Egyptian Prosthodontic Association (EPA Newsletter)

Bioactive Smart Adhesives in Fixed Prosthodontics: A Paradigm Shift in Adhesive Dentistry

Electronic Newsletter

Volume 5. Issue 7

July 2026

Introduction:

In recent years, the field of materials science has witnessed a remarkable evolution with the advent of smart materials. These materials, capable of responding dynamically to external environmental stimuli in a useful, reliable, reproducible and often reversible manner. [1]

McCabe Zrinyi (2009) defined bio smart materials as "Materials that can be altered by external stimuli and return to their original state once the stimulus is removed." This intelligent behavior is useful because the materials sense stimuli from their environment. These materials have properties that may be altered in stress, temperature, moisture, pH, and electric or magnetic fields. Due to their smart behavior, scientists have sought to utilize these materials in various fields.[2]

Bio intelligent smart adhesives are advanced dental adhesives capable of responding dynamically to changes in the oral environment. They aim to improve the longevity of indirect restorations while reducing biological complications such as hybrid layer degradation and secondary caries.

Smart adhesives materials are classified into:

1. **Remineralizing adhesives:**

They Contain bioactive fillers that release calcium and phosphate ions. One of the primary mechanisms by which bioactive dental adhesives prevent caries is the sustained release of therapeutic ions, namely calcium (Ca^{2+}), phosphate (PO_4^{3-}), and fluoride (F^-), at the adhesive–tooth interface. These ions facilitate the nucleation and growth of hydroxyapatite or fluorapatite crystals, which are more acid-resistant than natural tooth minerals, promoting remineralization of demineralized enamel and dentin. [3]

Materials such as bioactive glass and nano-hydroxyapatite (nHAp) are commonly used to enable ion release, particularly under acidic, caries-prone conditions.

TheraCem Ca (BISCO) is a dual cure self-adhesive resin cement that continuously realizes Ca ions and promotes alkalization of the local environment through acid neutralizing activity.

This mineral deposition reinforces the structural integrity of the adhesive–tooth interface, forms a stable, mineral-rich layer, seals dentinal tubules, reducing postoperative sensitivity, and fills micro-gaps, thereby minimizing bacterial infiltration and microleakage.[4]

2. **Antibacterial smart adhesives**:

Inhibit bacterial colonization at restoration margins.

PH responsive adhesives: respond to acidic changes in the oral environment, providing on – demand therapeutic activity. Bioactive adhesives incorporate antimicrobial agents as additive particles or functional monomers within the resin matrix, including silver nanoparticles (AgNPs), quaternary ammonium compounds (QACs), zinc oxide (ZnO), chlorhexidine.

In addition to direct antimicrobial effects, many agents demonstrate contact-killing or ion-mediated actions. For example, silver and zinc ions released over time inhibit bacterial growth without traditional antibiotics, providing sustained long-term antimicrobial protection.[4]

6. **Self-healing adhesives:**

These adhesives contain microcapsules capable of repairing micro cracks e.g. 7.5% Poly (urea-formaldehyde) (PUF) microcapsules filled with triethylene glycol dimethacrylate (TEGDMA) and a polymerization initiator.[5] **figure 1&2**

7. **Biomimetic adhesives:**

That imitate natural tooth structure and biological mineralization.

Smart glass ionomer cement (GICs):

Davidson first suggested the smart behavior of GIC. It is related to the ability of a gel structure to absorb or release solvent rapidly in response to a stimulus that can be temperature, change in pH.[6]

The other aspect of the smart behavior of these materials is the fluoride release and recharge capacity. The smart ionomer mimics the behavior of human dentin. Resin-modified glass ionomer cement, compomer or giomerare also seen to exhibit these smart characteristics. Ex. GC Fuji IX EXTRA**.**

It also undergo thermally induced volumetric changes close to those of the tooth substance.[2,7]

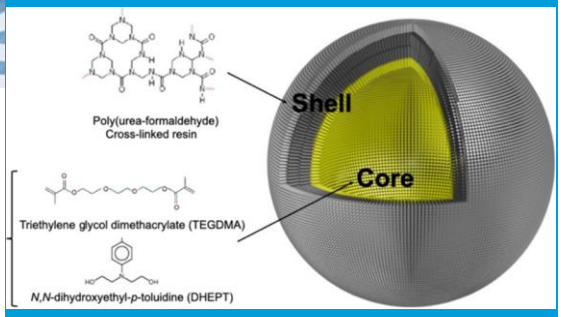

Figure 1: Graphical abstract showing the microcapsule components. The shell contains poly (urea-formaldehyde), and the core consists of TEGDMA-DHEPT healing agents.[11]

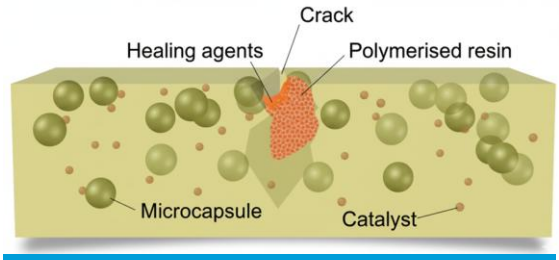

Figure 2: illustrates the **microcapsule-based self-healing polymer/composite concept.** where embedded microcapsules containing a healing agent rupture when a crack propagates through the material. The released healing agent contacts a dispersed catalyst, polymerizes, and seals the crack.[12]

5. Thermoactivated adhesives:

Thermo-activated adhesives typically include dual-curing resin cement and preheated resin composites (VOCO VisCalor Bulk) that use temperature (50-60° C) to temporarily lower their viscosity.

This process allows precise, ultra-thin cementation of fixed restorations like crowns, veneers, and bridges, accelerate polymerization, enhance wettability, increase the degree of conversion, and improve the final mechanical properties.

Some materials soften at specific temperatures, reducing shear bond strength and allowing safe, damage-free retrieval of restorations. [8,9]

Shape-changing materials (SCMs): characterized by shape-changing capability (SCC), defined as the ability of a material to alter its shape when exposed to an appropriate stimulus. Upon removal of the stimulus, they progressively recover their original shape. **Figure3** Such as polyacrylate copolymers polynorbornene, segmented polyurethanes, segmented polyurethane ionomers , epoxy-based polymers , thiolene-based polymers , crosslinked ethylene-vinyl acetate copolymer and styrene-based polymers.

1. Chameleon – Effect adhesives:

Chameleon –effect restorative materials utilize smart chromatic technology, adaptive translucency, and structural color mechanisms to blend seamlessly with surrounding tooth structure, reducing or eliminating the need for conventional shade matching. Examples include OMNICHROMA, Vitra APS Unique, and Beautifil II LS. Although these materials are restorative composites rather than adhesives, they represent an important application of smart materials in esthetic dentistry.[10]

Advantage of Bio-Intelligent adhesives in fixed prosthodontics:

Reduce liability to secondary caries

Longer restoration survivability

Improved hybrid layer strength

Enhance patient outcomes

Bioactive therapeutic effect

Reduce marginal leakage

Conservative tooth preparation support.

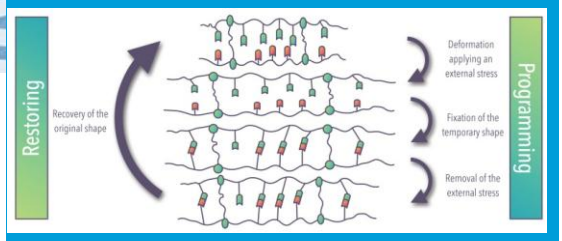

Figure3: Schematic representation of the molecular mechanism of shape-memory material (SMM)

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This Issue is Prepared by:

Dr. Abeer Atef Younis

Associate Professor of Fixed Prosthodontics, Faculty pf Dentistry, Tanta University.

Egyptian Prosthodontic Association (EPA)

Address: 15 Ahmed Abo El-Ela St. – 8th district Nasr City, Cairo Egypt.

Mobile : 010 28203484 (Calls & Whatsapp) Phone: 02 26705035