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Emerging Trends in Dental Materials: Enhancing Mechanical Properties and Biocompatibility with Advanced Fillers

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ABSTRACT

This literature review examines advancements in dental materials, emphasizing the enhancement of mechanical properties and biocompatibility through novel fillers. Traditional polymer-based dental materials often face limitations such as brittleness and low wear resistance, necessitating frequent replacements. By in tegrating biocompatible fillers like glass fibers, carbon nanotubes, and ceramic nanoparticles, researchers have significantly improved the strength, toughness, and fracture resistance of these materials.

The review traces the evolution of dental materials from early substances to modern composites, highlighting their specific applications in restorative dentistry.

It also explores the development of nano composites and the use of metal oxide nanoparticles, such as magnesium oxide (MgO), which offer superior bonding, antimicrobial properties, and improved mechanical performance.

Key words: Dental materials; Restorative dentistry; Biocompatible fillers Polymer composites Nano composites; Mechanical properties; Magnesium oxide nanoparticles

1. Introduction

Dental materials provide structural integrity and cosmetic appeal to dental restorations, making them indispensable to restorative dentistry. On the other hand, traditional dental materials made of polymers are brittle, weak, and have little wear resistance. These limitations may reduce the lifespan and practicality of dental restorations, raising the possibility of recurring problems and the requirement for replacement. Researchers have investigated to improve the properties of dental materials by the incorporation of biocompatible fillers into polymer matrices [1, 2].

The characteristics of dental materials based on polymers could be greatly enhanced by biocompatible fillers. It has been demonstrated that glass fibers, carbon nanotubes, and ceramic nanoparticles can all increase a material's toughness, strength, and resistance to fracture. It is crucial for consider the interfacial holding notwithstanding the ideal filler content and conveyance to give the expected mechanical benefits. Clinicians can give more trustworthy and dependable dental reclamations, which will work on clinical outcomes and patient fulfillment, by improving the mechanical properties of dental materials [3].

2. Dental Materials in Dentistry

Dental materials have changed after some time, supplanting materials like ivory and shells utilized in before dental reclamation techniques. The first dental mixture was made in the nineteenth 100 years and contained various metals, including tin, silver, and mercury. The twentieth century saw various critical progressions, including the production of blend and the presentation of resin-based composites, which were picked for their tooth-shaded appearance and glue properties, as well as the extending utilization of metal amalgams in dental reclamations. The late twentieth and mid-21st hundreds of years have seen further progressions in composite pitches, with an emphasis on expanded strength, toughness, and tasteful allure. Additionally, the formation of computerized dentistry, which utilizes computer aided design/CAM innovation, has completely changed the creation of dental prosthesis [4].

Dentistry involves a variety of materials are used in dentistry, including as metals, composites, ceramics, polymers, and gypsum products. Filler particles enhance the attractive appearance, of a resin matrix making them ideal in both direct and indirect restorations [5]. Polymers, such as acrylics and resins, are used in dentistry for a variety of applications, including the creation of dentures and composite restorations. Crowns and bridges are still made of conventional dental alloys, including as cobalt-chromium and gold alloys. Glass ionomer cements are used in luting processes and restorations to release fluoride. Plaster and dental stone are two examples of gypsum products that are necessary to make precise casts and models.

Biocompatibility to prevent negative reactions, sufficient mechanical capabilities (strength, hardness, and wear resistance) to sustain masticatory forces, and a natural appearance for aesthetic reasons are common qualities and attributes required in dental materials [6]. For adhering to dental structures and guaranteeing retention, adhesive properties are essential. Other important factors to take into account are corrosion resistance in the oral environment, radiopacity for visibility on dental radiographs, dimensional stability, durability, and ease of manipulation during treatments. This thorough understanding of dental materials highlights the continuous efforts in research and development to improve functionality and patient outcomes.

3. Dental Materials in Restorative Dentistry

The goal of restorative dentistry is to locate, diagnose, and treat oral health issues brought on by damaged or missing teeth as well as the supporting tissues that keep them in place. By restoring or replacing teeth that have been damaged by illness, accident, aging, or other causes, restorative dentistry seeks to enhance the function, aesthetics, and overall health of the mouth [7].

Dental materials play an important role in the field of restorative dentistry because they can be used to treat a variety of oral health issues, such as tooth loss and cavities. Because of its aesthetic appeal and wide range of uses, resin composites are quickly emerging as one of these materials that are frequently utilized. Resin composites do have some disadvantages, despite their benefits. These materials may eventually lose their mechanical strength and durability, which could result in malfunctions and the need for replacements or repairs [8].

1.3.1 *3.1 Polymer-Based Dental Materials*

In dentistry, a composite material is made by combination of different components with unique structures and characteristics. This is done in order to produce a material with improved qualities that none of the constituent parts could produce on its own. Filler and the resin phase are the two main components of composite materials [9].

Advantageous characteristics of the resin phase include its room temperature shape ability and rapid polymerization setting time. Conversely, the reinforcing filler adds strength, stiffness, hardness, and a decreased coefficient of thermal expansion. Moreover, the contraction that takes place during setting is lessened when the filler takes up a sizable portion of the composite material [10].

The properties of a filler materials are affected by the type, size, shape, and quantity of filler utilized, as well as the effective bonding between the filler and resin. Other properties include setting contraction, surface hardness, and coefficient of thermal expansion of filler content when applied to resins [11]. There may be comparable changes in other mechanical and thermal parameters. The strength, modulus of elasticity, and resistance to abrasion are all increased by the addition of filler. If the additional filler is translucent, it can also improve the optical properties of the composite material [12].

1.3.2 *3.2 Composition of Dental Composites*

All dental composites are made up of resin and fillers.

- **Resins**

Resin matrices contain modified methacrylates or acrylates, Bis GMA and urethane dimethacrylate are the most used monomers with the comonomer tri-ethylene glycol dimethacrylate (TEGMA) [3, 13].

Bis GMA, a difunctional methacrylate, is often synthesized through a reaction between glycidylmethacrylate and bisphenol A. It possesses two phenyl groups that contribute to the molecule's rigidity. The hydroxyl groups in Bis GMA facilitate intermolecular hydrogen bonding making it similar to thick treacle at room temperature. However, due to viscosity it is challenging to blend it with filler particles. TEGMA a fluid diluent monomer is used to reduce the viscosity. A common practice involves blending three parts Bis GMA with one-part TEGMA, followed by the addition of filler [14].

Urethane methacrylate monomers, either aliphatic or aromatic, are also used, with aromatic ones being more viscous. Unreacted acrylate or methacrylate groups may remain due to the high viscosity during setting. Camphorquinone is a photo initiator that initiates the polymerization reaction in dental composites when exposed to curing light, leading to the hardening of the material [15].

- **Fillers**

The type, concentration, particle size, and particle size distribution of the filler used in a composite material are major factor controlling properties [16].

Biocompatible fillers in dental materials are inert substances that are added to enhance the mechanical, physical, and aesthetic properties of the material while ensuring biocompatibility with the oral tissues. These fillers play a crucial role in dental composites and other dental materials. Commonly used biocompatible fillers in dental materials include glass fillers, ceramic fillers, salinized fillers, hybrid fillers, nano fillers [17].

Figure 1: Types of filling materials

- **Hybrid filler** filled composites have shown a promising potential the improvement in overall performances and properties of the composites. However, the prospective benefits of hybrid fillers reinforced composites depend mainly on the filler content, filler dispersion, and their surface nature [18].
- **Ceramic fillers** are another important class of material that offers excellent thermal conductivity, along with electrical insulation. This combination of interesting properties is desired for the electronic packing industry [19].
- **Glass filler** can be used in the form of fiber; it is then a so-called reinforcing filler, of hollow glass beads or of microspheres, making it possible to improve the performance of the polymer matrix or to reduce the mass of the parts produced [16].
- **Silica Filler**: The addition of filler could also lead to an increase of Young's modulus, and thus in the lower elongation of the composite material. For this reason, fillers with silicondioxide are generally involved in the preparation of epoxy composite material. With the proper choice of such type of filler, its right amount, and the method to integrate it into the selected composites, we can potentially improve their chemical, thermal, and electrical resistance qualities, mechanical properties, and dimensional stability [20].
- **Nano fillers** have particle sizes typically less than 100 nanometers, providing a significantly higher surface area compared to larger fillers. In dental composites, Nano fillers, such as Nano silica are added into the resin matrix to improve the overall properties of the composite. The properties and effects of Nano fillers in dental composites can vary depending on factors such as filler type, size, loading, and distribution. Proper formulation and optimization are crucial to harness the full potential of Nano fillers and achieve optimal clinical performance in dental restorations [16, 21].

4. Physical Factors of Fillers in Composite Materials

The major factors that must be kept in mind for adding filler in composite materials are:

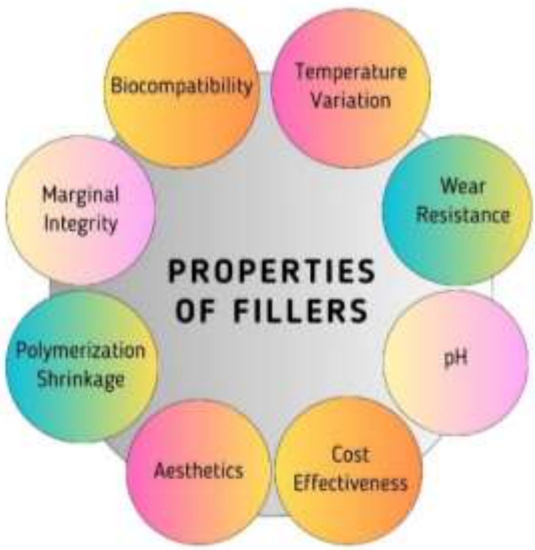

Figure 2: Properties of fillers in dental materials

Biocompatibility

The fillers used in dental materials should be compatible with the body and not cause harm to nearby tissues and cells. Researchers study the inclusion of these safe fillers to ensure that dental materials can be used without any risks inside the human body [22].

Wear Resistance

Over time, dental composites can gradually wear away due to the continuous forces from chewing, biting, and speaking. This can lead to the requirement for repair or replacement. The pressure on a small area of a tooth or dental material can be substantial, often reaching several kilograms [23].

Temperature Variations

The typical temperature range inside the mouth, under normal conditions, is between 32ºC and 37ºC. This range may depend on the mouth, whether open or closed. However, when consuming hot or cold food or beverages, the temperature range can expand significantly, ranging from 0ºC to as high as 70ºC [24, 25].

Marginal Integrity

The bond between the composite restoration and the natural tooth may weaken with time, causing gaps and potential leakage. This can lead to tooth decay and further damage.

Aesthetics

Dental materials utilized for restorations should have an appealing appearance that blends well with the adjacent teeth. By incorporating fillers, it becomes possible to attain the desired color, translucency, and other optical characteristics of the materials [26].

pH

Materials' durability can be affected by significant fluctuations in acidity or alkalinity as well as high levels of stress [27]. The pH levels of fluids in the oral cavity typically range from around pH 4 to pH 8.5, indicating varying degrees of acidity or alkalinity. However, the consumption of acidic fruit juices or alkaline medications can expand this range to pH 2 to pH 11 [28].

Polymerization Shrinkage

When dental composites are cured, they undergo a chemical reaction called polymerization. However, this reaction can cause the composite to shrink, resulting in the formation of gaps and potential leakage around the restoration [29, 30].

Cost Effectiveness

By improving the properties of dental materials, patients can save money by reducing the need for replacement or repair.

5. Nano composites in Dentistry

The field of dentistry got advanced with the introduction of Nano composites. These materials are becoming more and more well-liked because of their potential applications in various dental procedures [31]. The use of materials known as "Nano composites," which incorporate nanoparticles into a matrix, in prosthetic and restorative dentistry has shown promising results. Dental nano composites have changed over time, transitioning from conventional dental materials to nanotechnology-based materials.

Materials at the nanoscale are blended to make composite designs known as nano composites in the space of dentistry. Nanotechnology can be utilized to adjust the nuclear and atomic designs of materials to work on their mechanical, optical, and organic properties. This progress has been driven by the quest for materials that are more biocompatible, enduring, and stylishly satisfying — more like teeth [32].

Dental Nano composites can be divided into groups according to the kind of nanoparticles they contain and the particular uses for which they are intended. One well-known type of Nano filler is adding zirconia or silica nanoparticles to the resin matrix of composites [33, 34]. These Nano fillers improve the composite's mechanical strength and wear resistance, which enables them for usage in restorative dental procedures like fillings [34]. The usage of Nano hybrids, which blend nanoparticles with conventional glass or ceramic fillers, is another type of dental Nano composite. The material's overall qualities are improved by this hybridization, which increases its strength, toughness, and aesthetic appeal. Direct and indirect restorations using Nano hybrids can enhance restorative dentistry [21].

Dental Nano composites have benefits beyond their mechanical characteristics. Better polishability is made possible by their Nano scale size, which is essential for producing smooth and visually beautiful surfaces in dental restorations. Furthermore, the antimicrobial nanoparticles added to Nano composites reduce infections and secondary caries.

6. Metal oxide Nanoparticles in Dentistry

Metal particles in their oxides are a more stable and diverse form of nanomaterial's, mainly with applications in the chemical, physical, and materials sciences. Most of the metallic elements react with oxygen under different conditions to form metal oxides with different structural formulations [35].

Metal oxide nanoparticles are widely used in dentistry due to their potential as antibacterial agents and dental fillings. Their unique qualities, make them a great option for reinforcement in dental composites. In dental materials, antibacterial properties of ZnO NPs can be beneficial. Zinc oxide nanoparticles and cellulose Nano crystal have been discovered to have mechanical and antibacterial properties that are beneficial to dental resin composites. Antibacterial activity against Lactobacillus and Streptococcus mutants has been demonstrated in dental composite resins comprising nanoparticles of ZnO and Ag nanoparticles [36].

ZnO NPs have high photo catalytic activity and are believed to be more biocompatible than TiO2. They are used in the food industry for preserving colors and preventing spoilage through their antimicrobial activity [37].

7. Effects of Biocompatible Fillers on Dental Materials

Dental materials now have a lot more features and applications due to the introduction of biocompatible nanoparticles, which has significantly advanced the area. These nanoparticles are special because they can interact with biological systems in a harmonious way without causing problems. Biocompatible nanoparticles are important because they can improve the mechanical, cosmetic, and antibacterial qualities of dental materials without compromising their compatibility with the oral environment. [38].

Dental materials include a variety of biocompatible nanoparticle forms, providing many advantages. Because of their reinforcing qualities, silica nanoparticles are frequently employed to improve the strength and wear resistance of dental composites. Hydroxyapatite nanoparticles are a good fit for restorative dentistry applications because of their enhanced biocompatibility and bioactivity, which resemble the mineral component of normal teeth [39]. Strong antibacterial qualities of silver nanoparticles help to prevent infections and secondary caries. Because of its optical characteristics and biocompatibility, titanium dioxide nanoparticles are used to improve the aesthetics of dental materials.

There are several advantages to adding biocompatible nanoparticles to dental materials. Polymer-based dental materials can have their strength, hardness, and durability increased by the use of nanoparticles. Better polishability and color stability—two essential components in creating restorations that look natural—are made possible by nanoparticles from an aesthetic standpoint. Antimicrobial qualities assist prevent bacterial colonization, lowering the risk of infections, and improved biocompatibility ensures less negative interactions with oral tissues [17].

8. MgO Nanoparticles Addition to Dental Composites

Among the various types of metal oxide nanoparticles investigated, magnesium oxide (MgO) nanoparticles have shown promising potential due to their excellent bonding properties, biocompatibility, and stability [40].

The advantages of using MgO nanoparticles in dental applications can be highlighted by their properties:

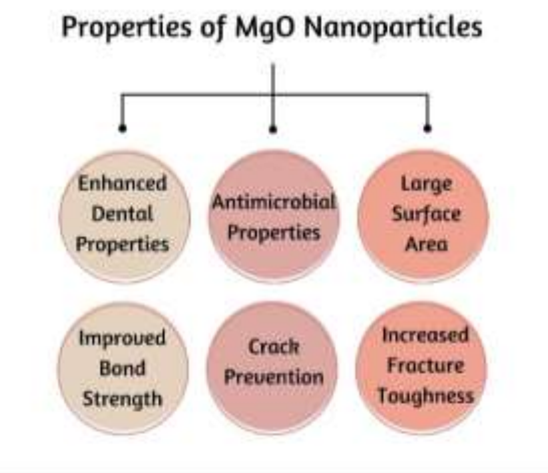

Figure 3: Properties of MgO nanoparticles

Enhanced Dental Properties: MgO Nanoparticles improve the mechanical properties of dental materials, particularly in restorative applications. Their incorporation can enhance strength, stiffness, and wear resistance [41, 42].

Antimicrobial Properties: MgO Nanoparticles exhibit antimicrobial, antiviral, and antifungal properties [43]. MgO nanoparticles loaded with antimicrobial agents incorporated into resin composites have the potential to prevent biofilm formation [44, 45].

Large Surface Area: MgO Nanoparticles possess increased surface area compared to bulk materials, for enhanced interactions and reactivity [46].

Improved Bond Strength: MgO Nanoparticles enhance the bond strength between dental biomaterials, such as resin composites, and dentin. This not only results in better adhesion but also increased longevity of dental restorations [47].

Crack Prevention: MgO nanoparticles addition to dental materials can prevent cracks. [43].

Increased Fracture Toughness: MgO nanoparticles increase their resistance to breaking and lengthen their lifespan, increasing the fracture strength [48].

9. Conclusion

The incorporation of biocompatible fillers into dental materials represents a significant advancement in restorative dentistry. These enhancements not only improve the mechanical properties, such as strength, toughness, and fracture resistance, but also ensure better biocompatibility and aesthetics. The evolution from traditional materials to modern composites and the development of nano composites, including nanoparticles like magnesium oxide (MgO), have markedly improved dental restorations' performance and durability.

Innovative techniques such as microwave-assisted bonding have further refined the interaction between polymers and nanoparticles, resulting in stronger and more durable restorations. These advancements help mitigate issues like polymerization shrinkage and wear resistance, while also offering superior aesthetic benefits. Overall, these advancements in dental materials promise better clinical outcomes and enhanced patient satisfaction. The continuous research and development in this field are crucial for meeting the evolving demands of dental practices and ensuring the long-term success of restorative treatments.

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