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Smart dental restoratives: Bioactive, responsive and therapeutic innovations

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Abstract:

Conventional restorative materials mainly replace lost tooth structure without actively responding to the oral environment. Smart restorative biomaterials introduce bioactive and stimulus-responsive properties to enable dynamic therapeutic functions. They can respond to pH, temperature, light and mechanical stress to deliver antimicrobial, remineralizing and regenerative effects. Emerging evidence suggests improved restoration longevity, reduced secondary caries and enhanced tissue healing with these materials. These advances may transform restorative dentistry toward precision-based, minimally invasive and biologically interactive clinical care.

Keywords: Smart restorative materials (SRMs), nanocomposites, bioactive ceramics, smart hydrogels, stimuli-responsive biomaterials, biomimetic dental materials

Background:

Advances in restorative dentistry have driven the evolution of restorative materials [1]. This evolution refers to the transition from conventional materials with simple applications to biocompatible materials with therapeutic potential [2]. Such is the case with smart restorative materials (SRMs). By definition, the properties of SRMs change in a controlled way in response to physiological or environmental stimuli such as stress, temperature, moisture, pH, or electric/magnetic fields. These materials are often called “responsive materials” due to their ability to adapt dynamically to changes in the oral environment [3]. Clinical relevance one of the main characteristics of SRMs is their stimulus-response function, which is achieved through the release of ions, especially in environments with a reduced pH.

Such is the case with nano-filled glass materials that release fluoride, hydroxyl and calcium ions, which are important for remineralization and protection of tooth tissue [3]. Another known mechanism in SRMs is their anti-inflammatory and antibacterial effect on dental tissue. This is the case with chlorhexidine gels, when used in root canal treatment. When this material is used to obturate the canal, hydroxyl ions are produced, increasing the pH in the root canal. When administered alone or in combination with other alkaline materials, this exhibits strong antimicrobial activity. This feature of SRMs is beneficial for patients such as children, elderly patients and patients at high risk of caries [4]. Thermal expansion is a factor that should be taken into account when choosing a restorative material. In the past, classic restorative materials exhibited greater thermal expansion, which affected the quality of the sealer and the integrity of the tooth structure [5]. Unlike classical restorative materials, SRMs improve marginal closure and stability against thermal expansion. This is the case with glass ionomers, which exhibit thermoresponsive and intelligent behavior. Such intelligent behavior in glass

ionomers refers to their imitation of human dentin and their biocompatibility. For example, such properties are found in compomers and glass ionomer cements. In addition to marginal closure, SRMs have good absorptive properties in the presence of mechanical stress. Thus, such materials can better withstand occlusal forces and thus maintain tooth integrity. Such is the case with passive materials in the composition of SRMs. This group includes glass ionomers that are modified with resin and composites. The main characteristic of such materials is their shape memory. Namely, when applying mechanical stress, they can remember their original shape and restore it when heated [6]. Therefore, it is of interest to report the recent advances and clinical relevance of smart restorative materials in contemporary restorative dentistry.

Types of SRMs used in dentistry:

Smart dental restorative materials can be broadly categorized into seven major groups based on their composition and origin: nanocomposite restorative materials, hydrogel-based materials, biomaterials, chemical materials, resin-based smart materials, smart carrier systems and ceramic or ceramic-derived restorative materials [7]. Nano-restorative materials are advanced smart dental systems that use nanotechnology for bio-intelligent, responsive behavior. Stimulus-responsive nanoparticles enable controlled ion or drug release to overcome biological barriers like cariogenic biofilms. Bio-nanocomposites and organic/inorganic nanocomposites provide antimicrobial activity, remineralization and oxidative stress scavenging, self-healing and enhanced interfacial stability while maintaining cytocompatibility. Functional nanoparticles-including amorphous calcium phosphate (ACP), metal-based (Ag, Zn, Cu, Mg, Ti, Fe₃O₄), polymeric and mesoporous silica allow pH, magnetic, or photo-responsive delivery, improving resistance to secondary caries, biofilm adhesion and material degradation [8].

Hydrogel restorative materials are versatile, biologically responsive dental biomaterials with 3-D polymer networks, high water content and tunable properties. Derived from natural or synthetic polymers via physical or chemical cross-linking, they can exhibit stimuli-responsive behaviour. Natural hydrogels offer biocompatibility, while synthetic ones provide mechanical stability. Advanced hydrogels-including nanogels and hybrid composites-exhibit antimicrobial, anti-inflammatory, self-healing and remineralizing functions, disrupting biofilms and enhancing local therapy. Injectable and photo crosslinked hydrogels show promise in periodontitis, peri-implantitis and endodontics and tissue regeneration [9]. Biomaterials from natural agents and extracts provide multiple benefits, especially antimicrobial and regenerative effects. Antimicrobial peptides (AMPs), including ϵ -polylysine and GH12, target pH-responsive activity against cariogenic biofilms and drug-resistant bacteria. This activity reduces the risk of recurrent caries and infections related to implants. Strategies such as surface immobilization, functional linkers and smart design improve their effectiveness. Chitosan, a natural polymer, offers antimicrobial, anti-inflammatory and pH-responsive properties and can be used in hydrogels, coatings, or nanoparticles to support dental tissue regeneration and biofilm control. Autologous bone and growth factors from dental sources are the gold standard grafts for bone regeneration. They support bone formation and integration while limiting immune reactions. Stem cell-based methods and dental particle biomaterials offer cost-effective, less invasive options [10]. Chemical and resin-based smart materials are widely used in restorative dentistry for their esthetic and biocompatible properties. Mechanical performance depends on filler content, size, composition and bonding. Functional additives and smart delivery systems provide antimicrobial, remineralization and self-healing effects. Stimulus-responsive nano- and multi-layered composites enable controlled ion/drug release and enhanced polymerization, bonding and multifunctional properties via light, thermal, or electrical activation [11]. Smart or intelligent carrier materials enable targeted antimicrobial and ion-release strategies. PH-responsive Zn-releasing glass particles and 2D metal-organic frameworks release active ions or reactive oxygen species in response to environmental stimuli, providing dynamic therapeutic effects. Ultrasonic vibration enhances the adhesive strength of glass fiber posts. Glass materials, including pH-responsive Zn-glass particles and glass ionomers, prevent demineralization and support antimicrobial action. However, compatibility with adjuncts like SDF requires optimization. These systems collectively offer stimuli-responsive, multifunctional restorative solutions [12]. Metal materials, especially nanostructured titanium, resist bacterial colonization and improve implant osseointegration. Surface modifications like hydrothermal

etching and laser micromachining modulate biofilm behaviour and mechanical performance. Ceramic and ceramic-based smart repair materials offer excellent biocompatibility, mechanical strength and versatility for tissue engineering and oral restoration. Smart functionalities are introduced via functionalization and composites, enabling structural support with biological activity. Metal-ceramic composites (*e.g.*, titanium-hydroxyapatite) enhance osseointegration, while magnesium alloys improve corrosion resistance and tissue interaction. 3D ceramic scaffolds with surface modification, nanoparticle coatings, or biopolymer integration boost cell adhesion, osteogenesis and antibacterial/antitumor activity. These developments have transformed ceramics into multifunctional, intelligent restorative and regenerative materials [13]. Biological and functional properties relevant to clinical use SRMs are advanced materials that interact dynamically with the oral environment, exhibiting stimulus-response behavior. This enables them to detect and respond to pH changes, temperature variations, mechanical stress and ionic fluctuations. The adaptive nature of SRMs allows the perseverance of mechanical strength, esthetics and functional durability while simultaneously providing biological and therapeutic benefits [14]. A defining bio-functional property of SRMs is their ability to respond under cariogenic or inflammatory conditions. The elevated pH or bacterial activity triggers the controlled release of therapeutic ions that activate antibacterial effects and mineral deposition. Thus, creating a protective feedback cycle, suppressing biofilm growth, promoting remineralization and enhancing the longevity of the restoration by adapting to dynamic intraoral challenges [15]. SRMs provide important functional advantages as outlined in Table 1. Bioactive glass-ceramics exhibit dual performance by combining high mechanical strength with ion-mediated mineralization. The integration of nanotechnology, for instance, the incorporation of silver, copper, or graphene-based nanoparticles into restorative polymers, has been shown to provide sustained antimicrobial effects and reinforce structural integrity. Chitosan-based systems are biocompatible and demonstrate pH-responsive antibacterial actions. SRMs exhibit stress-absorbing behavior, which improves the distribution of occlusal forces and reduces fatigue-related failure. Enhanced marginal sealing lowers the risk of microleakage, postoperative sensitivity and secondary caries. Sustained fluoride release supports long-term anticariogenic action by promoting remineralization at restoration margins [16]. These properties contribute to enhanced longevity of restoration and preservation of surrounding dental tissues, thus expanding the potential clinical applications of SRMs [17]. In addition to biological effects, SRMs provide important functional advantages as outlined in (Table 2).

Table 1: Biological Properties of SRMs

Biological Property	Mechanism	Materials
Antimicrobial Activity	Ag ⁺ , Zn ²⁺ and Cu ²⁺ disrupt bacterial membranes and metabolic pathways, inducing oxidative stress, leading to reduced biofilm viability [12]	Material nanoparticles doped polymers
Remineralization Potential	Ca ²⁺ and PO ₄ ³⁻ ions promote hydroxyapatite formation at the tooth-material interface.	Bioactive glass ionomer cements
Osteogenesis	Sr ²⁺ and Ca ²⁺ ions enhance osteoblast proliferation and bone matrix formation	Strontium-containing bioactive glass

Stimulation		
Angiogenesis Promotion	Cu ²⁺ promotes vascularization and tissue repair by VEGF expression (vascular endothelial growth factor [13]	Copper-doped mesoporous bioactive glass (Cu-MBG)
Biofilm suppression	Elevated local pH and targeted ion exchange inhibit acidogenic bacterial growth [4]	Alkaline filler-based materials

Table 2: Functional Properties of SRMs

Functional Property	Mechanism	Materials
Mechanical strength	Nanofillers and crystalline phases increase strength and fracture resistance	Nanocomposite; Bioactive Glass-ceramic system [8]
Reduced Polymerization Shrinkage	Nano Modification improves marginal adaptation	Nanohybrid resin composites
Thermal Compatibility	Coefficient of thermal expansion similar to dentin, reducing marginal gap formation, minimizes microleakage	Glass-ceramics, nanocomposites
Stimulus-Triggered Ion Release	Environmental changes activate therapeutic ion release	pH-responsive biomaterial [14]
Hygroscopic Expansion	Controlled water sorption improves marginal sealing, limiting microleakage	Glass ionomer-based systems
Fluoride Release	Sustained fluoride ion liberation inhibits demineralization and enhances remineralization	Fluoride-releasing composites [15]

Table 3: Indications and Clinical Applications of SRMs

Indications	Clinical Application	Materials
Caries Prevention	Reduce Secondary caries	Fluoride-loaded Chitosan Nanoparticles in Glass Ionomer Cement [17]
Biomimetic physical properties.	Enhance implant-bone osseointegration	Bioactive Glass Ceramics [18]
Responsiveness to the oral environment	Remineralisation of demineralised surfaces	Chitosan-based Glass Ionomer Cements [19]
Biocompatibility	Lesser monomer leaching from resin and its biological effects	CAD CAM dental polymer [20]

Table 4: Evidence-based performance of smart restorative materials

Material/ Technology	Study types	Key findings
Nanoparticles in restorative materials	Systematic review (2024)	Incorporation of nanoparticles improves composite and adhesive strength, enhances aesthetics and restores longevity. Casein Phosphopeptide-Amorphous Calcium Phosphate (CPP-ACP) combined with nano-sized sodium trimetaphosphate showed enamel remineralization [24]
CAD-CAM resin nanoceramic & PICN materials	Systematic review & meta-analysis (2025)	Survival rates of 90% at 3 years and 84.2% at 5 years in endodontically treated teeth. PICN materials showed lower failure rates (1.61 per 100 restoration-years) compared with resin nanoceramics (5.97 per 100 restoration-years). Debonding was the most common failure mode [25]
Low-shrinkage bioactive Giomer vs nanohybrid composite	Prospective controlled clinical trial (2023)	Both materials were clinically acceptable with predominantly FDI scores of 1-2. One Giomer restoration failed due to retention loss [26]
Ion- releasing resin composite	<i>In vitro</i> bioactivity, mechanical properties	Induced apatite precipitation after 30-9-days in simulated body fluid (SBF); increased microhardness with aging [27]
Microcapsule-based self-healing mechanism	Experimental study (2021)	Crack propagation causes microcapsules to rupture and release a healing agent that polymerizes and repairs damage. Healing efficiency depends on microcapsule size; larger capsules (198 ± 43 μm) achieved up to 76% self-healing efficiency [28]
Antimicrobial Composite	Resin Review of recent developments	Acid formation reduction, inhibit biofilm formation, decrease secondary caries; challenges are biocompatibility and controlled release [29]

Indications of SRMS:

Smart restorative materials (SRMs), due to their ability to sense changes and respond, provide therapeutic, protective and aesthetic benefits in modern dentistry. Their main indications include:

Caries prevention:

Dental caries have always posed a challenge for the dentist. It results from interactions between acid-producing microorganisms, food and tooth factors. These can be prevented by a restorative material that has antimicrobial properties and resists the demineralisation of the tooth [17]

Biomimetic physical properties:

There is a growing need for a restorative material that can mimic the tooth in aesthetics and have similar physical properties close to enamel at the same time [18]. The conventional materials cannot satisfy all the conditions and innovation is much needed

in this regard. The closer one is Nanohybrid composite, but they have not achieved an elastic modulus comparable to enamel and dentin, which can lead to long-term wear and fatigue.

Responsiveness to the oral environment changes:

The oral environment is complex with constant changes in pH, masticatory force, temperature and chemicals in food. Smart materials are needed where they respond to changes in the environment and help protect the teeth from damage resulting from changes in the oral environment [19].

Biocompatibility of restorative materials:

Biocompatibility is an essential feature of all materials used in dentistry. When we attempt to restore missing parts of our teeth, the replacement material itself should not cause adverse reactions or worsen the situation. Therefore, there is a need for innovation to minimize or prevent adverse reactions caused by restorative materials [20].

Clinical applications:

These smart abilities enable a wide range of applications of SRMs in modern dentistry.

Bioactive glass ceramics:

These smart materials release antimicrobial ions (Calcium and Phosphate ions) and help in forming hydroxyapatite. These are specifically being used in implantology to enhance implant-bone osseointegration [21].

Chitosan-Based pH-Responsive Coatings:

Chitosan is a biopolymer with mucoadhesive, pH-responsive and antimicrobial properties. Glass ionomer cements modified with chitosan have been shown to exhibit superior antimicrobial activity against *Streptococcus mutans* and Casein Phosphopeptides-Amorphous Calcium Phosphate (CPP-ACP) incorporated composite resins, glass ionomers precipitate hydroxyapatite when pH drops [22].

Nano-metals to prevent peri-implantitis:

The most important property of nano surfaces is that they eliminate spaces between surfaces. In case of implants, a narrow space between the implant and bone harbours pathogenic microbes leading to periimplantitis. Surface modification of the implant by hydrothermal etching creates needle-like nanostructures in titanium. This can enhance osseointegration and resist bacterial colonization [23].

CAD CAM polymers to reduce monomer leaching from resins:

Many studies have proved that the unbound or uncured monomers and other compounds can leach out from the PMMA or bis-GMA-based polymer material. CAD CAM polymers have shown less monomer release and are more biocompatible than the conventional polymers. Table 3 summarizes these indications and clinical applications of smart materials.

Clinical performance through literature:

The clinical relevance of SRMs is increasingly investigated and supported by laboratory and clinical trials and systematic reviews. Current evidence highlights improvements in mechanical durability, biological activity and long-term survival when smart technologies are incorporated into restorative systems. Table 4 shows clinical performance and key findings of smart restorative materials through current literature. Nanoparticle-enhanced restorative materials demonstrate improved mechanical properties, aesthetics and clinical longevity with survival rates exceeding 84% at 5 years. Emerging technologies include remineralizing agents (CPP-ACP with nano-sodium trimetaphosphate), bioactive ion-releasing composites that promote apatite formation, self-healing materials achieving up to 76% repair efficiency and antimicrobial formulations that reduce secondary caries. PICN (polymer interpenetrating ceramic network) materials outperform resin nanoceramics in failure rates.

Clinical implications:

From a clinical standpoint, the stimulus-responsive and bioactive properties of SRMs carry direct implications for treatment planning and patient selection. Patients at elevated caries risk, including children, older adults with xerostomia and individuals undergoing orthodontic treatment, may benefit most from fluoride- or calcium-releasing restoratives that provide ongoing remineralizing protection beyond the restoration margin [17]. Similarly, in implant dentistry, nanostructured and ion-releasing surfaces that promote osseointegration and resist peri-implant biofilm formation may be particularly valuable in patients with a history of peri-implantitis or compromised bone quality [21, 23]. Incorporating SRMs selectively in these higher-risk groups, rather than as a uniform replacement for conventional materials, may allow clinicians to target therapeutic benefit where it is most needed while limiting unnecessary cost. Translating SRMs into routine clinical use also requires attention to practice-level factors. Survival data for CAD-CAM resin nanoceramic and polymer-infiltrated ceramic network restorations suggest that smart materials can be integrated into standard prosthodontic workflows without compromising clinical performance [25]. However, broader adoption will depend on clinician familiarity with the handling characteristics of bioactive and stimuli-responsive formulations, as well as the development of standardized application protocols and outcome reporting to support evidence-based material selection [30-33]. Cost and accessibility remain practical barriers, particularly in resource-limited settings, underscoring the need for affordable formulations alongside premium options. As digital workflows, including AI-assisted design and 3D/4D bio printing, continue to mature, SRMs are likely to be increasingly incorporated into personalized restorative planning, supporting a shift toward individualized, risk-stratified restorative care.

Challenges, limitations and future perspectives:

SRMs have been developed to overcome the limitations of conventional dental materials by actively interacting with the oral environment. Despite promising laboratory findings, several challenges continue to restrict their widespread clinical application. A major challenge is incorporating smart functionalities without compromising mechanical performance. The addition of bioactive fillers, antibacterial agents, or self-healing components may affect filler-matrix bonding and polymerization, potentially reducing flexural strength, fracture resistance and fatigue performance under occlusal loading. Long-term functional stability also remains a major concern. Therapeutic effects such as ion release, antibacterial activity and remineralization may decline over time because of depletion of active components and material degradation. Improving polymer-network stability, regulating therapeutic-agent release and enhancing resistance to hydrolytic degradation are therefore essential for maintaining consistent performance. Biocompatibility represents another important limitation. Although nanofillers and ion-releasing components can enhance therapeutic activity, excessive concentrations or uncontrolled release of metallic ions and nanoparticles may adversely affect cellular viability and tissue responses. Optimizing release

kinetics, preventing nanoparticle aggregation and establishing safe therapeutic concentrations will be essential for achieving a balance between efficacy and biocompatibility. Clinical evidence remains comparatively limited, particularly regarding long-term mechanical durability, restoration survival and performance under functional oral conditions. Large-scale, well-designed clinical trials with extended follow-up are required to establish the safety, effectiveness and longevity of SRMs and to determine their advantages over conventional restorative materials. Future research should focus on multi-stimulus-responsive systems, bioinspired functionalization, controlled therapeutic-agent delivery and improved material-tissue interactions. Integration with nanotechnology, artificial intelligence and digital manufacturing, including 3D and 4D bioprinting, may facilitate patient-specific restorations capable of adapting to individual biological and functional demands. Such developments could accelerate the transition of SRMs from experimental technologies to clinically reliable, personalized restorative solutions.

Conclusion:

SRMs represent a significant advancement in restorative dentistry by offering adaptive, therapeutic functions. Addressing challenges related to mechanical performance, long-term stability, biosafety and clinical validation will be essential for translating these innovations from the laboratory to routine clinical practice. Multidisciplinary research integrating material science, biology and computational technologies is likely to produce future restorations that are safer, more functional and better suited to patient-centered clinical needs.

References:

- [1] Alomran WK *et al.* *J Funct Biomater.* 2025 **16**:104 [PMID: 40137383]
- [2] Abozaid D *et al.* *Odontology.* 2025 **114**:349. [PMID: 40819015]
- [3] Rath HP *et al.* *Cureus.* 2023 **15**:e47265 [PMID: 38021497]
- [4] Teja KV *et al.* *BMC Oral Health.* 2023 **23**:849. [PMID: 37951871]
- [5] Ferracane JL. *J Funct Biomater.* 2024 **15**:173 [PMID: 39057295]
- [6] Maloo LM *et al.* *Cureus.* 2022 **14**:e30789 [PMID: 36457623]
- [7] Sun J *et al.* *Mater Today Bio.* 2025 **35**:102349 [PMID: 41089722]
- [8] Montoya C *et al.* *Bioact Mater.* 2022 **24**:1. [PMID: 36582351]
- [9] Zhao L *et al.* *Pharmaceutics.* 2023 **15**:2514. [PMID: 37896274]
- [10] Sun J *et al.* *Mater Today Bio.* 2025 **35**:102349. [PMID: 41089722]
- [11] Ved M *et al.* *Cureus.* 2025 **17**:e82858. [PMID: 40416140]
- [12] Vasluianu RI *et al.* *J Funct Biomater.* 2025 **16**:318 [PMID: 41003389]
- [13] Yadav D *et al.* *Curr Pharm Biotechnol.* 2024 **25**:981 [PMID: 37594093]
- [14] He Y *et al.* *Pharmaceutics.* 2023 **15**:1837 [PMID: 37514024]
- [15] Mandhalkar R *et al.* *Cureus.* 2023 **15**:e33779 [PMID: 36819367]
- [16] Pandey A. *Dental.* 2024 **6**:15. [DOI: 10.35702/dent.10015]
- [17] Altınışık H *et al.* *Clin Oral Investig.* 2024 **28**:504 [PMID: 39196417]
- [18] Zhang K & Van Le Q. *J Compos Compounds.* 2020 **2**:10. [DOI: 10.29252/jcc.2.1.2]
- [19] Nishanthine C *et al.* *Int Dent J.* 2022 **72**:785. [PMID: 35810014]
- [20] Wei X *et al.* *Clin Oral Investig.* 2022 **26**:2887. [PMID: 35083585]
- [21] Singer L *et al.* *BMC Oral Health.* 2023 **23**:105. [PMID: 36797710]
- [22] Mazzaoui SA *et al.* *J Dent Res.* 2003 **82**:914 [PMID: 14578505]
- [23] Rawat N *et al.* *ACS Omega.* 2022 **7**:47070 [PMID: 36570258]
- [24] Dipalma G *et al.* *J Clin Med.* 2024 **13**:5268 [PMID: 39274481]
- [25] Yuen JJX *et al.* *J Prosthet Dent.* 2025 **133**:1437.e1 [PMID: 39922746]
- [26] Toz-Akalin T *et al.* *Oper Dent.* 2023 **48**:10 [PMID: 36508717]
- [27] Bompolaki D *et al.* *Dent Clin North Am.* 2022 **66**:517 [PMID: 36216444]
- [28] Ning K *et al.* *Dent Mater.* 2021 **37**:403 [PMID: 33353737]
- [29] Sun Q *et al.* *Polymers (Basel).* 2021 **13**:1590 [PMID: 34069312]
- [30] Wang X & Ding T. *J Funct Biomater.* 2024 **15**:165 [PMID: 38921538]
- [31] Marovic D *et al.* *Materials (Basel).* 2022 **15**:4042 [PMID: 35744101]
- [32] Zailai A *et al.* *Cureus.* 2026 **18**:e102221 [PMID: 41585617]
- [33] Jiang W *et al.* *Caries Res.* 2021 **55**:21. [PMID: 33341803]

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