

Research Progress and Industrial Transformation of Dental Polymer Materials

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Abstract

Conventional oral materials are artificial synthetic materials and auxiliary materials used to repair human oral and maxillofacial defects or missing soft and hard tissues. Currently, commonly used oral materials include metals, ceramics, molecular composites, etc. Among them, polymer materials are due to their structure. It is widely used in oral materials due to its diversity and its own physicochemical properties. This article mainly describes the application status of polymer materials in stomatology and the direction of industrial transformation of polymer materials for stomatology in the future, for reference.

Keywords

Molecular materials; Stomatology; Industrialization

1. Introduction

The human maxillofacial region can suffer defects or loss due to factors such as disease, trauma, and physiological degeneration that interfere with the normal physiological function of oral tissues. This can affect the integrity of oral tissues and organs, and consequently, their proper function and aesthetic appearance. Therefore, the materials and auxiliary materials required to repair these missing or defective tissues and achieve proper function or aesthetic appearance are oral materials. The development of oral materials must keep pace with the advancement of dentistry, and the application of new materials has also driven advancements in oral medical technology. Among the various oral materials, polymers are widely used in oral clinical trials due to their excellent biocompatibility and good physical properties. This article focuses on the application of polymer materials in dentistry, specifically the clinical uses and properties of various materials, aiming to provide insights into the development and industrial transformation of their application in dentistry.

2. Polymer Materials for Oral Prevention

With improving living standards, dental caries has become a common oral disease. Due to its irreversible nature, dental caries requires a focused approach to prevention. Commonly used preventive products include: plaque/caries indicators, fluoride-releasing materials such as fluoride varnish, and pit and fissure sealants.

2.1 Plaque/Caries Indicators

Plaque/caries indicators are agents used to indicate dental conditions. To eradicate the condition, further restoration and effective sterilization are necessary. Plaque indicators utilize the strong binding ability of dyes and bacteria. During mouthwash, the dye remains in the plaque area, indicating the condition and facilitating subsequent treatment. Plaque indicators are generally available in a variety of forms: tablets, sprays, liquids, gels, and more. They are available in two-color or single-color versions, with recommended use based on the specific pathogens and cost. After a caries indicator reveals the location of caries, further treatment primarily involves bacterial removal to ensure recurrence or complete restoration. For deeper, more thorough removal, the restorative material requires enhanced antibacterial properties. This is typically achieved by adding a biocide. Alternatively, sonodynamic or photodynamic methods can be used to achieve antibacterial properties.

2.2 Anti-caries Materials

Pit and fissure sealants and fluoride-containing materials are the main materials for preventing caries. They mainly prevent caries by blocking bacterial invasion through sealing the pits and fissures of teeth, thereby improving the acid resistance of tooth enamel. Pit and fissure sealants are mainly composed of a light-curing material based on methacrylate and a resin-based material for cavity repair; fluoride-containing materials are a combination of fluoride varnish based on natural resin, a coating material based on ethyl acetate, and fluorinated foam [1].

3. Polymer Materials for Oral Restoration

Compared to metal-ceramic materials, polymer materials can be manipulated in color and hue using various additives, allowing them to more perfectly match the aesthetic appearance of natural teeth and exhibiting improved biocompatibility. Currently, commonly used polymer materials for oral restoration include resin-based composites with a polymerizable resin matrix and inorganic fillers or fiber reinforcements, and denture materials based on methyl methacrylate. Resin materials include direct restorative materials, indirect restorative materials, enamel adhesives, and pretreatment agents; denture materials include denture relining materials, maxillofacial prostheses, denture resins, and removable base resins. Treatment failure is primarily due to damage to the restorative material or microbial infection. Therefore, research is focused on enhancing the antibacterial and antimicrobial properties of restorative materials or improving their physical properties. More importantly, these efforts aim to preserve the mechanical advantages and excellent bonding properties of the original materials.

3.1 Denture Materials

The basic requirements for denture materials are: good biocompatibility, non-toxicity, odorlessness, chemical stability, water insolubility with low water absorption, excellent physical properties, low cost, and simple production. Common denture materials are categorized into soft polymers and hard polymers. Hard polymers, such as polymethacrylate resins and their modified products, are primarily used for denture bases, dentures, and denture liners. Soft polymers, primarily silicone rubber and acrylic soft resins, are used for denture liners and maxillofacial restorations. Hard polymers are widely used due to their low cost, good biocompatibility, and stability in the oral environment. However, due to their poor physical properties, they are prone to breakage during use, leading to treatment failure. To achieve better treatment outcomes and reduce the risk of tooth fracture, composite materials composed of fillers and resin matrices are currently more recommended.

Dental fillers include fiber fillers and inorganic fillers. Nanoscale fiber fillers and inorganic fillers are often added to enhance the strength of the matrix. Due to their dispersibility within resins, fiber fillers are essential for enhancing the physical properties of resin materials. Adding nanoparticles of zinc oxide, zirconium oxide, and other materials to polymethacrylate resins not only improves the resin's antibacterial properties but also enhances its flexural and tensile properties. However, excessive addition is crucial, as this can weaken the resin's strength and lead to treatment failure. Therefore, choosing the right dental filler, adding it in the right proportions, and employing optimal processing techniques are crucial to achieving the desired balance of properties and achieving optimal therapeutic results.

Because polymer materials have high porosity and roughness, they are more suitable for bacterial growth. Therefore, the addition of other materials is necessary to enhance their antibacterial properties. There are two common methods for improving the antibacterial properties of denture materials: adding antimicrobial substances, such as zirconium oxide nanoparticles, chitosan, and quaternary ammonium salts, not only enhances the resin's physical properties, but also provides antibacterial effects and improves aesthetics. Alternatively, coating the material with antimicrobial substances, such as antimicrobial peptides, salivary histones, and hyaluronic acid, effectively inhibits initial fungal adhesion and biofilm formation, thereby achieving an antibacterial effect.

3.2 Resin-based Composites

Resin-based composites include polyacid-modified composite resins, fiber-reinforced resin composites, and composite resins. Polyacid-modified composite resins are more similar to composite resins in terms of performance, forming a complex material consisting of a composite resin and glass ionomer dissolved in water. Fiber-reinforced resin composites offer high strength, excellent fatigue resistance, and superior aesthetics, and are composed of a polymerizable resin and reinforcing fibers. Composite resins, on the other hand, are composed of methacrylate resins and inorganic particulate fillers.

Resin-based composites are prone to treatment failure and secondary caries due to polymerization shrinkage and

interfacial microleakage. Polymerization shrinkage occurs when flexible polymer chains entangle during the curing process, leading to material damage and treatment failure. However, this problem can be significantly improved by adding fillers to the resin base material that can mitigate polymerization shrinkage, along with excipients that enhance mechanical properties. Silanes are commonly used as fillers to improve the mechanical strength of the resin material and reduce polymerization shrinkage.

Polymerization shrinkage of restorative resins can also cause microleakage at the edges of restorations, potentially leading to bacterial invasion and infection, resulting in secondary caries. Therefore, it is necessary to add antibacterial and antimicrobial materials to the restoration materials to improve the antibacterial properties of the restoration resin and improve the success rate of treatment. At present, the most commonly used antibacterial agents are mixed quaternary ammonium salts and polymeric quaternary ammonium salts. Antimicrobial peptides, antibiotics and other antibacterial materials can be used on polymer chains to effectively kill *Streptococcus mutans*. However, because the addition of organic substances will inevitably affect the physical properties of the composite material to a certain extent, it is necessary to add nanomaterials with antibacterial and antimicrobial effects to enhance the antibacterial and antimicrobial capabilities of the composite material while also enhancing its physical properties. Materials containing silver phosphate and calcium phosphate particles have antibacterial properties, high strength and elastic modulus properties; materials containing nano silver, quaternary ammonium salts and nano amorphous calcium phosphate have a diffusion bactericidal effect, increase the surrounding pH value, resist acidification, promote mineralization, and increase hardness. Therefore, adding a multifunctional polymer material for oral restoration can not only reduce the bacterial adhesion of oral biofilm and play an antibacterial and antimicrobial effect, but also improve the strength and fracture resistance of the restoration material. It is a new antibacterial material [2].

4. Polymer Materials for Oral Implants and Tissue Reconstruction

Oral implant materials primarily refer to implantable biomaterials designed to be partially or fully embedded in the soft tissue and bone of the oral and maxillofacial region. As treatment materials for oral and maxillofacial conditions, they are primarily intended to repair defects in oral and maxillofacial tissues and organs, restore their basic physiological functions, or repair missing or damaged oral and maxillofacial tissues and organs. Basic performance requirements include good biocompatibility, excellent chemical stability, reasonable physical and mechanical properties, antibacterial and sterilization properties, and enhanced clinical operability. Currently, commonly used polymer materials for oral implants and tissue reconstruction include metals, ceramics, and organic polymers. Due to the widespread interest in organic polymers, the following analysis will analyze the performance of polymer materials from three perspectives.

4.1 Artificial Root Materials

Artificial root materials are designed to transfer and distribute occlusal forces and other forces acting on dental implants to the jawbone tissue, thereby reducing the stress on the implant and extending its lifespan. Traditional metal and metal oxide materials are widely used due to their excellent tissue compatibility. However, they are susceptible to bacterial attachment, resulting in weak antibacterial and antimicrobial properties, making them more susceptible to inflammation and implant failure. Therefore, the incorporation of polymer materials into implants enhances antimicrobial efficacy and increases the lifespan of implants.

4.2 Artificial Defect Restorative Materials

In the dental industry, artificial defect restorative materials primarily refer to synthetic materials used to replace or repair bone tissue in maxillofacial bone defects or to reconstruct tissue that has lost its physiological function. Artificial bone defect restorative materials must not only meet the biosafety and physical properties of implant materials but also meet specific biological requirements such as osteoconduction, osteogenesis, and osteoinduction. The main types of restorative materials are metals, ceramics, organic polymers, and composite materials. In recent years, the commonly used bone defect repair materials based on organic polymers mainly include: composite scaffolds containing hydroxyapatite and hemihydrated calcium sulfate, bone replacement materials for alveolar repair that encapsulate collagenase, degradable injectable composite materials for bone defect repair, and hydrogel materials with multiple functions such as tissue adhesion and cell compatibility for promoting mandibular regeneration [3]. The main principles of these materials are still antibacterial and enhanced physical and mechanical properties.

4.3 Soft Tissue Reconstruction Materials

Oral soft tissue reconstruction materials are a kind of prosthetic prosthesis, the main material of which is a

maxillofacial prosthetic repair material containing silicone rubber or polytetrafluoroethylene. Among them, silicone rubber material is a polymer material with good physical and chemical stability and physiological inertness, and is non-toxic, odorless, and has good anti-aging properties and excellent biocompatibility. It is currently an ideal oral soft tissue repair material. However, silicone rubber also has disadvantages such as low molecular polarity, strong hydrophobicity, and poor affinity for tissue cells. Further surface modification is required, and surface treatment or blending modification using various methods such as radiation surface grafting and plasma surface treatment can better meet the use effect. Polytetrafluoroethylene has good elasticity and flexibility, is easy to physically reshape, and has better organization and fewer complications. It is a white polymer with high crystallinity and high chemical stability [4].

5. Other Oral Polymer Materials

Other oral polymer materials primarily serve as oral restorative materials, including polishing materials, gingival retraction materials, impression materials, abrasives, periodontal diaphragms, oral ulcer treatments, and tissue wound healing aids. Impression materials are primarily used to record or reproduce the appearance of oral soft and hard tissues. Therefore, they require excellent biosafety and a comfortable consistency, as well as appropriate working and setting time cycles. They also need good hydrophilicity, softness, and elasticity. After setting, they also need sufficient tear and compression strength, precise detail reproducibility, and physical stability. Currently, the most commonly used impression materials are seaweed, agar, and rubber, and they have advanced processing and production capabilities.

Enamel damage caused by caries or tooth wear is typically filled with restorative resins. However, inducing enamel growth and remineralization in the defect area using a new material is a highly advanced treatment option. Because enamel is the hardest tissue in the human body, no restoration can match the perfection of the human body's natural healing capabilities. Current medical treatments primarily use protein and peptide molecular solutions to induce mineralization or hydrogels to drive mineralization. However, neither approach truly simulates the natural structure of human enamel and cannot match its unique physical properties. Therefore, further research is needed to mimic the structure and function of natural enamel. For example, experts have developed a biomimetic alumina template-assisted double-layer adhesive that forms a mineral with well-oriented hydroxyapatite crystals that is comparable to natural enamel.

Dental tissue has tubules, and sensitive neural sensors connect the tubules to the dental pulp cavity. Therefore, when dentin is exposed to the environment for various reasons, it can cause significant pain. There are two common methods for alleviating dentin hypersensitivity: A spray with neuropolarizing substances such as potassium ions is generally used; if radical treatment is required, effective occlusion of the dentinal tubules is required. Dendrimers, self-assembling peptides, and bioactive glass are commonly used to induce collagen mineralization.

Tooth regeneration and functional restoration are currently a major research challenge in the medical field. The most important aspect is the study of root regeneration, which involves not only material research but also the study of human mechanisms. In recent years, many experts have been studying the differentiation and regenerative capabilities of stem cells, primarily with the goal of developing drugs or materials that, when combined with dentin, can regenerate dental tissue within the human body. This will be a research direction for the medical community for many years to come.

6. Conclusion

This article primarily introduces the application and development of polymer materials in the fields of prevention, repair, and regeneration in dentistry. It also briefly describes the functions and current status of different molecular materials based on the needs of the field. The aim is to highlight the research progress of polymer materials for dentistry and to provide directions for the industrial transformation of polymer materials, hoping that future medical research can meet market needs and product applications.

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