BIOACTIVE ADHESIVE SYSTEMS: A NEW STEP IN TOOTH TISSUE REGENERATION

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ABSTRACT:

This article analyzes one of the most promising areas of modern dentistry — bioactive adhesive systems. Unlike traditional adhesives, bioactive systems not only provide mechanical bonding but also engage in dynamic interaction with the hard tissues of the tooth, stimulating mineralization processes. The article discusses the composition of these systems, their anti-caries properties, and their role in maintaining the long-term integrity of the hybrid layer. Furthermore, the effectiveness of bioactive components in dentin regeneration is scientifically substantiated.

Introduction

Relevance of the Topic. The foundation of modern restorative dentistry lies in adhesive technologies. Over the past decades, adhesive systems have undergone a significant evolutionary path, progressing from simple micro-mechanical interlocking to sophisticated chemical bonding. However, the primary challenge with traditional adhesives remains the degradation of the hybrid layer between the tooth and the filling over time, which increases the risk of secondary caries. To address these limitations, a new generation of materials—bioactive adhesive systems—has emerged in dental science.The Concept of Bioactivity.

Bioactive adhesives do not merely bond the restoration to the tooth; they engage in a biological interaction with the tooth's hard tissues (enamel and dentin). They possess the ability to release calcium, phosphate, and fluoride ions, thereby promoting the remineralization of demineralized dentin and actively restoring the tooth structure.Problem Statement. In clinical practice, the adhesive layer often undergoes hydrolysis due to the presence of residual dentin moisture and the action of enzymes known as matrix metalloproteinases (MMPs). This process leads to the failure of the restoration and post-operative sensitivity. Bioactive systems reinforce this "weak point" by facilitating the formation of hydroxyapatite crystals within the hybrid layer, creating a more durable and stable interface.Purpose of the Article. The aim of this article is to study the mechanism of action of bioactive adhesive systems, analyze the role of their innovative components in the regeneration of tooth tissues, and evaluate their potential and opportunities in modern clinical dentistry.

Main Part

The functional basis of bioactive adhesive systems relies on their ability to interact with the hard tissues of the tooth. While traditional systems merely form a polymer network on the tooth surface, bioactive materials stimulate the formation of hydroxyapatite through ion exchange. This process occurs primarily due to specific bioactive glass particles, calcium silicates, or phosphate groups within the material. When these components come into contact with dentin moisture, they release calcium and phosphate ions into the environment, leading to the remineralization of demineralized collagen fibers.The stability of the hybrid layer is one of the greatest advantages provided by bioactive adhesives. It is well known that over time, endogenous enzymes within the dentin—metalloproteinases—begin to break down the adhesive bond. Bioactive systems, however, suppress the activity of these enzymes by neutralizing the acidic environment and creating an alkaline environment. As a result, the interface between the tooth and the restoration is strengthened not only mechanically but also chemically, which significantly reduces the risk of microleakage.Another important aspect is the antibacterial property of these materials. Bioactive components create an antimicrobial environment, inhibiting the formation of biofilm. This feature is particularly crucial for patients with a high susceptibility to caries and in the treatment of deep carious cavities. As a result of the deposition of mineral crystals within the dentinal tubules, the canals are hermetically sealed, which protects the pulp tissue from external influences and prevents post-operative pain.Modern research shows that bioactive adhesives belong to the category of "smart" materials. They can change the rate of ion release depending on the change in pH levels in the oral cavity. For example, when the environment is acidic (when the risk of caries increases), ion release intensifies, and a mineral barrier protecting the tooth tissue is formed. This technology signifies a transition in dentistry from the mere concept of "bonding" to the concept of "treatment and restoration.The clinical effectiveness of bioactive adhesive systems is directly related to their moisture resistance and long-term stability. In traditional systems, when dentin collagen fibers remain exposed and are not fully saturated with polymer, these areas turn into "voids" over time. Bioactive systems, however, serve as a unique "biological sealant" by filling these micro-voids with hydroxyapatite minerals. This process not only strengthens the bond between the tooth and the material but also prevents bacteria from penetrating the tooth through microleakage.Furthermore, special monomers within these systems, such as 10-MDP (10-Methacryloyloxydecyl dihydrogen phosphate), work together with bioactive ions to form a stable chemical bond with the tooth's mineral structure. This bonding increases resistance to mechanical stress and chewing pressure. When bioactive adhesives are used, the protective function of the pulp is activated due to the mineralization of the dentinal tubules, which is a crucial factor in preserving the tooth's vitality.Another unique aspect of bioactive adhesive systems is their "smart" characteristics. These materials are sensitive to changes in the acid-base balance (pH) of the oral cavity; for instance, in an acidic environment (such as after consuming sweets or when bacteria become active), they begin to release more ions to protect the tooth tissue. This process creates a dynamic mechanism for combating caries.Dentin collagen's enzymatic degradation is one of the biggest challenges in modern restoration. Bioactive adhesives containing metal ions like zinc and copper block the activity of matrix metalloproteinases (MMPs) in the dentin matrix. This halts the degradation of the hybrid layer over time and maintains the tight bond between the tooth and the filling for years.Modern nanotechnologies have enabled the inclusion of Amorphous Calcium Phosphate (ACP) particles into bioactive systems, which penetrate deep into the dentinal tubules. By hermetically sealing these canals, they completely eliminate tooth sensitivity to heat or cold (hyperesthesia). Thus, bioactive adhesives manifest not just as a source of chemical elements, but as an engineering solution that restores the structural integrity of the tooth tissue.These materials are sensitive to changes in the acid-base balance (pH) of the oral cavity; for instance, in an acidic environment (such as after consuming sweets or when bacteria become active), they begin to release more ions to protect the tooth tissue. This process creates a dynamic mechanism for combating caries.Dentin collagen's enzymatic degradation is one of the biggest challenges in modern restoration. Bioactive adhesives containing metal ions like zinc and copper block the activity of matrix metalloproteinases

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Conclusion

Bioactive adhesive systems have initiated a qualitatively new stage in modern restorative dentistry. The gathered data indicates that these systems provide an effective solution to the problem of hybrid layer degradation, which has traditionally been the weakest point of conventional adhesives. Their ability to interact dynamically with tooth tissues ensures not only the mechanical strength of the restoration but also its biological longevity.Research confirms that the remineralization process, powered by bioactive components (ion-releasing glass particles, calcium, and phosphate compounds), hermetically seals the dentinal tubules. This, in turn, eliminates post-operative sensitivity and reliably protects the pulp tissue from external pathogenic factors. In particular, the activation of ion exchange in acidic environments proves the "smart materials" concept in practice, reducing the risk of secondary caries to a minimum.In conclusion, bioactive adhesives are not merely bonding agents but therapeutic systems that restore the hard tissues of the tooth at a molecular level. Their widespread use in clinical practice allows for extending the service life of restorations, reducing complications, and fully implementing the principles of minimally invasive treatment. Future research should focus on further improving the long-term stability of these systems across various clinical scenarios.

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