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Bioactive Materials for the Future of Dentistry

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Abstract: The term bioactivity is becoming more common in the fields of medicine and dentistry. Its positive implications often lead to its use in marketing dental restorative materials. However, there is some confusion surrounding the definition of the term, and concerns about its potential overuse have been raised. In response, FDI has decided to publish a Policy Statement regarding the bioactivity of dental restorative materials to clarify the term and outline some precautions for its use in advertising. The background information for this Policy Statement was gathered from current literature, primarily from the PubMed database and various online sources. Bioactive restorative materials should provide beneficial effects that are local, intended, and non-toxic, without interfering with the primary function of the material, which is to replace dental tissue. Three mechanisms of bioactivity for these materials have been identified: purely biological, a combination of biological and chemical, or strictly chemical. When the term bioactivity appears in advertisements or descriptions of dental restorative materials, it is essential to provide scientific evidence—whether from in vitro or in situ studies, and ideally from clinical trials—that outlines the mechanism of action, the duration of the effect (particularly for materials that release antibacterial agents), and the absence of significant adverse biological side effects, such as the development and spread of antimicrobial resistance. Also, it must be proven that the main goal—like fixing the shape and function of damaged or missing teeth—is not harmed. This should be backed up by data from lab tests and studies on patients.

Keywords: Bioactive material; dentistry; remineralization.

Teeth were among the first organs to have their function effectively restored using inert filling materials that are now well-known to the public, such as amalgams, polymeric resin composites, and gutta-percha. These materials have provided significant benefits to the health of millions of patients around the globe. In recent decades, there has been remarkable progress in the field of dental materials. However, dental diseases like caries and periodontitis remain very common among people of all ages [1].

Many of the practical issues and discomfort linked to dental and periodontal decay have been significantly reduced due to modern methods of restoring hard and soft dental tissues. However, the dental filling procedures we have today are still not ideal; even though amalgams offer long-term stability, they have increasingly fallen out of favor due to concerns about mercury release, risks to dental practitioners, and challenges with waste management [2].

The polymeric resin composites that have replaced traditional materials are known to promote bacterial adherence and biofilm formation [4]. In terms of current endodontic procedures, these methods leave the refilled tooth significantly more fragile and susceptible to fractures compared to natural teeth. Additionally, while dental implants have become a common solution for complete tooth replacement, they are not without their issues. The dental implant root is directly anchored to the alveolar bone, which results in inadequate cushioning against masticatory forces and can lead to long-term problems such as marginal bone loss and peri-implantitis [3]. So, there's a clear need for new biomaterials that can not only provide mechanical support but also integrate biologically with the restored dental tissues.

These bioactive materials are expected to interact with the body's cells and the oral environment to help regenerate natural tissue and prevent future tooth decay [4]. As a result, bioactive materials are likely to become the foundation of advanced dentistry in the future. Some interesting studies have been published about improving dental resin composites and materials used for filling root canals by adding antibacterial properties [5].

These improvements aim to prevent secondary cavities and infections in root canals. Secondary cavities are a major health issue and are the main reason why many dental restorations fail. These infections happen because the dental adhesives and resin composites used today tend to encourage bacteria to stick to and grow on the restored areas [5]. Additionally, these materials tend to break down over time, causing cracks and requiring repeated treatments, which can further damage the teeth [10]. Some problems with dental restoration failure might be solved by adding substances that kill bacteria on contact, such as quaternary ammonium or tiny particles and tubes made of metal oxides , into the resin material.

This would help stop the growth of bacteria that form sticky layers on teeth. These methods have already been tried in small clinical studies, like one by Melo et al., where a special compound was mixed with dental resin to create a mouth device that could effectively reduce harmful bacteria . Another approach involves adding tiny particles of amorphous calcium phosphate, which slowly release calcium and phosphate over time, helping to rebuild tooth enamel [6].

In general, the current trend indicates that over the next ten years, there will likely be fast progress in creating and testing new, improved dental filling materials. This growth is largely driven by the dental industry's strong interest in developing new products with better features. Currently, the preferred treatment for severe dental pulp inflammation (irreversible pulpitis) involves endodontic procedures and sealing root canals with non-reactive materials like gutta-percha. However, a major issue with modern endodontic treatments is that the tooth's pulp is completely removed, losing its natural ability to maintain and mineralize the tooth. Without a functioning pulp that contains cells (odontoblasts) that produce dentin, the tooth becomes much more likely to crack or develop further problems [7].

One of the biggest challenges in dentistry today is figuring out how to regrow a working periodontal ligament after putting in a dental implant. The PDL is a thin band of strong, flexible tissue full of collagen and blood vessels. It connects the tooth root to the surrounding jawbone and helps absorb the pressure from chewing. When a tooth is removed, the empty socket fills with dense bone, which is later used to anchor the implant. However, because the implant is directly attached to the bone, the bone ends up bearing more stress than it would with a natural tooth. Over time, this can lead to bone loss around the implant and increase the risk of infection, known as peri-implantitis [8].

The buildup of dental plaque biofilms and the ongoing inflammation linked to micro-fractures in bone due to excessive mechanical stress on the implant surface only speed up this issue. Consequently, there is a pressing need for biomaterials that can regenerate periodontal ligament-like tissue around dental implants to improve their long-term stability. The primary challenge with traditional bioscaffolds, such as those made from collagen or fibrin, is that they often promote mineralization and bone formation on the implant surface. While these scaffolds are excellent options for repairing periodontal bone defects, an effective strategy for reconstructing the periodontal ligament should ideally involve a biomaterial that resists mineralization. Recently, we explored the potential of human Decellularized Adipose Tissue in this regard, showing that this biomaterial has a significantly lower tendency to be mineralized by osteogenic stem cells compared to other conventional scaffolds like collagen [9].

In the field of implantology, bioactive materials have been utilized as coatings to enhance the osseointegration of dental implants and improve their overall biological performance. Dental implants are typically constructed from bioinert materials such as stainless steel 316L, commercially pure titanium, its alloy Ti-6Al-4V, and cobalt–chromium alloys. Various techniques can be employed to apply bioactive coatings to the surfaces of dental implants, including enameling, sol–gel processes, electrophoresis, laser cladding, and thermal spraying. The first bioactive glass, 45S5 Bioglass, was developed around 50 years ago. Other bioactive coatings include hydroxyapatite, zirconium dioxide, titanium dioxide, and zinc oxide. The properties of these materials can be further improved by incorporating active agents for specific purposes. For example, adding silver ions to the bioactive glass structure can enhance its antibacterial properties [10].

There is a significant increase in research focused on tissue engineering and bioactive materials for dental applications. Unlike previous generations of dental materials, which were primarily selected for their inert properties and minimal adverse reactions, the next generation of dental materials is anticipated to have genuine biological effects on the surrounding oral and dental tissues, enhancing integration and functionality.

In conclusion, research in dental materials is evolving from a focus on biocompatibility to an emphasis on bioactivity. Today, the ideal dental material not only needs to be biocompatible [18], but also should exhibit biomimetic and bioactive characteristics. Various bioactive materials can be utilized in endodontics, restorative dentistry, and implantology, with the choice of the right material depending heavily on the specific application and its properties.

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