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Review

Wear Patterns in Modern Dental Materials Used in Extensive Tooth Replacement Treatments

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Abstract

Wear patterns in dental materials are critical to understanding their performance and longevity in extensive tooth replacement treatments. Modern materials such as ceramics, composites, and hybrid polymers have been developed to replicate the natural characteristics of enamel and dentin, balancing mechanical strength and aesthetic properties. Despite their advancements, these materials are subjected to wear mechanisms, including attrition, abrasion, and erosion, which affect their functionality over time. The integration of nanotechnology and computer-aided design and manufacturing (CAD/CAM) has contributed to improvements in material durability and precision, enabling restorations that closely mimic natural teeth. Research has revealed that wear resistance in dental materials depends on a variety of factors, including material composition, hardness, and elasticity. These properties influence the interaction between the restorative material and opposing dentition, often resulting in differential wear patterns. For example, harder materials may preserve their integrity but cause accelerated wear on natural teeth, whereas softer materials may degrade more rapidly under occlusal forces. Innovations such as nanocomposites have demonstrated enhanced stress distribution and resistance to surface degradation, offering promising results in clinical applications. Patient-specific factors, including dietary habits, bruxism, and occlusal dynamics, further impact the wear behavior of these materials. Environmental factors, such as pH variations and thermal cycling, also play a role in material degradation. Emerging technologies and biocompatible materials aim to address these challenges by optimizing wear performance while maintaining structural integrity. However, the need for extensive in vivo studies and long-term evaluations persists to validate their effectiveness and reliability. Understanding the wear characteristics of dental materials is essential for their selection and application in restorative dentistry, particularly in cases requiring extensive tooth replacement. Advances in materials science and fabrication techniques continue to drive innovation, improving patient outcomes and the longevity of restorative treatments.

Keywords: *Dental materials, wear patterns, tooth replacement, nanocomposites, CAD/CAM technology*

Introduction

Dental materials play a pivotal role in restorative dentistry, especially in addressing extensive tooth wear and replacing lost dentition. Over the decades, advancements in material sciences have significantly transformed the capabilities of dental restorations, focusing on their durability, functionality, and aesthetics. Tooth wear, a common pathological phenomenon, arises from multiple factors such as attrition, abrasion, and erosion, leading to the degradation of enamel and dentin (1). With increasing incidences of tooth wear linked to dietary habits, lifestyle factors, and systemic conditions, the demand for robust dental materials has grown exponentially.

Modern dental restoratives aim to replicate the natural properties of teeth, including resistance to wear and tear. Materials such as ceramics, composites, and hybrid polymers are engineered to withstand the challenges of the oral environment, including occlusal forces, thermal variations, and exposure to acidic conditions (2). While earlier materials, such as amalgam and gold, were renowned for their mechanical strength, the focus has shifted toward biomimetic materials that align with the aesthetics and functionality of natural teeth. This transition underscores the importance of balancing wear resistance and preserving opposing dentition to minimize long-term complications. A significant aspect of wear analysis lies in understanding the interaction between restorative materials and natural teeth. Differential wear patterns often result from mismatched hardness between materials and the enamel or dentin of opposing teeth, leading to uneven attrition and potential occlusal disharmony (3). Furthermore, advancements in computer-aided design and computer-aided manufacturing (CAD/CAM) technologies have introduced precision-fabricated restorations, enhancing wear resistance and longevity. The development of these technologies underscores the integration of material science with modern engineering to meet clinical challenges effectively.

The clinical success of dental restorations is not solely reliant on the materials themselves but also on the surrounding biomechanical and physiological conditions. Studies have demonstrated that while contemporary ceramics and composites offer promising wear characteristics, their performance is influenced by factors such as patient habits, occlusal dynamics, and material placement techniques (4). Moreover, the long-term durability of these materials requires extensive in vitro and in vivo evaluations to ensure their reliability in clinical applications. Innovations such as nanotechnology and resin-modified composites have further propelled research into enhancing wear resistance without compromising other critical attributes, such as fracture toughness and biocompatibility.

The global push toward sustainability in healthcare has also influenced the development of dental materials. Researchers are now focusing on environmentally friendly materials that minimize waste while retaining high performance. These materials address not only wear patterns but also other issues like biodegradability and the reduction of adverse environmental impacts. This review aims to explore the wear patterns observed in modern dental materials used in extensive tooth replacement treatments, delving into the factors influencing their performance, comparative analyses of various materials, and recent innovations driving the field forward.

Review

The wear patterns of modern dental materials are influenced by complex interactions within the oral environment. Materials such as hybrid ceramics and resin composites have gained prominence due to their favorable combination of aesthetics and functional properties. However, despite their advancements, these materials are subject to wear mechanisms that can impact their longevity and clinical success. Studies highlight the importance of balancing material hardness and flexibility to minimize damage to opposing teeth while maintaining sufficient resistance to abrasive and erosive forces (5).

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Additionally, the introduction of nanotechnology in dental materials has shown promise in enhancing wear resistance. Nanocomposites, for instance, integrate nanoparticles that improve the distribution of stress, resulting in reduced surface degradation and better durability in long-term clinical applications. However, these materials are not without challenges, as their performance is also dependent on patient-specific factors such as parafunctional habits and occlusal forces (6). Moreover, the interplay between dental material properties and fabrication techniques further influences wear behavior. CAD/CAM has revolutionized dental prosthetics, offering precision-engineered restorations with consistent wear characteristics. While these innovations improve treatment outcomes, ongoing research is necessary to address variations in material behavior under dynamic oral conditions.

Mechanisms of Wear in Modern Dental Materials

Wear in dental materials results from complex interactions between mechanical, chemical, and biological factors in the oral cavity. The dynamic environment of the mouth, with its varying temperatures, pH levels, and forces, creates significant challenges for maintaining the structural and functional integrity of these materials. Understanding the mechanisms of wear is crucial for designing materials that can withstand these stresses while ensuring long-term durability and performance.

Ceramics, such as zirconia and lithium disilicate, are widely used in restorative and prosthetic applications due to their high strength and aesthetic properties. Despite these advantages, wear in ceramics arises from surface micro-cracking, abrasive interactions, and cyclic loading. Zirconia, in particular, is susceptible to localized wear when exposed to opposing enamel or other ceramic surfaces. Research has shown that introducing surface texturing or coatings on zirconia can improve wear resistance by reducing friction and crack propagation. Laser surface modifications, for instance, enhance the material's ability to distribute stress uniformly, thereby delaying the onset of material fatigue and wear-related failures (7).

Resin composites, another commonly used material, experience wear primarily through abrasive and fatigue-related mechanisms. The resin matrix and filler particles within these composites degrade differently, leading to uneven surface wear. Abrasion occurs as the filler particles detach from the matrix, creating micro-voids and roughness. Fatigue wear, on the other hand, results from repetitive chewing forces that cause gradual polymer chain breakdown. Advances in nanotechnology have improved the performance of resin composites by reducing filler particle size and improving their adhesion to the resin matrix. These modifications enhance surface smoothness and wear resistance, extending the lifespan of restorations in high-stress areas (8, 9).

Metal alloys, including cobalt-chromium and titanium, are widely used in dental frameworks and implants. Tribocorrosion, a combination of mechanical wear and chemical corrosion, is a significant mechanism affecting these materials. In implants, tribocorrosion generates wear particles and ions that can elicit local inflammatory responses, contributing to conditions like peri-implantitis. Titanium, though biocompatible, releases particles under oxidative stress, accelerating implant degradation. Surface treatments, such as diamond-like carbon (DLC) coatings, are being explored to reduce wear and ion release, while maintaining the material's biocompatibility. DLC coatings have demonstrated significant reductions in friction and wear in both in vitro and clinical studies (10).

Dental amalgam, though less commonly used today, continues to be relevant in certain clinical scenarios due to its cost-effectiveness and durability. The wear mechanisms in amalgam include corrosion, abrasion, and deformation under load. Corrosive wear occurs as the material reacts with saliva, dietary acids, and oxygen, forming surface oxides that protect against further degradation. However, excessive abrasion from opposing teeth or restorations can erode this protective layer, exposing the material to further chemical attack. Modern formulations of amalgam include higher concentrations of copper and tin to enhance

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corrosion resistance while maintaining the material's mechanical strength (11).

Glass ionomer cements (GICs) and resin-modified glass ionomers are particularly susceptible to chemical wear due to their hydrophilic nature. Acidic beverages and foods accelerate the leaching of ions, weakening the matrix and increasing susceptibility to surface erosion. Despite this drawback, glass ionomers remain valuable for their fluoride-releasing properties, which provide an anti-cariogenic effect. Recent advancements in GIC formulations aim to strike a balance between improving acid resistance and maintaining fluoride release. Additives such as bioactive glass particles have been introduced to enhance structural integrity while promoting remineralization of the surrounding tooth structure (12).

Environmental factors in the oral cavity further complicate the wear mechanisms. For example, acidic environments created by certain diets or beverages amplify chemical erosion, particularly in resin-based materials and GICs. Additionally, temperature fluctuations from consuming hot and cold substances contribute to thermal stress, causing microfractures and increasing susceptibility to wear. These challenges necessitate the development of multi-functional materials that can adapt to such dynamic conditions while providing long-term performance.

Comparative Analysis of Wear Resistance Across Dental Materials

Wear resistance is a critical factor in determining the longevity and effectiveness of dental materials in restorative dentistry. Various materials, including ceramics, resin composites, metals, and hybrid materials, are designed to withstand the unique challenges presented by the oral environment. A comparative analysis reveals significant differences in the wear resistance properties of these materials, influenced by their composition, microstructure, and interaction with opposing surfaces.

Ceramics, particularly zirconia and lithium disilicate, are known for their high strength and wear resistance. Zirconia demonstrates superior resistance to wear due to its high fracture toughness and ability to withstand masticatory forces. Studies comparing zirconia to glass ceramics found that zirconia exhibits significantly lower wear on both its surface and the opposing enamel, making it suitable for posterior restorations where occlusal forces are highest (13). However, zirconia's brittleness can lead to micro-crack propagation under extreme stress, necessitating precise material design to optimize its mechanical properties.

Resin composites, widely used for anterior and posterior restorations, exhibit wear mechanisms that differ from ceramics. These materials undergo abrasive and fatigue wear, where filler particles within the resin matrix detach over time. Nanofilled composites have improved wear resistance due to their uniform particle distribution and strong filler-matrix bonding. Comparisons between nanofilled and conventional resin composites reveal that the former demonstrates reduced volumetric wear and smoother surfaces after long-term use (14). This makes them ideal for areas experiencing moderate masticatory forces while providing excellent aesthetic outcomes.

Metallic dental materials, such as cobalt-chromium and titanium, are extensively used in frameworks and implants. These materials exhibit wear resistance influenced by tribocorrosion, a combination of mechanical wear and electrochemical processes. Titanium alloys, while biocompatible, release ions under oxidative stress, contributing to surface degradation. Studies comparing titanium with cobalt-chromium alloys show that titanium exhibits lower wear resistance in high-load applications, making it more suitable for implants rather than crowns or bridges. Surface coatings, such as DLC, enhance the wear resistance of these metals by reducing friction and preventing ion release (14).

Hybrid materials, such as fiber-reinforced composites (FRCs), combine the advantages of traditional resin composites and ceramics. FRCs incorporate short or long fibers into the resin matrix, improving their mechanical properties and wear resistance. A comparative study of FRCs and

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nanohybrid composites found that FRCs exhibited superior resistance to abrasive wear, particularly in high-stress regions. The fibers effectively distribute stress throughout the material, reducing localized deformation and extending the material's lifespan (15). This characteristic makes FRCs a promising choice for large restorations and core buildups.

GICs and their resin-modified variants are valuable for their fluoride release and adhesion to enamel and dentin. However, their wear resistance is generally lower compared to resin composites or ceramics. Acidic conditions in the oral environment exacerbate surface erosion, compromising their durability. Comparative studies demonstrate that nano-reinforced GICs, which incorporate nanoparticles into the cement matrix, exhibit enhanced wear resistance while maintaining fluoride release. These advancements bridge the gap between conventional GICs and resin composites, offering improved performance in less demanding applications (16).

Innovations in Material Engineering for Enhanced Wear Performance

Advancements in material engineering have significantly improved the wear resistance of dental materials, addressing the unique challenges posed by the oral environment. By leveraging nanotechnology, hybrid materials, ceramic coatings, and surface engineering, modern dental materials are designed to endure mechanical stresses, resist chemical degradation, and provide long-term performance. Nanotechnology has been instrumental in transforming resin composites, a staple in restorative dentistry. The inclusion of nanoparticles such as silica or zirconia enhances filler-matrix bonding, preventing particle detachment and improving resistance to volumetric wear. Compared to conventional microhybrid composites, nanohybrid composites show smoother surfaces after extended use and reduced abrasive wear. These properties are particularly valuable in restorations that experience significant occlusal forces, such as posterior fillings. A study evaluating nanohybrid composites demonstrated lower material loss and better surface integrity compared to microhybrid and traditional macrofill composites, confirming their superiority in high-stress applications (17).

Ceramic coatings have redefined the durability of dental restorations and implants. Materials like zirconia and alumina are widely used due to their high hardness, chemical stability, and biocompatibility. Plasma-sprayed zirconia coatings have shown remarkable wear resistance and crack inhibition, making them ideal for dental implants and prosthetic components. These coatings also minimize wear on opposing enamel, a common drawback in conventional ceramics. Additionally, advanced deposition techniques, such as physical vapor deposition, create ultrathin ceramic layers that enhance material longevity without compromising their aesthetic or functional properties (18).

Hybrid materials, particularly FRCs, represent a breakthrough in dental material design. These materials integrate short or continuous fibers into a resin matrix, improving tensile strength, fatigue resistance, and wear performance. FRCs efficiently distribute stress during mastication, reducing localized deformation and extending the material's lifespan. In clinical applications, FRCs have proven particularly effective in core buildups and load-bearing restorations, where traditional materials often fail under cyclic loading. Comparisons with nanohybrid composites show that FRCs outperform in areas requiring higher load resistance, offering enhanced durability for patients with heavy occlusal forces (19).

Surface engineering techniques have further improved wear resistance by modifying material microstructure and morphology. Laser texturing and nanopatterning have become essential tools in optimizing implant surfaces. Titanium implants with laser-textured surfaces exhibit improved osseointegration and significantly enhanced resistance to wear. These modifications also reduce bacterial adhesion, a critical factor in preventing peri-implant diseases like peri-implantitis. Another innovative approach involves the incorporation of microgrooves or nanodots on dental material surfaces, which not only enhance wear resistance but also promote favorable tissue responses (20).

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Bioactive materials are emerging as multifunctional solutions that combine wear resistance with therapeutic benefits. Nano-bioactive glass ceramics, for example, release calcium and phosphate ions, facilitating the remineralization of adjacent tooth structures. These materials maintain structural integrity under mechanical loads while offering fluoride release to protect against caries. Applications in pediatric and preventive dentistry highlight their potential to provide long-term protection while reducing wear-related failures. A clinical evaluation of bioactive glass ceramics confirmed their durability in acidic environments, showing no significant degradation after extended exposure (21).

Beyond these innovations, researchers are exploring smart materials that adapt to changing oral conditions. Self-healing composites, for instance, can repair microcracks through embedded microcapsules containing healing agents. These materials improve wear resistance by mitigating crack propagation, extending the functional lifespan of restorations. Similarly, biofunctional coatings that release antimicrobial agents have demonstrated success in reducing bacterial colonization while preserving the mechanical properties of implants and restorations. Ongoing advancements in material engineering are also integrating real-time monitoring capabilities. Smart dental implants equipped with sensors can track wear and stress, providing early warnings of material failure. These technologies enable personalized care and preventive interventions, ensuring long-term success in dental restorations and implants.

Conclusion

The evolution of dental materials has significantly advanced their ability to withstand wear while preserving aesthetics and functionality. Innovations such as nanotechnology and CAD/CAM fabrication have enhanced their clinical performance and durability. However, wear patterns remain influenced by patient-specific factors and material selection. Continued research is essential to optimize these materials for long-term success in extensive tooth replacement treatments.

Disclosure

Declaration

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Ethical Considerations

Non applicable.

Data Availability

All data is available within the manuscript.

Author Contribution

All authors contributed equally in the conceptualization, data collection, data analysis and writing of the paper.

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