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Review

Evaluation of Longevity and Performance of Various Dental Filling Materials

Zeinah Ali Alshehri[1], Fatma Abdulqader Azouz[2], Adnan Turki Almutairi[3], Mahmoud Hamed Al-Johani[4], Riyadh Obied Alanazi[5], Ali Mohammed Almakrami[6]

[1] *Dental Department, Al Thager General Hospital, Jeddah, Saudi Arabia*
[2] *Dental Department, Ministry of Health, Medina, Saudi Arabia*
[3] *Dental Department, Shaqra General Hospital, Riyadh, Saudi Arabia*
[4] *Dental Department, East Jeddah Hospital, Jeddah, Saudi Arabia*
[5] *North Riyadh Dental Center, Ministry of Health, Riyadh, Saudi Arabia*
[6] *Dental Department, New Najran General Hospital, Najran, Saudi Arabia*

Correspondence should be addressed to **Zeinah Ali Alshehri**, Dental Department, Al Thager General Hospital, Jeddah, Saudi Arabia. Email: Da.zeina@hotmail.com

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Abstract

Dental filling materials are critical components of restorative dentistry, serving to restore function, aesthetics, and structural integrity to teeth affected by decay or trauma. The longevity and performance of these materials depend on various factors, including their composition, mechanical properties, environmental exposure, and patient-specific variables. Amalgam, once the gold standard for restorations due to its durability and self-sealing properties, has seen a decline in use due to environmental and aesthetic concerns. Composite resins have gained popularity for their superior aesthetics and versatility, though their susceptibility to wear, polymerization shrinkage, and microleakage remains a challenge. The oral environment, with its fluctuating pH, temperature changes, and enzymatic activity, places significant stress on restorative materials. These factors can lead to chemical degradation, marginal breakdown, and reduced mechanical stability over time. Advanced materials like ceramics and bioactive composites show promise in addressing these challenges, offering enhanced resistance to wear and fracture while promoting biological interactions that support oral health. Patient-specific factors such as dietary habits, oral hygiene, parafunctional activities, and systemic conditions further influence restoration outcomes. Innovations in material science, coupled with individualized treatment approaches, are essential to improving the success rates of dental restorations. By understanding the interplay of material properties, environmental stressors, and patient factors, clinicians can make informed choices to optimize restorative outcomes and enhance long-term oral health.

Keywords: *Dental filling materials, longevity, wear resistance, oral environment, restorative dentistry*

Introduction

Dental filling materials are fundamental in restorative dentistry, addressing structural, functional, and aesthetic needs in managing caries, trauma, or other defects. Over the years, numerous materials have been developed, each with unique compositions, mechanical properties, and clinical outcomes. The ideal filling material should exhibit long-term durability, biocompatibility, resistance to wear, and ease of application, while maintaining aesthetics that mimic natural dentition. However, achieving a balance between these properties remains a challenge in clinical practice.

Amalgam was historically considered the gold standard for its longevity and strength. Despite its cost-effectiveness and durability, its mercury content raised significant environmental and health concerns, leading to a gradual decline in its use globally (1). In contrast, composite resins have gained popularity due to their aesthetic appeal and ability to bond directly to tooth structure. However, their susceptibility to wear and marginal degradation has sparked debates over their long-term performance compared to traditional materials (2).

Glass ionomer cements, lauded for their fluoride release and chemical bonding to enamel and dentin, are particularly advantageous in pediatric and preventive dentistry. However, their lower mechanical strength limits their application in load-bearing areas (3). Resin-modified glass ionomers and newer hybrid materials have attempted to bridge the gap between aesthetics, functionality, and durability, albeit with varying clinical success. Similarly, advancements in ceramics and bioactive materials have introduced options that promise superior longevity and biocompatibility, but often at a higher cost and technical complexity (4). Given the growing emphasis on evidence-based dentistry, understanding the factors influencing the longevity and performance of dental filling materials is crucial. This review explores the evolution of filling materials, evaluates their clinical outcomes, and highlights future directions.

Review

The longevity and performance of dental filling materials are influenced by a combination of material properties, clinical techniques, and patient-related factors. Amalgam, despite its historical prominence, demonstrates remarkable durability, with clinical studies showing survival rates exceeding 10 years in many cases. However, the declining use of amalgam is largely attributed to its aesthetic limitations and environmental concerns associated with mercury (5, 6). Composite resins, on the other hand, have become the material of choice for anterior and posterior restorations due to their aesthetic appeal and advancements in adhesive technology. Nevertheless, their longevity is often compromised by polymerization shrinkage, wear, and secondary caries development, especially in high-stress occlusal areas (7).

Emerging materials, such as bioactive composites and ceramics, offer promising alternatives with improved resistance to degradation and enhanced biocompatibility. These materials not only restore function but also actively promote remineralization and prevent secondary caries. Clinical trials have demonstrated their potential for longer survival rates in challenging cases. Additionally, patient factors such as oral hygiene, dietary habits, and parafunctional activities, like bruxism, significantly impact the success of restorative materials. Continued research and material innovation are essential to overcome existing limitations and optimize clinical outcomes in diverse patient populations.

Material Composition and Mechanical Properties

Dental filling materials owe much of their clinical success to their inherent composition and mechanical properties, which determine their ability to withstand functional demands and resist degradation over time. Amalgam, one of the earliest and most widely used materials, is a metallic alloy consisting primarily of mercury, silver, tin, and copper. Its high compressive strength and self-sealing properties due to corrosion make it ideal for load-bearing posterior restorations (8). However, amalgam lacks esthetic appeal, and its long-term

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success can be compromised by marginal fracture or structural bulk loss in extensive restorations.

Composite resins have revolutionized restorative dentistry, offering superior aesthetics and versatility. These materials consist of an organic polymer matrix, such as bisphenol A-glycidyl methacrylate (Bis-GMA), reinforced with inorganic fillers like silica. The filler content significantly impacts their mechanical properties, with higher filler loads enhancing strength, wear resistance, and fracture toughness (9). However, composites remain vulnerable to polymerization shrinkage, which can cause marginal gaps and subsequent microleakage, potentially compromising the restoration's longevity. Advances in nanotechnology have introduced nanoparticle fillers, which improve packing density and surface smoothness while maintaining mechanical integrity.

Glass ionomer cements (GICs) and resin-modified glass ionomers (RMGIs) differ from composites in their acid-base reaction mechanism and fluoride-releasing properties. The ability of GICs to bond chemically to enamel and dentin makes them favorable for non-load-bearing areas, particularly in pediatric and preventive dentistry (10). However, their lower compressive strength and wear resistance limit their application in high-stress regions. RMGIs attempt to overcome these limitations by incorporating resin components, which enhance their strength and esthetics, making them a more versatile option in clinical practice.

Ceramic materials represent another significant development in restorative dentistry, particularly in cases requiring superior esthetics and biocompatibility. Lithium disilicate ceramics and zirconia-based materials are among the most widely used, known for their high flexural strength, fracture toughness, and resistance to wear. These properties, combined with advancements in CAD/CAM technology, enable the fabrication of highly accurate and durable restorations (11). Despite their many advantages, ceramic restorations are brittle and require precise bonding techniques to minimize the risk of failure. Each material's performance is also influenced by its interaction with the oral environment. Factors such as thermal cycling, pH fluctuations, and mastication forces continuously challenge their mechanical properties. Understanding these dynamics and selecting materials based on their composition and expected clinical demands are critical for achieving long-term success.

Resistance to Wear and Fracture

Wear and fracture resistance are critical factors that influence the longevity and clinical performance of dental filling materials. These properties ensure restorations can endure the mechanical forces exerted during mastication and the dynamic oral environment over time. Among traditional materials, dental amalgam exhibits excellent wear resistance due to its ability to adapt to occlusal forces through surface corrosion. This unique characteristic often compensates for minor marginal discrepancies, making amalgam a durable choice for posterior restorations (12, 13). However, its susceptibility to bulk fracture in larger restorations remains a limitation, particularly in the absence of adequate support from surrounding tooth structure.

Composite resins, widely adopted for their superior aesthetics, present unique challenges in terms of wear resistance. Modern composites have significantly improved, with enhanced filler technologies mitigating wear-related degradation. Studies show that nanohybrid composites, due to their smaller particle size and better filler-matrix interaction, exhibit better wear resistance than older microfilled or macrofilled composites (14). Nevertheless, in posterior load-bearing areas, composites are more prone to surface wear compared to materials like amalgam or ceramics. This is especially evident in patients with parafunctional habits such as bruxism, where occlusal forces are abnormally high.

Ceramics, particularly zirconia and lithium disilicate, are known for their exceptional resistance to wear and fracture. These materials exhibit a low wear rate against opposing enamel, making them ideal for esthetic and functional restorations. Zirconia, in particular, benefits from its transformation toughening mechanism, where

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microcracks are arrested by phase transformation, reducing the likelihood of catastrophic fracture (15). However, issues such as chipping, especially in veneered zirconia restorations, necessitate meticulous design and fabrication to maximize longevity. Lithium disilicate ceramics offer a balance of strength and esthetics, with studies highlighting their ability to endure occlusal forces while maintaining surface integrity under normal conditions.

Glass ionomer cement and their resin-modified counterparts have less impressive wear resistance, often exhibiting surface degradation under occlusal stress. These materials, while advantageous for their fluoride release and chemical bonding, are unsuitable for high-stress applications. Innovations in glass hybrid technology aim to address these limitations, providing better wear resistance without compromising their preventive benefits (16). The trade-off between mechanical durability and bioactivity remains a significant consideration in their use. Restorative materials' performance in resisting wear and fracture is not solely dictated by their intrinsic properties but also by external variables such as occlusal loading patterns, dietary habits, and parafunctional activities. These factors necessitate a tailored approach in selecting materials, ensuring optimal performance for the specific demands of each case.

Impact of Oral Environment on Material Degradation

The oral environment is a complex and dynamic system that presents numerous challenges to the durability of dental filling materials. Factors such as fluctuations in pH, temperature variations, enzymatic activity, and continuous mechanical forces significantly contribute to the degradation of restorative materials. These variables interact synergistically, compromising the structural and functional integrity of restorations over time.

Acidic conditions in the oral cavity, resulting from dietary habits or pathological conditions like gastroesophageal reflux disease, accelerate the degradation of certain materials. Glass ionomer cements, for instance, are particularly susceptible to acid erosion, which undermines their surface integrity and diminishes their fluoride-releasing capability. While resin-modified glass ionomers are less prone to acid attack, their long-term resistance remains inferior compared to resin-based composites (17). These challenges highlight the need for careful material selection in patients with high caries risk or acidic oral environments.

Moisture plays a dual role in material degradation. On one hand, the water sorption of materials like composites can lead to hydrolysis of the polymer matrix, weakening the bonds between filler particles and the resin matrix. On the other hand, water acts as a medium for the elution of unreacted monomers, further compromising mechanical properties. Studies indicate that prolonged exposure to water can lead to a gradual loss of strength and elasticity in composites, especially in those with high hydrophilicity (18). Enhanced formulations with hydrophobic resin matrices have been developed to mitigate these effects, though they are not immune to long-term degradation.

Temperature fluctuations, typical in the oral cavity during food and beverage consumption, impose thermal stresses on restorative materials. Composite resins and ceramics experience repeated cycles of expansion and contraction, potentially leading to marginal microleakage and subsequent material failure. This phenomenon, known as thermal cycling, has been shown to weaken the bond between the restorative material and the tooth structure, creating pathways for bacterial infiltration (19, 20). Materials with coefficients of thermal expansion similar to that of natural enamel, such as certain ceramics, are better equipped to withstand these stresses. Enzymatic activity in saliva, such as that of esterase enzymes, contributes to the chemical degradation of composite resins. These enzymes catalyze the breakdown of ester bonds in resin matrices, reducing their mechanical stability. The susceptibility of resin-based materials to enzymatic degradation underscores the importance of material advancements that resist such biochemical challenges (21). Modifying the composition of the resin matrix and filler content is an ongoing area of

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research aimed at improving the long-term resilience of dental restorations.

Patient-Specific Factors Influencing Filling Longevity

The success and longevity of dental fillings are not solely dependent on the materials used or the clinician's expertise; patient-specific factors also play a pivotal role in determining the durability and effectiveness of restorations. These factors include oral hygiene practices, dietary habits, parafunctional activities, salivary characteristics, and systemic health conditions. Understanding these individualized factors is essential for tailoring restorative strategies to achieve optimal outcomes. Oral hygiene is perhaps the most influential factor in maintaining the integrity of dental fillings. Poor hygiene practices contribute to plaque accumulation and bacterial colonization, increasing the risk of secondary caries at the margins of restorations. Patients with suboptimal hygiene are more likely to experience early restoration failures due to recurrent decay (22). Regular dental checkups, coupled with patient education, can significantly reduce this risk by promoting better plaque control and early intervention for minor issues. Dietary habits, particularly the consumption of acidic and sugary foods, exacerbate material degradation and caries risk. Acidic diets contribute to enamel erosion and destabilize the interface between the restorative material and the tooth structure. Sugars, on the other hand, feed cariogenic bacteria, further weakening the restoration's longevity (23). Educating patients on dietary modifications and the importance of reducing acid and sugar intake can help mitigate these risks.

Parafunctional activities, such as bruxism and clenching, place excessive stress on dental restorations. These forces can cause wear, fracture, or debonding of the restoration over time, especially in load-bearing areas. Studies have shown that patients with bruxism experience higher rates of failure with composite resins and ceramics due to their susceptibility to mechanical fatigue (24). In such cases, the use of high-strength materials like zirconia or the incorporation of protective measures, such as night guards, is recommended to prolong restoration life.

Salivary characteristics also influence the performance of restorations. Reduced salivary flow, commonly seen in patients with xerostomia, compromises the natural buffering capacity of the oral environment. This leads to a higher risk of acid attack on both natural teeth and restorations, accelerating their degradation. Additionally, saliva contains enzymes that can degrade resin-based materials, further reducing their longevity (25). Addressing xerostomia through hydration strategies, saliva substitutes, or pharmacological interventions is crucial for these patients.

Finally, systemic health conditions, such as diabetes mellitus, can adversely affect dental restoration longevity. Poor glycemic control is associated with increased oral infections, delayed healing, and changes in saliva composition, all of which negatively impact restorations. Similarly, patients undergoing treatments such as chemotherapy or radiotherapy for cancer may experience oral side effects, including mucosal changes and reduced saliva production, that compromise the effectiveness of restorations. Clinicians must consider these systemic factors during treatment planning and adapt restorative strategies accordingly.

Conclusion

In evaluating the longevity and performance of dental filling materials, factors such as material properties, oral environmental conditions, and patient-specific variables play crucial roles. Advancements in material science have significantly improved the durability and versatility of restorations, yet challenges remain, particularly in high-stress and compromised oral conditions. Tailored treatment approaches that consider individual patient needs and clinical demands are essential for optimizing outcomes. Ongoing research and innovation will continue to enhance the effectiveness and reliability of dental restorative materials.

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Data that supports the findings of this study are embedded within the manuscript.

Author Contribution

The authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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