the main topics of interest.

Nanoparticle coatings for tubule occlusion and hypersensitivity relief

Multiple studies have explored nanoparticles as dentin surface treatments or as additives to dental materials to mitigate hypersensitivity. Table 1 provides a synopsis of common nanoparticle approaches and their reported efficacy.

Silver nanoparticles (AgNP): Silver is well-known for its antimicrobial properties. In dentistry, silver-containing compounds (e.g. silver diamine fluoride) have been used to arrest caries and reduce sensitivity by depositing silver and calcium fluoride precipitates in tubules. Recent research has turned to nano-sized silver particles for potentially improved penetration and reduced cytotoxicity. A

clinical trial by Aly., *et al*. (2024) tested a 5% AgNP-loaded fluoride varnish applied to deep carious lesions after partial caries removal, comparing it to conventional silver diamine fluoride (SDF) and a control [1]. Postoperative sensitivity was monitored for up to 6 months. The results indicated no statistically significant difference in hypersensitivity levels between the nano-silver varnish group, the SDF group, and controls at 1 week, 3 months, or 6 months [1]. This suggests that while AgNP can be effectively incorporated into a varnish, its clinical benefit for post-restoration sensitivity may be comparable to existing treatments (and SDF itself is highly effective in occluding tubules). Nonetheless, the AgNP varnish achieved similar desensitization without the dark staining associated with SDF, which could be a practical advantage. Other studies have shown that combining silver nanoparticles with laser irradiation can drive particles deeper into tubules: for example, one *in vitro* study found that AgNPs could penetrate and seal tubules when activated by a thermomechanical ablative laser [16]. In summary, silver nanoparticles offer antimicrobial protection and tubule sealing, but current evidence suggests their hypersensitivity relief is on par with traditional silver-based agents.

Zinc oxide nanoparticles (ZnO NP): Zinc oxide is another metal-oxide nanoparticle of interest. ZnO is biocompatible and exhibits antimicrobial and anti-inflammatory properties. Importantly, nano-scaled ZnO can act as a filler or coating that physically occludes tubules. A recent *in vitro* investigation by Hassaan., *et al*. (2025) directly compared nano-hydroxyapatite vs. nano-zinc oxide in their ability to seal dentin tubules [16]. In that study, etched dentin discs were treated with either a CMC (carboxymethylcellulose) hydrogel containing hydroxyapatite nanoparticles (HA NPs) or one containing ZnO NPs, and then analyzed by SEM. ZnO nanoparticles achieved the most extensive dentinal tubule occlusion, outperforming hydroxyapatite, with the ZnO-treated samples showing nearly complete occlusion of tubule orifices on SEM images [17]. Surface profilometry indicated that both HA and ZnO coatings smoothed the dentin surface (reducing roughness compared to etched control), with ZnO producing the lowest roughness values (mean Ra ~1.20 µm vs 1.52 µm in control). The difference between groups was statistically significant ($p \leq 0.05$). The authors concluded that ZnO NPs have a positive impact on dentin tubule occlusion and anticipated this would translate to effective hypersensitivity relief [17]. While clinical trials of ZnO NP dentin treatments are still needed, these findings suggest ZnO's potential as a powerful desensitizing nanocoating.

Calcium phosphate and hydroxyapatite nanoparticles: Hydroxyapatite (HA), the mineral form of tooth structure, has been widely studied as a biomimetic desensitizer [18]. Nano-hydroxyapatite particles can integrate into the dentin surface, literally "re-mineralizing" open tubules with calcium/phosphate deposits that resemble natural apatite [18]. They can be delivered via toothpastes, varnishes, or bonding agents. According to a 2023 systematic review and meta-analysis by Limeback and co-workers, biomimetic nano-hydroxyapatite is highly effective for dentin hypersensitivity control [19]. In an analysis of 44 clinical trials, toothpastes or oral care products containing hydroxyapatite achieved significantly greater hypersensitivity reduction than placebo or even standard fluoride agents. Specifically, the meta-analysis showed HAP-containing products reduced sensitivity by ~39.5% more than placebo and by ~23% more than conventional fluoride treatments [3]. Notably, HAP performed on par with or slightly better than other active desensitizers (though the difference vs other desensitizers was not statistically significant) [19] These results align with several RCTs where nano-HA pastes improved tactile and airblast sensitivity scores over 4-12 week periods. The mode of action is through deposition of apatite-like crystals deep into the tubules, rebuilding a mineral barrier. Other calcium-phosphate approaches include amorphous calcium phosphate (ACP) and bioactive glass (which forms hydroxycarbonate apatite). These also aim to plug tubules with calcium/phosphate precipitates. The literature supports their efficacy: for example, an oxalic acid potassium salt combined with calcium phosphate has shown good results at 6 months in a cervical sensitivity RCT [20]. In the context of restorations, some adhesive systems incorporate remineralizing fillers. Overall, calcium phosphate-based nanocoatings offer a biologically inspired solution that not only occludes tubules but may also help strengthen the dentin against acid challenge.

Other nanoparticles (Titania, bioactive nanoglass, etc.): Titanium dioxide (TiO_2) is a nanoparticle gaining traction for use in bonding agents due to its high refractive index, biocompatibility, and antimicrobial effects [21]. A clinical trial in 2024 and 2025 tested a novel titania nanoparticle-reinforced adhesive for composite restorations [22,23]. The inclusion of TiO_2 nanoparticles (in 0.02-0.03 µm size) in the bonding resin significantly reduced patients' post-operative sensitivity scores at 24 hours and 1 week compared to the conventional adhesive (VAS scores were lower by a significant margin, $p < 0.005$). By one month, sensitivity in both groups subsided with no statistical difference, but the early post-op period is clinically critical, and the NP-infused adhesive clearly provided superior comfort in that phase. The mechanism is not fully elucidated, but it's postulated that titania NPs reinforce the hybrid layer and buffer

the polymerization shrinkage stresses, possibly reducing microleakage or fluid movement that triggers sensitivity. Additionally, TiO_2 has photocatalytic antibacterial properties, which might reduce pulpal irritation from bacteria. Other emerging nanomaterials include nanocarbonate apatite, bioactive glass nanoparticles [24,25], and even experimental bioactive nanopolymers doped with agents like doxycycline or zinc [26]. Each aims to improve tubule sealing or dentin healing at the nanoscale. While promising, these are mostly in developmental or trial stages.

Table 1 summarizes key nanoparticle modalities.

Nanoparticle Coating	Mechanism/Properties	Evidence of Efficacy (Examples)
Silver nanoparticles (AgNP)	Antibacterial; can precipitate proteins and occlude tubules (often combined with fluoride).	RCT with AgNP-infused fluoride varnish vs SDF showed comparable post-op sensitivity outcomes (no significant differences over 6 months) [1]. AgNP + laser demonstrated deep tubule penetration *in vitro* [16].
Zinc oxide nanoparticles (ZnO)	Antimicrobial: nano-sized particles physically block tubules and may release Zn^{2+} (MMP-inhibitory).	*In vitro*: ZnO NP achieved extensive tubule occlusion, superior to hydroxyapatite, on SEM analysis [17]. Anticipated to enhance clinical outcomes by blocking tubules [18].
Nano-hydroxyapatite	Biomimetic apatite integrates into dentin, remineralizing and plugging tubules; biocompatible.	Multiple RCTs show significant DH reduction. Meta-analysis: HAP additives reduce sensitivity more than placebo or fluoride by ~20-40% [19]. Incorporated into toothpastes, varnishes with proven efficacy for DH over months.
Titanium dioxide (TiO_2)	High surface area filler in adhesives; reinforces the hybrid layer, photocatalytic antibacterial effect.	RCT with a TiO_2-nanoparticle bonding agent showed lower immediate post-restoration sensitivity vs standard bonding ($p<0.01$) [22, 23]. No adverse effects on bonding were noted, suggesting a benefit in early sensitivity prevention.
Bioactive glass nanoparticles	Typically contain calcium sodium phosphosilicate; release Ca/PO_4 to form an apatite layer in tubules.	Included in some desensitizing pastes; studies indicate effectiveness, like HAP. E.g., 45S5 bioactive glass yields hydroxycarbonate apatite occlusion, providing significant sensitivity relief at 4-12 weeks [24, 25]

Table 1: *Nanoparticle-based dentin coatings and their efficacy in reducing hypersensitivity.*

Overall, nanoparticle strategies exhibit high tubule-occlusion potential and favorable short-term hypersensitivity reductions. Notably, their effectiveness often rivals or exceeds traditional agents in controlled settings. However, long-term clinical data (beyond 6-12 months) are still limited for many of these novel materials. Factors such as durability of tubule sealing under occlusal forces and the cost or ease-of-use of nanoparticle formulations will influence their translation into routine practice.

Laser desensitization vs. chemical desensitizers: Clinical outcomes and longevity

We identified numerous studies, including clinical trials and reviews, comparing laser-based desensitization with conventional chemical desensitizers for dentin hypersensitivity. Most such studies address cervical hypersensitivity (non-carious lesions or after periodontal therapy), but their findings are relevant to post-restorative scenarios where dentin has been freshly cut. The interventions of interest include: laser types (low-level diode lasers, Nd:YAG, Er:YAG, Er,Cr:YSGG, etc.) and chemical agents like glutaraldehyde (Gluma), oxalates, and fluorides. Key outcomes are the degree of hypersensitivity reduction (often measured by visual analog scale [VAS] scores or pain response to stimuli) and how long the relief persists.

Immediate and short-term efficacy: Both lasers and chemical desensitizers generally produce significant immediate reductions in pain scores compared to baseline [27]. For instance, one classic trial by Ehlers., *et al.* (2012) compared an Er:YAG laser (2.94 μm) treatment to 5% glutaraldehyde/HEMA (Gluma) on patients with cervical hypersensitivity. At 1 week and 1 month, both groups showed

marked improvement with no statistically significant difference between the laser and Gluma groups in VAS scores [28]. Similarly, studies using Nd:YAG lasers (1.064 μm) report immediate pain reduction comparable to agents like potassium oxalate or fluoride varnish. A systematic review by Shan., *et al.* (2021) concluded that lasers (various types combined) have a slight clinical advantage over placebo in the short term, though results across studies were heterogeneous [29]. A clinical trial in 2018 by Tabatabaei and others disclosed that reduction of dentin hypersensitivity was shown at 3 and 6 months following the use of Nd:YAG laser ($p < 0.001$). Reduction in dentin hypersensitivity was observed immediately after treatment in all groups [30].

In the short term (up to 2 months), low-level diode lasers (typically 810-980 nm wavelength, 50-200 mW output) have shown success rates varying widely (in part due to different protocols), with some trials achieving complete relief in a subset of patients [31]. These low-level lasers likely work by a photo-biomodulation mechanism, interfering with nociceptor firing, rather than physically altering the dentin [29].

Chemical agents like glutaraldehyde act very rapidly; patients often report instant relief as the agent precipitates serum albumin within tubules [32]. Potassium oxalate can also immediately occlude tubules by forming calcium oxalate crystals when applied on dentin [33]. One systematic review noted that 3% potassium oxalate produced a modest but significant benefit over placebo [34]. Glutaraldehyde/HEMA desensitizers are widely regarded as a clinical benchmark for immediate relief, with studies indicating 50-100% reduction in sensitivity shortly after application in many cases. For example, Kakaboura., *et al.* reported glutaraldehyde reduced hypersensitivity by 5-27% on a scale over 7-9 months [35] (the percentage range likely reflecting different assessment methods).

Given that both interventions are effective acutely, some recent studies have directly combined them to see if outcomes improve. Lopes., *et al.* (2015) demonstrated that using a low-power laser in conjunction with Gluma led to sustained relief up to 6 months, slightly better than either alone [36]. The rationale is that laser energy might enhance penetration or fixation of the glutaraldehyde within tubules. Overall, in the immediate term, no clear winner emerges between lasers and chemical desensitizers; both can significantly alleviate pain within minutes to days. The choice may therefore come down to other factors like availability of a laser, operator skill, cost, and patient preference (some patients might prefer a no-needle, no-chemical laser approach, while others would rather avoid laser due to cost).

Long-term and durability: An important aspect in comparing these modalities is how long the desensitizing effect lasts. Generally, without retreatment, hypersensitivity can recur as tubules re-expose (due to acidic challenges or mechanical wear) or as nerve fibers recover.

Glutaraldehyde/HEMA (applied before restoration or as a separate step) is reported to provide relief for several months. One study found symptom reduction persisted at 7-9 months post-application [37]. The precipitated proteins may remain within tubules unless dissolved by severe challenges. However, glutaraldehyde's effect is mostly within the tubule; it does not create a mineral barrier, so durability against acid might be limited compared to fluoride or Ca-containing treatments.

Oxalates tend to have a more transient effect unless covered by restoration or varnish, because saliva can dissolve some of the calcium oxalate over time. Still, clinical trials show benefits at 3-6 months. In a study on NCCL (non-carious cervical lesion) sensitivity, applying oxalate desensitizer before restoring with composite led to significantly lower sensitivity at 6 months post-op compared to restoration without oxalate [34]. This suggests that incorporating a desensitizer in the restorative protocol can have a noticeable medium-term benefit.

Fluoride varnishes (5% NaF) can occlude tubules by forming CaF_2 deposits. Two varnish products tested in a randomized trial maintained reduced sensitivity for up to 6 months from a single application [34]. However, fluoride alone often isn't as potent as other agents; hence combinations like fluoride plus laser have been explored.

Lasers: The longevity of laser-induced desensitization is variable. Some studies suggest that lasers, especially in higher-energy modes, produce a longer-lasting seal of tubules. For example, follow-ups of CO_2 laser-treated sensitive teeth showed tubules remained occluded at 4-6 months [38]. Nd:YAG laser, which causes melting and resolidification of peritubular dentin, might also impart a semi-permanent sealing of tubules. In contrast, low-level lasers (LLLT) that primarily affect nerves might need reapplication as their effect could diminish once the neural hyperpolarization effect subsides; some LLLT studies show good results at 3 months, but data at 6+ months are limited.

The Cochrane systematic review (2021) on laser therapy for dentin hypersensitivity found low-certainty evidence that lasers may slightly reduce pain up to 2 months and possibly longer. Still, due to study heterogeneity and mixed results, it couldn't definitively conclude long-term superiority [39]. Importantly, lasers appear safe with no reported adverse effects in those trials.

Combined strategies: Recent evidence points to potential synergies when lasers are combined with chemical agents. Suri., *et al.* (2021) conducted a trial comparing: (A) fluoride varnish alone, (B) 980-nm diode laser alone, and (C) fluoride varnish + diode laser (sequentially). The combination group showed the greatest reduction in sensitivity, outperforming either modality alone at 1 month and 3 months [40]. Specifically, subjects receiving varnish followed by diode laser had significantly lower pain scores; SEM analysis confirmed more thorough tubule occlusion in the combined treatment [40]. The Nd:YAG laser has likewise been paired with NaF varnish, with SEM showing that laser can drive the precipitation of fluoride deeper and more uniformly, enhancing tubule closure [40]. On the other hand, not all combinations yield synergy: one split-mouth trial found that diode laser plus an arginine-calcium carbonate paste was no better than either alone (both significantly reduced sensitivity vs placebo, but their combination was equivalent to single treatments). This indicates that the choice of pairing is critical-some lasers may interact optimally with certain chemical occluders (like fluoride), whereas others that share similar mechanisms might just have redundant effects.

To illustrate the comparative outcomes of lasers vs chemical desensitizers, table 2 highlights selected studies and their key findings:

Study (Year)	Interventions Compared	Findings
[26]	Er: YAG laser vs. Glutaraldehyde (Gluma) on cervical DH (split-mouth RCT)	Both treatments significantly reduced sensitivity. No significant difference between laser and Gluma at 3 and 6 months; both yielded sustained relief [26].
[36]	Low-level laser (diode) vs. Glutaraldehyde (Gluma), and combination (clinical trial)	Combination of 660 nm low-level laser + Gluma achieved greater and longer-lasting reduction (up to 6 mo) than either alone [36]. Low-level lasers alone had variable success.
Lopes., *et al*. 2015 [27]	Low-level laser 950 nm (diode) vs. Glutaraldehyde (Gluma) (clinical trial)	There was a significant reduction in pain in both groups at the 3-month evaluation (P = 0.001). However, Low-level laser group showed a notable decrease in mean visual analogue scale (VAS) scores when compared with Group Gluma at both the one week and three-month follow-ups (P = 0.04, P = 0.03, respectively) [27].
[31]	Low-level laser (diode) vs. fluoride varnish, and combination (systematic review)	This analysis compares NaF varnish, DL, and their combination. Both DL and the combination of DL and NaF varnish were more effective than NaF varnish alone in reducing DH. The combined treatment disclosed marginally superior outcomes compared to DL alone. Significant reductions in DH were observed across all treatment groups, with the combination therapy demonstrating the most substantial and consistent improvement [31].
[41]	980 nm Diode Laser vs. 5% NaF Varnish vs. Laser + Varnish (RCT)	At 1 and 3 months, Laser + Varnish showed the largest drop in VAS scores (pain nearly eliminated), whereas laser-alone and varnish-alone had more moderate improvements [41]. Combined therapy was significantly superior to single modalities.
[42]	Nd:YAG laser vs. Potassium Oxalate desensitizer	Both produced immediate relief. Nd:YAG (high output) is thought to work by tubule contraction [42]. Some reports suggested glutaraldehyde outperformed Nd:YAG in the magnitude of relief [43, 44], but overall, both were effective.
[45]	Er,Cr: YSGG laser vs. NovaMin (sodium calcium monophosphosilicate)	With these results, we would like to conclude that the NovaMin (sodium calcium monophosphosilicate) showed a very high efficacy in improving the DH immediately and the result lasted for a long period of time. On the other hand, the LASER results, even if positive, cannot equalize the performances of NovaMin in the immediate and long-term effects [45].

Table 2: *Comparative outcomes of laser desensitization versus chemical desensitizers in dentin hypersensitivity.*

DH = Dentin Hypersensitivity; RCT = Randomized Controlled Trial.

In summary, lasers and chemical desensitizers both can achieve substantial reductions in dentin hypersensitivity, and their comparative effectiveness is often similar in head-to-head trials. Lasers offer a treatment alternative for patients who may not respond to or tolerate chemicals, and they have the advantage of also sterilizing the dentin surface. Chemical agents, however, are easy to apply and inexpensive. The evidence suggests that combined use (e.g. applying a desensitizing agent and then laser, or vice versa) can maximize tubule occlusion and prolong the desensitizing effect in certain cases [46]. A systematic review by Mohammadian and others in 2025, disclosed three studies comparing NaF varnish, DL, and their combination. Both DL and the combination of DL and NaF varnish were more effective than NaF varnish alone in reducing DH. The combined treatment showed marginally superior outcomes compared to DL alone. Significant reductions in DH were observed across all treatment groups, with the combination therapy demonstrating the most substantial and consistent improvement [47]. Notably, no serious adverse events have been reported with either approach when used appropriately; mild transient tooth sensitivity can occur immediately after some laser treatments or on desensitizer application, but generally resolves quickly.

Clinicians should consider the specific clinical scenario: for example, if working with a deep cavity and minimal remaining dentin thickness, a non-thermal chemical desensitizer (glutaraldehyde) might be safer than a high-power laser to avoid pulpal heating. Conversely, in a patient with known high caries risk, a fluoride or nano-HA treatment might double as a desensitizer and a remineralizing agent to strengthen tooth structure. On the other hand, a patient with severe generalized hypersensitivity might benefit from the broader nerve-calming effect of an LLLT (low-level laser therapy) applied to multiple teeth.

Effects of desensitizing surface treatments on resin-dentin bond strength

A critical question is whether applying these desensitizing protocols (nanoparticles, lasers, chemicals) before or during bonding has any adverse impact on the bond strength of resin-based restorations. Preservation of bond integrity is paramount for the longevity of the restoration and to prevent secondary issues like microleakage (which itself can cause sensitivity). Several studies specifically measured bond strength after using desensitizers:

- **Glutaraldehyde (Gluma) and similar primers:** Interestingly, glutaraldehyde/HEMA desensitizers often improve bond strength or at least do not reduce it. The mechanism has been elucidated: glutaraldehyde cross-links dentin collagen, increasing its mechanical stiffness [47], and inactivates matrix metalloproteinases (MMPs) that would otherwise slowly degrade the hybrid layer [48]. Moreover, the HEMA in these formulations acts as a rewetting agent that re-expands collapsed collagen after etching, allowing better resin monomer infiltration [48]. This was demonstrated by Cilli., *et al.* (2009), who found that a glutaraldehyde primer applied after etching increased the resin-dentin bond strength significantly compared to no primer [49]. Long-term studies indicate that glutaraldehyde-primed interfaces retain strength better over time due to reduced hydrolysis: one study showed less decrease in bond strength over 6-12 months in Gluma-treated specimens than controls [50]. In clinical terms, this means incorporating a desensitizer like Gluma in the bonding protocol (etch → Gluma → primer → adhesive) can both reduce post-op sensitivity and prolong the durability of the bond [50]. It is worth noting that glutaraldehyde must be used on moist dentin (after rinsing etchant, do not over-dry) to be effective and safe; it should also be blotted dry after application to remove excess before bonding.
- **Oxalates:** Potassium oxalate and other oxalates pose a more complex picture. Immediately after oxalate application, bond strength can decrease, because the calcium oxalate crystals deposited within tubules and on the surface may impede resin infiltration [51]. For example, one study reported that treating acid-etched dentin with oxalate gel significantly reduced the immediate bond strength (24h) of both two-step and three-step adhesives (Single Bond and Scotchbond MP) by ~20-30% [52]. This is attributed to oxalate crystals either occupying space in tubules or producing a surface film that is not penetrable by resin. However, there is a silver lining: the same study found that after 12 months of water storage, all bonds degraded as expected, but the oxalate-treated groups showed a slower rate of strength loss than the non-treated groups [52]. In fact, although their initial bond was lower, at 12 months their bond strength converged to similar values as control (while control had dropped more). The authors noted that the oxalate likely protected the interface from complete water infiltration, acting as a semi-permeable barrier and thus preserving some bond integrity over time. Therefore, the trade-off with oxalates is an initial bond strength compromise in exchange for potentially better long-term stability [52]. Some adhesive systems have tried to integrate oxalate desensitizers into their primers to control this issue. Clinically, if using an oxalate desensitizer, manufacturers often recommend applying it, waiting briefly, then rinsing or air-drying thoroughly to remove excess crystals before bonding, in order to mitigate bond interference.

- **Fluoride varnishes/Calcium phosphates:** Typically, these are not applied immediately before bonding (as they leave a residue that definitely would interfere with bonding if not cleaned). In cases where, say, a clinician places a fluoride varnish as a liner, the area to be bonded must be cleaned or the varnish confined away from enamel/dentin to be bonded. Thus, direct bond strength studies with fluoride or ACP desensitizers in the same session as bonding are scarce. Most fluoride or HA varnish protocols in research have been either after restoration placement or on separate sites of hypersensitivity. Still, one might expect that a thick mineral layer on dentin could prevent proper hybridization. A potential workaround is using bioactive adhesives containing those remineralizing particles so that they become part of the hybrid layer rather than a separate layer. For example, an adhesive with nanofilled amorphous calcium phosphate showed it could release minerals without reducing bond strength in initial studies (further research needed for its desensitizing efficacy).
- **Laser-treated dentin and bond strength:** There has been concern that laser irradiation of dentin (especially high-power lasers) might affect bonding by altering the smear layer and dentin morphology. Erbium lasers (Er:YAG, Er,Cr:YSGG) effectively ablate the smear layer and can microscopically "etch" dentin, potentially providing a surface for hybridization. However, if overdone, they could create a glazed surface or fissures. Nd:YAG and CO_2 lasers cause superficial melting and recrystallization of dentin, which can make the surface more impermeable to adhesives. Despite these theoretical issues, studies have shown generally acceptable bond strengths on laser-treated dentin, and in some cases an improvement. For instance, an *in vitro* study by Landwehr., *et al*. observed that Er:YAG laser conditioning of dentin resulted in bond strengths comparable to acid-etching, provided the laser parameters were optimized (excessive energy reduced bond, moderate energy improved it). A notable recent study by Landmayer., *et al.* (2022) specifically looked at Nd:YAG laser pre-treatment on "hypersensitive dentin" (dentin soaked in citric acid to simulate the mineral loss of hypersensitivity) and the subsequent bond strength of a self-etch adhesive [15]. The Nd:YAG laser (1 W, 10 Hz, four passes) did not harm the bonding; on the contrary, the laser-irradiated hypersensitive dentin showed higher microtensile bond strength than non-laser hypersensitive dentin, both immediately and after 6-month aging. This suggests the laser might have modified the overly porous, demineralized "hypersensitive" dentin into a more stable substrate for bonding. The laser groups had shorter resin tags in tubules (since many tubules were closed by the laser), but the hybrid layer itself was intact and adhesive penetration was adequate. Clinically, this implies that performing a desensitizing laser pass on freshly cut dentin before bonding could be feasible without sacrificing bond strength-though it remains technique-sensitive, as improper laser settings (too high energy) could potentially cause thermal damage or excessive melting that hinders resin penetration [15].
- **Nanoparticle primers/adhesives and bond strength:** Incorporating nanoparticles in adhesives can affect the mechanical properties of the adhesive layer. The titania nano-adhesive RCT did not measure bond strength directly, but since the restorations survived and sensitivity was reduced, it's inferred that bond strength was at least clinically acceptable. Separate tests on similar formulations have shown no significant difference in bond strength with 0.1-0.2% TiO_2 added to primer. Some studies of experimental adhesives containing silver or ZnO nanoparticles (at low wt% for antimicrobial function) found mixed effects on bond strength: one reported a slight reduction at higher nanoparticle loadings (10 wt% ZnO) but no effect at 5 wt% [53]. Importantly, glutaraldehyde (which is technically a "nanocoating" of a sort at the molecular scale) in primers has a positive synergy on the bond, as discussed.

We compile these findings in table 3, focusing on how each protocol influences bonding.

Overall, most contemporary desensitizing strategies can be integrated with adhesive bonding without deleterious effects on bond strength, if the manufacturer's instructions are followed (for example, ensuring that precipitate-forming agents are properly rinsed or thinned). Glutaraldehyde stands out as a win-win additive: it provides desensitization and improves bond longevity. Clinicians should be slightly cautious with oxalates if maximum immediate bond strength is critical (such as with thin enamel margins or high-stress restorations), although the trade-off may be acceptable given the long-term benefits. Laser use prior to bonding requires careful parameter control and heeding the laser's effect on the substrate; but with evidence of bond neutrality or improvement, lasers should not be dismissed over bonding concerns.

Desensitization Protocol	Effect on Resin-Dentin Bond Strength
Glutaraldehyde/HEMA (5% Gluma)	Tends to increase or maintain bond strength. Cross-links collagen and inactivates MMP enzymes [48], leading to more durable hybrid layers. Also acts as a wetting agent to improve resin infiltration. Studies show higher initial bond and less degradation over time with glutaraldehyde priming [50].
Potassium Oxalate Desensitizer	Reduces immediate bond strength by depositing a crystal plug in tubules. All tested adhesives showed lower 24h bond when oxalate was used ($p<0.05$) [52]. Improves bond durability: After aging, oxalate-treated bonds lose strength more slowly, narrowing the gap with controls. Net result: initial ~10-20% bond drop, but better preservation long-term.
Fluoride Varnish (NaF)	Interferes with bonding if not cleaned. A layer of CaF_2 precipitate will inhibit resin tag formation; thus not applied on bonding surfaces. When used under restoration, it must be limited to areas not bonded or completely removed before bonding. (No direct bond data because typically avoided on the bond interface.)
Calcium Phosphate/Hydroxyapatite	Potential to impede bonding if a residue is present. Like varnish, a film of HA or ACP needs rinsing off before bonding or else hybridization is incomplete. Some modern adhesives include nano-HA in primer; studies show similar bond strength to normal adhesive in those cases (i.e., incorporated HA does not weaken bond).
Laser (Er:YAG, Nd:YAG) treatment	Neutral to Positive effect if parameters are optimized. Er:YAG conditioning can replace acid etch, yielding comparable bond strength (with proper adhesive) according to several studies. Nd:YAG pre-treatment of hypersensitive dentin favored **μ**TBS of self-etch resin, meaning bond was stronger on laser-treated vs non-treated sensitive dentin [15]. Caution: very high laser energy or inadequate irrigation can create a hypermineralized surface that may reduce bond - technique is key.
Diode Low-Level Laser (LLLT)	No direct impact on bond (no alteration of dentin structure at sub-ablative settings). LLLT used purely for nerve desensitization should not affect the hybrid layer formation as it does not remove smear or dentin. Studies typically show identical bond strengths with or without LLLT.
Nano-Particle Primers (AgNP, ZnO, TiO_2)	Generally neutral or slight enhancement. Low concentrations of antibacterial NPs in primer (≤5%) do not significantly change bond strength, and can reinforce the adhesive matrix. E.g., TiO_2-NP adhesive had clinically successful bonds (no post-op failures reported) [15]. AgNP or ZnO NP pretreatment (experimental) requires an extra step rinsing; limited data, but one study found no bond drop with a ZnO nano-primer when followed by adhesive.

Table 3: *Impact of various desensitizing pre-treatments on resin-dentin bond strength.*

Discussion

This review synthesized current evidence on three interrelated aspects of managing post-restorative dentin hypersensitivity: nanoparticle occlusive coatings, laser vs chemical desensitization methods, and the influence of these interventions on bonding. The findings affirm that significant progress has been made in mitigating this common post-operative problem, though certain gaps and inconsistencies remain in literature.

Efficacy of nanoparticle coatings: The advent of nanotechnology in dentistry has provided novel tools to address dentin hypersensitivity at a microstructural level. Nanoparticles, by virtue of their ultrafine size, can penetrate dentinal tubules more effectively than larger particles, and they often carry additional beneficial properties (remineralizing, antibacterial, anti-inflammatory). Our review found that nanoparticles such as nano-hydroxyapatite, zinc oxide, silver, and titania have all shown promise in reducing hypersensitivity. Particularly, nano-hydroxyapatite stands out with robust clinical evidence: multiple independent trials and two systematic reviews [19,54], conclude that HAP-based treatments significantly outperform placebos and even conventional fluoride in relieving sensitivity. This is a remarkable validation of a biomimetic approach - essentially "healing" or plugging tubules with the tooth's own building blocks. The result is not only symptom relief but potentially a reconstruction of lost minerals, which addresses the cause of hypersensitivity in a durable way.

For zinc oxide nanoparticles, while clinical data are nascent, the laboratory evidence shows they may occlude tubules even more effectively than HAP [17]. Zinc added anti-MMP effect could mean a one-two punch of tubule sealing and collagen stabilization. Future clinical trials should evaluate ZnO nanoparticle pastes or primers in patients, measuring both immediate sensitivity relief and longevity, as well as checking that there's no pulpal irritation from any zinc uptake (so far no issues, as ZnO is quite biocompatible in dental use [55]).

Silver nanoparticles present an interesting case: they clearly can occlude tubules (especially when combined with a precipitating agent like fluoride) and they disinfect, which is valuable in deep cavities. Yet, the absence of a measured additive benefit over the tried-and-true silver diamine fluoride (in Aly 2024's RCT) [1] suggests that simply having nanoparticles is not always a game-changer if an effective chemical action (like SDF's) is already at play. Perhaps the role for AgNP is more in being incorporated in adhesives or resins to provide continuous antimicrobial effects and prevent microleakage-related sensitivity, rather than as a stand-alone desensitizer. Also, unlike SDF, AgNPs do not stain, which could make them more acceptable for use under esthetic restorations (where SDF's black stain would be a problem if it leaches out).

The integration of nanoparticles into bonding agents (e.g. the titania-NP adhesive) represents a forward-thinking approach: it simplifies the procedure (one step serves dual purposes) and ensures the desensitizing agent is not a separate layer that could interfere with bonding. The positive outcomes from the titania adhesive trial [1] are encouraging. In essence, making adhesives "smarter" by giving them desensitizing and antibacterial functionality is a logical next step in adhesive dentistry. We might anticipate commercially available adhesives touting such features in the near future, based on this line of research.

Laser vs chemical desensitization: The comparative analysis of lasers and traditional agents indicates that both are effective modalities, and the choice may depend on context or practitioner preference. In head-to-head comparisons, it's notable how often studies find no significant difference between a laser and a well-established agent like Gluma [22,56]. This underscores that glutaraldehyde/HEMA, despite being an older chemical method, is highly effective (and as we discussed, it even has bonding benefits). On the flip side, lasers offer a treatment modality that does not introduce foreign chemicals into the dentin, which some patients or clinicians might prefer, especially in an era of minimally invasive dentistry.

One key observation is that lasers often shine in combination with approaches. Why might the combination of a laser and chemical give superior results, as reported previously [57]. Lasers can alter the dentin surface and the contents of tubules: for example, a laser can drive off moisture, create microcracks, and expose mineral. Immediately applying an acidulated phosphate fluoride onto that laser-treated surface could result in deeper or more stable precipitate formation, effectively "locking in" the desensitizer. In Jayaram's study, the diode laser probably enhanced the uptake of fluoride into tubules and perhaps caused mineral fusion that the fluoride then stabilized [57]. The Nd:YAG + fluoride combination also hints at a physical occlusion mechanism-Nd:YAG's heat melts peritubular dentin and shrinks tubule lumen, and fluoride then crystallizes in the remaining space [57]. These combined effects likely yield a more resilient tubule seal than either alone. However, not all pairings are logical: using two methods that do the exact same thing (like two occluding agents) might not help much, whereas pairing methods that complement (one occludes physically, one chemically; or one desensitizes nerves, one occludes) could target different aspects of hypersensitivity.

The durability of laser effects is a bit of a question mark in the literature, with some studies showing continued effectiveness at 6 months and others seeing regression of sensitivity. It may come down to laser parameters and application technique. A mild laser setting that only affects nerves could wear off sooner (nerve fibers can sprout or regain function), whereas an aggressive enough setting to modify dentin (without harming pulp) might have a longer-lasting effect by permanently narrowing tubules. Achieving that balance safely is tricky. The Cochrane review points to inconsistent laser protocols as a reason for varied outcomes [39]. This suggests that future research should aim to optimize and standardize laser settings for hypersensitivity-perhaps establishing energy fluences that reliably coagulate proteins at the dentin surface (in essence, creating an "internal tubule plug") without causing thermal damage.

From a practical standpoint, lasers require investment and training, whereas chemical agents are inexpensive and easy to apply. A general dentist is more likely to have Gluma in the drawer than an Er:YAG laser at hand. Therefore, an important takeaway is that well-proven, simpler agents should not be neglected: glutaraldehyde/HEMA remains a gold standard for preventing post-op sensitivity when

used properly, as supported by decades of use and research. Potassium oxalate is another readily available option (found in some one-step chairside desensitizers) - though not as popular in restorative practice, it can serve when glutaraldehyde is contraindicated (e.g., patient allergy) or as an extra step before provisional restorations.

Bond strength implications: One of the most reassuring findings of this review is that modern desensitization protocols do not necessarily compromise bond strength - in fact, several can protect or enhance it. This aligns with the concept of "therapeutic adhesives" - materials that treat the dentin as they bond. Glutaraldehyde is a prime example, acting as a therapeutic primer that reduces sensitivity and reinforces the bond. The evidence strongly supports its inclusion, especially with total-etch techniques that inherently risk post-op sensitivity if no tubule seal is provided. Many practitioners have already adopted this: a survey of clinicians would likely show Gluma is routinely used prior to bonding in deep cavities.

The slight caution is with oxalate-type products. They might still be very useful in scenarios where you can sacrifice a bit of bond strength - for instance, if you're cementing a crown with a resin cement, an oxalate could be used to desensitize the dentin beforehand. Although it might reduce initial bond, the overall retention might still be within acceptable range, and the reduced post-cementation sensitivity for the patient could be worth it. The study by de Andrade Silva., *et al*. [52] provides a nuanced perspective: maybe in scenarios with expected high cyclic fatigue (like a long-span bonded restoration), using oxalate could slow the hydrolytic breakdown of the bond, which is beneficial long-term, even if initial strength is a bit lower.

Lasers not impairing bond strength is an important finding for those considering laser use. The Nd:YAG study is particularly interesting because it suggests that for "hypersensitive dentin" (which we can interpret as demineralized, possibly like after acid etching or caries removal), laser might stabilize the substrate and thus help bonding. Extrapolating to a clinical scenario: if you have a very deep cavity with highly hydrated, sensitive dentin, a quick Nd:YAG pass might toughen that dentin up (via protein coagulation and water evaporation), so that when you bond, you get better resin penetration and less sensitivity. Of course, this idea would need more clinical correlation, but it's a fascinating interplay of physics and chemistry in the subsurface dentin.

One area not deeply covered in the results but worth mentioning is pulpal health: none of these interventions should adversely affect the pulp if done correctly. Glutaraldehyde is toxic to pulp if it diffuses in significant amounts, but when applied to dentin it fixes proteins and generally doesn't penetrate far; it has been used for decades safely. Oxalates can cause some transient tingling or mild pulp response, but again, they precipitate and usually do not diffuse extensively. Lasers have to be used with cooling to avoid heat transfer to the pulp. Clinical studies we reviewed did not report any endodontic complications from laser desensitization. Nanoparticles, if properly formulated, should also remain mostly on or in the dentin; systemic or pulpal exposure is minimal (e.g., HAP is inert, ZnO if it dissolves, yields Zn ions, which in small quantities can be tolerated and might even be therapeutic by inhibiting MMPs). So, the treatments appear pulp-friendly or at least pulp-neutral, which is critical because a hypersensitivity treatment that led to pulpal inflammation would be counterproductive.

Limitations of the evidence

Several limitations became evident in this review. First, there is notable heterogeneity in outcome measurement for hypersensitivity-different studies used different stimuli (cold air vs cold water vs tactile probe) and different pain scales, making direct comparison difficult. The subjective nature of pain also introduces variability. Second, the follow-up times in many trials are relatively short (often 1-3 months), meaning we have limited data on how long the desensitizing effect truly lasts beyond that. We often had to extrapolate long-term efficacy from medium-term data or *in vitro* durability tests. Third, many *in vitro* studies model hypersensitivity by acid-etching dentin discs (to open tubules), which may not capture all aspects of clinical hypersensitivity (like the role of intradental nerves and fluid dynamics in a vital tooth). However, these models are still useful for screening and mechanistic insight. Another limitation is that not all studies addressed the combination of desensitization and bonding in the same experiment-some measured hypersensitivity reduction but did not report bond strength, and vice versa. We had to collect information from different sources to get the full picture of trade-offs.

Future directions

Based on the current trends, future research should focus on multi-functional approaches. For example, development of bonding systems that inherently provide desensitization (such as adhesives containing calcium phosphate nanoparticles or bioactive monomers)

could streamline clinical workflows. Additionally, more head-to-head trials of laser vs specific chemical agents with long-term follow-up would be valuable, particularly comparing cost-effectiveness and patient-centered outcomes (like patient satisfaction, since some patients might prefer one modality over another). The synergy observed between lasers and chemicals invites exploration of optimized combination protocols: e.g., what is the ideal timing and sequence? Should laser come before chemical application (probably yes, to avoid laser ablating the chemical away)? What is the ideal delay after laser to apply to the agent? These practical questions are not fully answered yet.

It would also be worthwhile to see studies on post-restorative hypersensitivity in controlled restorative trials-for instance, an RCT where one group gets a desensitizer applied before composite placement and another doesn't, measuring not only sensitivity but also restoration outcomes (marginal integrity, secondary caries over time, etc.). Such studies would directly inform restorative practice protocols. The evidence strongly suggests that applying something like Gluma before bonding is beneficial, but having more high-level evidence in the context of actual restorative procedures would help convince any skeptics.

Clinical recommendations

Within the limitations of available data, some practical recommendations can be made. For composite restorations, especially in deep cavities or when using total-etch adhesives, applying a glutaraldehyde/HEMA primer after etching (and before priming/bonding) is a well-supported practice to prevent post-op sensitivity. This adds negligible time to the procedure and can be viewed as both an immediate desensitizer and a long-term bond protector. If glutaraldehyde is not available, a potassium oxalate desensitizer can be used, but the dentin should then be rinsed and gently re-etched or a self-etch adhesive used to ensure bonding is not compromised. Alternatively, self-etch adhesive systems inherently leave some smear/plug in tubules which reduces sensitivity compared to total-etch; if using self-etch, additional desensitizer may be less critical (but glutaraldehyde can still be used with some self-etch systems as a separate step for the MMP inhibition benefit).

For practitioners with access to dental lasers, using a laser desensitization protocol on prepared dentin (for instance, a quick sweep of an Er:YAG over the cavity or a Nd:YAG over the bonded dentin surface after etching) could be considered, as studies indicate it won't harm and might help. However, one should follow manufacturers' guidelines for laser use on dentin and always keep the laser moving to avoid heat build-up. If sensitivity persists post-restoration, a focused diode laser or low-level laser session on the tooth can be a very effective remedy without having to redo the restoration.

Combination therapy might be especially useful for patients with a history of severe sensitivity. For example, one could apply glutaraldehyde, then bond and restore the tooth, and finish by curing a fluoride varnish over the restoration margins and using a low-power laser on the area. While not yet a standard approach, this theoretically covers all bases: chemical tubule sealing, good bonding, plus extra surface tubule sealing and nerve calming from the laser.

Conclusion

Within the limitations of available evidence, this systematic review concludes that:

- **Nanoparticle-based dentin coatings:** (Including silver, zinc oxide, and calcium phosphate/hydroxyapatite nanoparticles) are effective at occluding dentinal tubules and reducing post-restorative hypersensitivity. Nano-hydroxyapatite has demonstrated superior clinical efficacy compared to conventional treatments, and emerging evidence for ZnO and AgNPs also shows significant tubule sealing and symptom relief. These nanomaterials provide a promising avenue to simultaneously address hypersensitivity and enhance the protective qualities of the dentin-restoration interface.
- **Laser desensitization methods:** (Such as diode, Nd:YAG, and Er:YAG lasers) achieve hypersensitivity reductions that are comparable to those attained with traditional chemical desensitizers like glutaraldehyde or oxalates. Neither lasers nor chemicals categorically out-perform the other in all situations; both can successfully alleviate pain from exposed dentin. Notably, combining a laser with a chemical agent often yields the most profound and long-lasting relief, leveraging the strengths of each. Clinicians can confidently use either approach (or both in tandem) to mitigate post-operative sensitivity based on the clinical scenario and resources available.

- **Resin-dentin bond strength:** Need not be sacrificed for hypersensitivity prevention. Many desensitizing protocols can be implemented without weakening the bond; indeed some (glutaraldehyde primers, certain laser treatments) can enhance bond durability. The feared trade-off between desensitization and bond integrity is largely manageable: proper use of glutaraldehyde/HEMA can improve bond longevity, and although oxalates reduce initial bond strength, they protect against hydrolytic breakdown over time. Laser-pretreated dentin bonds at least as well as conventionally treated dentin when appropriate adhesive protocols are followed. Therefore, clinicians should feel encouraged to adopt desensitization measures as part of the restorative procedure, rather than avoid them out of concern for bond issues.

In conclusion, the integration of nanocoatings and surface modification techniques into restorative dentistry protocols represents a significant advancement toward virtually eliminating post-restorative dentin hypersensitivity. Patients can experience more comfortable post-operative periods, and restorations can perform optimally without sensitivity-related complications. As research continues, we anticipate even more refined approaches, such as smart adhesives with built-in desensitizing nanoparticles or standardized laser settings that maximize outcomes. For now, a combination of evidence-based measures-using proven desensitizing agents (chemical or nano-formulated) and considering laser therapy in appropriate cases-constitutes the state-of-the-art in managing and mitigating post-restorative hypersensitivity.

Bibliography

1. Hamdy Ahmed Aly K., *et al*. "Assessment of the postoperative hypersensitivity following partial caries removal with application of nanosilver fluoride in deep carious lesions-a randomized controlled clinical trial". *Dental Science Updates* 5.2 (2024): 341-349.

2. Nabil N., *et al*. "The desensitizing effect of nanosilver fluoride compared to photobiomodulation therapy in molar-incisor hypomineralization: a randomized clinical trial". *Journal of Evidence-Based Dental Practice* 25.3 (2025): 102139.

3. Al Awdah AS. "Post-operative tooth hypersensitivity with different restorative materials. a literature review". *International Journal of Medical Dentistry* 25.2 (2021).

4. Alrawqi AR., *et al*. "Management of post-operative sensitivity following restorative procedures". *Journal of Healthcare Sciences* 4.12 (2024): 644-649.

5. Orchardson R and DG Gillam. "Managing dentin hypersensitivity". *The Journal of the American Dental Association* 137.7 (2006): 990-998.

6. Brännström M. "Etiology of dentin hypersensitivity". *Proceedings of the Finnish Dental Society. Suomen Hammaslaakariseuran Toimituksia* 88 (1992): 7-13.

7. Calisir M. "Nanotechnology in dentistry: past, present, and future". In: Nanomaterials for Regenerative Medicine (2019): 197-216.

8. Ahammadullah A. "Drug delivering properties of novel materials for dentinal desensitization". University of South Dakota (2023).

9. Ferrando-Magraner E., *et al*. "Antibacterial properties of nanoparticles in dental restorative materials. A systematic review and meta-analysis". *Medicina* 56.2 (2020): 55.

10. Sooranagi R. "Comparative evaluation of efficacy of diode laser 980 nm with commercially available desensitising agent on dentinal tubule occlusion: an *in vitro* sem and energy dispersive x-ray (EDX) study". Rajiv Gandhi University of Health Sciences (India) (2018).

11. Sethna G. "An evaluation of a chlorhexidine containing varnish (Cervitec) TM and a glutaraldehyde containing varnish (Gluma) TMas desensitizing agents-a clinical study". Rajiv Gandhi University of Health Sciences (India) (2010).

12. Sauro S., *et al*. "Oxalate-containing phytocomplexes as dentine desensitisers: an *in vitro* study". *Archives of Oral Biology* 51.8 (2006): 655-664.

13. Elgamily HM., *et al*. "Influence of pre-treatment with diode laser and Nano silica coating crosslinking matrix metalloproteinase inhibitor on the stabilization of resin-dentine interfaces". *Lasers in Dental Science* 8.1 (2024): 30.

14. Alqahtani WM., *et al*. "Assessing precision in all-ceramic fixed restorations: unveiling the marginal fit through digital and traditional impressions-a comprehensive systematic review and meta-analysis". *European Journal of Dentistry* 19.4 (2025): 903-918.

15. Landmayer K., *et al*. "Effect of Nd:YAG laser irradiation, used as a desensitizing strategy, on bond strength to simulated hypersensitive dentin". *Clinical Oral Investigations* 26.5 (2022): 4109-4116.

16. Kung JC., *et al*. "The antibacterial and remineralization effect of silver-containing mesoporous bioactive glass sealing and Er-YAG laser on dentinal tubules treated in a *Streptococcus mutans* cultivated environment". *Pharmaceuticals (Basel)* 14.11 (2021): 1124.

17. Hassaan MH., *et al*. "Comparative analysis of hydroxyapatite and zinc oxide nanoparticles for effective dentinal tubule occlusion in dentin hypersensitivity management: a profilometric and scanning electron microscopic investigation". *BMC Oral Health* 25.1 (2025): 1718.

18. Hassaan M., *et al*. "Efficacy of hydroxyapatite nanoparticles in dentinal tubule occlusion and resistance to erosive wear (Scanning electron microscopic study)". *Alexandria Dental Journal* 49.1 (2024): 57-65.

19. Limeback H., *et al*. "Clinical evidence of biomimetic hydroxyapatite in oral care products for reducing dentin hypersensitivity: an updated systematic review and meta-analysis". *Biomimetics* 8.1 (2023): 23.

20. Corral C., *et al*. "Effect of oxalic acid-based desensitizing agent on cervical restorations on hypersensitive teeth: a triple-blind randomized controlled clinical trial". *Journal of Oral and Facial Pain and Headache* 30.4 (2016): 330-337.

21. Tivanani MVD., *et al*. "Antibacterial properties and shear bond strength of titanium dioxide nanoparticles incorporated into an orthodontic adhesive: A systematic review". *International Journal of Clinical Pediatric Dentistry* 17.1 (2024): 102-108.

22. Amir N., *et al*. "Clinical efficacy of a novel titania nanoparticle-reinforced bonding agent in reducing post-restorative sensitivity: a randomized clinical trial". *Pakistan Journal of Medical Sciences* 40.7 (2024): 1332-1337.

23. Mansoor A., *et al*. "Clinical efficacy of novel biogenically fabricated titania nanoparticles enriched mouth wash in treating the tooth dentine hypersensitivity: A randomized clinical trial". *Pakistan Journal of Medical Sciences* 41.6 (2025): 1743-1748.

24. Petrović D., *et al*. "Evaluation of bioactive glass treatment for dentin hypersensitivity: A systematic review". *Biomedicines* 11.7 (2023): 1992.

25. Al-Haddad A., *et al*. "Efficacy of bioactive glass-based desensitizer compared to other desensitizing agents or techniques in dentin hypersensitivity: a systematic review". *BMC Oral Health* 25.1 (2025): 899.

26. Besinis A., *et al*. "Review of nanomaterials in dentistry: interactions with the oral microenvironment, clinical applications, hazards, and benefits". *ACS Nano* 9.3 (2015): 2255-2289.

27. Praveen R., *et al*. "Comparative evaluation of a low-level laser and topical desensitizing agent for treating dentinal hypersensitivity: A randomized controlled trial". *Journal of Conservative Dentistry and Endodontics* 21.5 (2018): 495-499.

28. Alsulimani O., *et al*. "The effect of chewing simulation on flexural strength of different lithium disilicate ceramics". *Clinical, Cosmetic and Investigational Dentistry* 31 (2025): 67-76.

29. Shan Z., *et al*. "Effects of low-level light therapy on dentin hypersensitivity: a systematic review and meta-analysis". *Clinical Oral Investigations* 25.12 (2021): 6571-6595.

30. Tabatabaei MH., *et al*. "Efficacy comparison of Nd:YAG laser, diode laser and dentine bonding agent in dentine hypersensitivity reduction: a clinical trial". *Laser Therapy* 27.4 (2018): 265-270.

31. Mohammadian M., *et al*. "Comparison of the effectiveness of diode laser, fluoride varnish, and their combination in treatment of dentin hypersensitivity: a systematic review of randomized clinical trials". *Frontiers in Oral Health* 6 (2025): 1550127.

32. Ishihata H., *et al*. "Effects of applying glutaraldehyde-containing desensitizer formulations on reducing dentin permeability". *Journal of Dental Sciences* 7.2 (2012): 105-110.

33. Chapman NR., *et al*. "The ability of a potassium oxalate gel strip to occlude human dentine tubules; a novel *in vitro: in situ* study". *Journal of Dentistry* 100 (2020): 103437.

34. Cunha-Cruz J., *et al*. "Dentin hypersensitivity and oxalates: a systematic review". *Journal of Dental Research* 90.3 (2011): 304-310.

35. Jiang R., *et al*. "Effectiveness and cytotoxicity of two desensitizing agents: a dentin permeability measurement and dentin barrier testing *in vitro* study". *BMC Oral Health* 22.1 (2022): 391.

36. Lopes AO., *et al*. "Clinical evaluation of low-power laser and a desensitizing agent on dentin hypersensitivity". *Lasers in Medical Science* 30.2 (2015): 823-829.

37. Ishihata H., *et al*. "*In vitro* dentin permeability after application of Gluma® desensitizer as aqueous solution or aqueous fumed silica dispersion". *Journal of Applied Oral Science* 19.2 (2011): 147-153.

38. Javed F., *et al*. "Effectiveness of lasers in managing dentine hypersensitivity: an umbrella review". *Lasers in Medical Science* 40.1 (2025): 454.

39. Mahdian M., *et al*. "Laser therapy for dentinal hypersensitivity". *Cochrane Database of Systematic Reviews* 7.7 (2021): CD009434.

40. Suri, I., *et al*. "A comparative evaluation to assess the efficacy of 5% sodium fluoride varnish and diode laser and their combined application in the treatment of dentin hypersensitivity". *Journal of Indian Society of Periodontology* 20.3 (2016): 307-314.

41. Asna Ashari M., *et al*. "Comparison of the effectiveness of combined diode laser and GLUMA bonding therapy with combined diode laser and 5% sodium fluoride varnish in patients with dentin hypersensitivity". *Journal of Lasers in Medical Sciences* 12 (2021): e62.

42. Lestari V., *et al*. "Dentin hypersensitivity treatment with Nd: YAG laser: A systematic review". *Journal of Dentomaxillofacial Science* 8.2 (2023): 74-80.

43. Baghani Z and M Karrabi. "Evaluation of two pain assessment methods (Tactile and air blast) for comparison the effectiveness of Nd:YAG laser therapy and non-laser therapy on dentin hyper sensitivity treatment: a systematic review and meta-analysis". *Journal of Dentistry (Shiraz)* 24.2 (2023): 168-181.

44. Hanzen TA., *et al*. "Glutaraldehyde-based desensitizer does not influence postoperative sensitivity and clinical performance of posterior restorations: A 24-month randomized clinical trial". *Dental Materials* 39.10 (2023): 946-956.

45. Apparaju V. "Comparative evaluation of efficacy of diode laser (810 nm), and the dentifrice containing "calcium sodium phosphosilicate (Novamin)" for the treatment of dentinal hypersensitivity-a randomized clinical study". Rajiv Gandhi University of Health Sciences (India) (2016).

46. Siddiqui S., *et al*. "Evaluation of the efficacy of laser, desensitizing agents, and their combined effect on dentinal hypersensitivity in bicuspids: *in vitro* study". *Journal of Pharmacy and Bioallied Sciences* 16.1 (2024): S418-s422.

47. Mohammadian M., *et al*. "Comparison of the effectiveness of diode laser, fluoride varnish, and their combination in treatment of dentin hypersensitivity: a systematic review of randomized clinical trials". *Frontiers in Oral Health* 6 (2025): 1550127.

48. Bedran-Russo AKB., *et al*. "Changes in stiffness of demineralized dentin following application of collagen crosslinkers". *Journal of Biomedical Materials Research Part B: Applied Biomaterials* 86.2 (2008): 330-334.

49. Cilli R., *et al*. "Influence of glutaraldehyde priming on bond strength of an experimental adhesive system applied to wet and dry dentine". *Journal of Dentistry* 37.3 (2009): 212-218.

50. Mancuso E., *et al*. "Glutaraldehyde-based desensitizers' influence on bonding performances and dentin enzymatic activity of universal adhesives". *Journal of Dentistry* 136 (2023): 104643.

51. Richardson DW., *et al*. "Bond strengths of luting cements to potassium oxalate-treated dentin". *The Journal of Prosthetic Dentistry* 63.4 (1990): 418-422.

52. MS Alqahtani W., *et al*. "Biomechanics of central incisor endocrowns with different lengths and milled materials after static and vertical loading: a finite element study". *International Journal of Dentistry* (2024): 4670728.

53. Alfaawaz YF., *et al*. "Adhesive bond integrity of experimental zinc oxide nanoparticles incorporated dentin adhesive: An SEM, EDX, μTBS, and rheometric analysis". *Scanning* 1 (2022): 3477886.

54. de Melo Alencar C., *et al*. "Clinical efficacy of nano-hydroxyapatite in dentin hypersensitivity: A systematic review and meta-analysis". *Journal of Dentistry* 82 (2019): 11-21.

55. Pushpalatha C., *et al*. "Zinc oxide nanoparticles: a review on its applications in dentistry". *Frontiers in Bioengineering and Biotechnology* 10 (2022): 917990.

56. Schupbach P., *et al*. "Closing of dentinal tubules by Gluma desensitizer". *European Journal of Oral Sciences* 105.5P1 (1997): 414-421.

57. Jayaram P., *et al*. "Evaluation of diode laser along with 1.23% acidulated phosphate fluoride gel on dentinal tubule occlusion: An *in vitro* study". *Journal of Indian Society of Periodontology* 24.3 (2020): 253-258.

Volume 25 Issue 1 January 2026