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Literature Review

Dental Polymeric Composites: A Narrative Review of Properties and Clinical Performance

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ABSTRACT

Introduction: Synthetic and natural polymers have attracted significant interest due to their adaptability and wide use in biomedical sciences. Their chemical and physical properties can be tailored to meet specific requirements, making them essential in the development of advanced healthcare solutions. **Objective:** The objective of this narrative review is to highlight the biomedical applications of polymers, with particular emphasis on the dental field, while assessing their stability, degradation, and bioactivity. **Methods:** Relevant literature was analyzed to examine recent developments in polymer modification, functional performance, and biomedical utility. **Results:** Results show that polymers are not restricted to biomaterial applications but also play a vital role in drug delivery systems, where stability and degradation behavior are crucial for maintaining bioactivity. **Conclusion:** Polymers represent indispensable tools in biomedical sciences, with dentistry and drug delivery systems offering promising avenues for future research and clinical practice.

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INTRODUCTION

Polymers are large molecules composed of repeating structural units called monomers that are covalently bonded to form long chains structures[1]. The early use of natural materials like cellulose and natural rubber to the sophisticated synthetic polymers that define modern technology, medicine, and industry. Polymers are widely used in dentistry because of their versatility, biocompatibility, ease of fabrication, and aesthetic properties[2]. They are employed in various restorative, prosthodontic, orthodontic, endodontic, and preventive dental applications[3]. The recent developments of dental polymer materials enhancing mechanical strength and durability, improving biocompatibility and bioactivity, reducing polymerization shrinkage and toxicity, integrating nanotechnology and digital manufacturing (3D printing) and developing smart and biodegradable materials for regenerative applications[4,5].

Dental polymer materials have many advantages that make them widely used in dentistry. They are lightweight and comfortable for patients to wear, especially in dentures and oral appliances. These materials are aesthetic, as they can be easily colored and polished to match the natural appearance of teeth. Polymers are also easy to handle and shape, allowing dentists to mold and cure them directly in the mouth. They show good biocompatibility when properly processed, causing little irritation to oral tissues. In addition, dental polymers do not corrode like metals and have low thermal conductivity, which reduce tooth sensitivity to temperature changes[6].

Despite their many benefits, dental polymers also have several disadvantages. One major drawback is polymerization shrinkage, which can cause gaps at the tooth–restoration interface and lead to microleakage or secondary caries. They often have lower mechanical strength and wear resistance compared to metals and ceramics, making them less suitable for areas under heavy chewing forces. Dental polymers can absorb water and stains, leading to discoloration, swelling, and changes in properties over time. They may also release residual monomers if not fully cured, which can irritate or damage surrounding oral tissues[4].

The architecture of polymers arrangement as a numerous assemblage of normal structural units for the construction of 3D structure which has an extensive distribution in all biological systems. The variety of cytoskeleton through the structural of proteins and intracellular filaments and the mechanical properties of muscles or cartilage to keratin of hairs and skin which interact with the surroundings. In the beginning, natural polymers such as cellulose, hair and horn have been exploited by human and they have applications in biomedical field, such as sewing material.[7]

Synthetic polymers have attracted great attention because of different medical application, and they are varied like natural polymers. Recently, synthetic polymers are developed and modified to be able to exploit in different application. Polyamides and polyesters are an example of these polymers. Different chemical and physical properties can be achieved by polymerization process which contain functional groups in its chain structure[8]. Mechanical propertied can be obtained by combination of fibers of the same composition into the intermediate[9]. Mechanical properties, like a polymer shape, which is distorted and return to their original form by a specific condition such as, temperature, pH, light and magnetic field.

Different application can be found in biomedical for instance, drug delivery system, sutures, vascular stents, orthodontic therapy, removal of clot, occlusion of ductus arteriosus.[10,11] Polymers which respond or degrade to the environmental conditions have attracted a lot of attention. Responses to physical stimulant like mechanical stress, light irradiation, temperature changes, electricity, and other combinations can be used to activate a drug release[12-15]. Polymers can react with inner biochemical triggers such as, metabolites, drugs, enzyme concentrations or antigens and pH, and separately respond to a physiological state[16]. In addition, appropriate set let response to organize a homeostasis of urate concentration or coagulation and blood glucose[17-19]. The aim of this narrative review is to study and evaluate the use of polymer materials in dentistry, focusing on their composition, properties, and applications in various dental procedures.

Polymer in Dentistry

The component, esthetic and biocompatibility of polymers used in dentistry have a high concerning. Materials should be supporting a high weight and cut forces, resists thermal increase and shrinking to give hardness of the filling used. Fillings contain polymerized resin, filler-resin interface and filler[20]. Mainly, fillers are inorganic materials with micrometer or nanometer range of particle size. Fillers are usually reacted with silane to improve the binding to the polymer chain. Generally, the resin contains mono-methacrylate or di-methacrylate, and different compounds, variable viscosity, and additives to improve shrinking volume[20]. Photo initiation of free radical polymerization is commonly used, however self-heling one or two component are still used and have benefit for specific applications[20,21].

Composites Resins

The most common materials that can be used in dentistry was a polymeric composite resin to restore teeth caries. In 2006, 70% of American used composite materials to restore teeth cavity[22]. The advantages of composites comprise the simplicity compared to indirect repair, adhesion to teeth tissues, teeth-colored, esthetics, sufficient, mechanical durability with low price in comparison with repairs by crowns and ceramics. In addition, composites have nontoxic compared to amalgams which contain mercury[23]. However, different studies have stated high failure rates and shorter lifetime and durability of composite repair compared to amalgams[24]. For instance, a study examined age between (8-12) years old of 1,748 amalgams and composite. Generally, 10.1% of all the repair failed of age seven years old. The survival rate of composite restoration was 85.5% which is lower than of amalgam restoration of 94.4%[25].

Composites lead to coagulating more bacterial attachment than amalgam, which resulted in more biofilms formation on the surface. These bacteria are the main source of infections and inflammations. In the medical fields, a secondary caries is the failure of composite restoration[26]. Bulk fractures are the second reason that causes failure of composite repair. A mechanical load leads to accumulation and micro-crack in the repair[27]. Consequently, different research has modified novel composites with oral biofilm-reduction, self-healing, and teeth mineral-regeneration. The anti-biofilm agents could inhibit bacteria colonies and improve the strength and function of the teeth against caries. The self-healing ability of composites with the capability to restore the cracks and recover the stress-bearing ability. Therefore, researchers found an advanced method to significantly increase the lifetime of teeth restoration. This review focused on the latest improvements of biomedical composites dental polymer that restore decomposition of teeth structures and at the same time have the ability of self-healing technology.

Polymethyl Methacrylate (PMMA)

Polymer was widely utilized in dentistry as denture, and one of the most important polymers used in this field is PMMA[28]. The main protocol to make it was by free radical polymerization of MMA monomer and PMMA beads. The highly viscous resin dough formed the multiphase denture base polymer. The dough-like uniformity allowed packing of the resin into the denture molds and reduced polymerization of the resin, giving dentists enough time to shape the denture before it hardens. Once fully polymerized, the material forms a strong and well-adapted denture base. Bowen was the first one who introduced cross-linking thermoset monomers in dentistry[29].

Cross-linking dimethacrylate (DMA) monomers were also used as denture base resins. The monomer of MMA can be polymerized to PMMA by free radical polymerization which can be utilized in dentistry and orthopedics applications. This type of polymerization is exothermic and can cause damage in soft tissues, therefore little quantity should be used, and saline solution may be used for cooling. Because the PMMA is biologically inert, it may be reacted with the rest-monomers in the polymer chain[30].In addition, PMMA was also used in lenses because of its optical properties. The presence of hydroxyethyl methacrylate group which is hydrophilic lead to the formation of hydrogel. This is important in non-specific protein adsorption and anti-fouling agents in different applications such as, protein adsorption and coating on contact lenses[31,32].

Denture Teeth

Generally, the main composition of resin polymer teeth is PMMA beads and stains in a cross-linked polymer matrix. Usually, the cross-linked polymer matrix of teeth is not spread in the teeth construction. For instance, the gingival saddle pontic area may not be as highly cross-linked as the incisal or occlusal area of the teeth. Bonding of the polymer teeth to the denture base polymer enhanced through the less cross-linked structure in the part of the saddle pontic[33].

Teeth Protection

The collagen fibers should be protected from degradation when adhesive to dentin teeth was used at the interface of resin-dentin.[34-37] Biomaterials have been used to functionalize the adhesive used and to provide mineral source within the HL and subsequent remineralization of the essential dentin, these materials include, phosphoproteins, carboxylic acid-containing polyelectrolytes, calcium phosphate, glass particles, tri-calcium phosphate. All of them have important to growth of minerals at the demineralized dentin. Many fillers such as, hydroxyapatite (HAp) and some nanoparticles acting as biologically active materials.[38-42] Moreover, the uses of polymeric nanoparticles with zinc represents a significant innovation in dental regenerative biomaterials. The novelty of this article lies in its focus on the integration of functional biomaterials and polymeric nanoparticles, particularly zinc-based systems, to enhance resin–dentin adhesion and promote dentin remineralization. Unlike previous studies that primarily investigated conventional fillers such as hydroxyapatite or calcium phosphates, this work emphasizes the innovative role of polymeric zinc nanoparticles as bioactive agents, offering new potential for dental regeneration and long-term adhesive stability.

CONCLUSIONS

Various types of polymers have been used different biomedical fields. Versatile polymer types with different degree of crystallization and crosslinking and with adjustable molecular weight and specific functional groups make these polymers important to a wide range of applications. Toxicity and biocompatibility are the main factors that should be taken in our account in addition to polymer stability, stiffness, tensile and elasticity. Biodegradation considered one of the most essential properties of some polymers that can be utilized in orthopedic surgery because these types of polymers may be disappeared after its actions inside the humane body and degrade to control the drug release.

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