



UDC: 616.314-089.28:615.462

FROM BIOINERTNESS TO BIOACTIVITY: A COMPREHENSIVE REVIEW OF MODERN APPROACHES IN MATERIAL SELECTION FOR FIXED DENTAL PROSTHESES

Ataxonov Azizbek Abdisalomovich

Assistant of the Department of orthopedic dentistry and orthodontics
Andijan State Medical Institute, Andijan city

Annotation: This analytical review provides an in-depth examination of the modern principles for selecting materials for fixed dental prostheses, with a primary focus on the significant paradigm shift from traditional bioinert materials to a new generation of bioactive and bio-integrative materials. The article presents a detailed comparative analysis of the advantages and disadvantages of major material classes, including metal alloys (addressing risks of ion release, cytotoxicity, and hypersensitivity), zirconia and advanced ceramics (highlighting high biocompatibility, excellent mechanical properties, and resistance to microbial adhesion), and polymer composites (discussing challenges like residual monomers and oxidative stress). The review concludes that the future of restorative dentistry lies in enhancing the biological integration of biomaterials through advanced surface modification techniques, plasma coatings, nano-structured composites, and bioactive surfaces. These innovations are crucial for improving long-term clinical outcomes, extending the functional lifespan of prostheses, and promoting the health of surrounding oral tissues.

Keywords: biointegration, dental biomaterials, surface modification, zirconia dioxide, cytotoxicity, bioactivity, fixed prosthodontics, biological interface, tissue engineering.

INTRODUCTION

The evolving landscape of restorative dentistry - The restoration of dental arch defects using fixed orthopedic constructions remains a cornerstone of modern dentistry, aimed at restoring function, phonetics, and aesthetics for patients with partial adentia. The global prevalence of tooth loss, as highlighted by the World Health Organization (WHO), underscores the high demand for reliable and long-lasting prosthetic solutions. The long-term clinical success of these restorations is a multifactorial issue, depending not only on precise clinical execution and the mechanical strength of the prosthesis but, most critically, on the biological compatibility of the chosen material with the host's oral tissues.

Historically, the primary goal in dental materials science was to develop bioinert materials—those that could exist within the biological environment with minimal adverse reactions. However, the field is currently undergoing a profound transformation. The focus is shifting from the passive concept of bioinertness (simply avoiding harm) to the active and dynamic concept of bioactivity. This new paradigm involves designing materials that can actively and favorably interact with the biological system, promoting tissue integration and even stimulating regeneration. This article provides a comprehensive analysis of this evolution, evaluating the biological and mechanical performance of traditional and advanced materials, and exploring the future directions aimed at creating a truly seamless integration between prosthetic devices and the human body.



The biological interface: a complex microenvironment - The junction where a prosthetic material meets the oral tissues—the gingiva, periodontal ligament, and alveolar bone—is termed the "biological interface." This is not a static boundary but a dynamic microenvironment governed by a cascade of complex biochemical and cellular events. The material's surface properties, including its chemical composition, surface energy, roughness, and topography, dictate the initial interactions. These interactions include:

Protein adsorption: Immediately upon exposure to saliva and crevicular fluid, the material's surface is coated with a layer of proteins (e.g., albumin, fibronectin). This conditioning film, known as the Vroman effect, directly influences subsequent cellular attachment and behavior.

Cellular response: The nature of the adsorbed protein layer determines the response of local cells. Favorable surfaces promote the adhesion, proliferation, and differentiation of fibroblasts and osteoblasts, leading to soft tissue integration and osseointegration. Unfavorable surfaces can trigger inflammatory responses, inhibit cell growth, or lead to the formation of a fibrous capsule, isolating the foreign body.

Microbial Colonization: The oral cavity hosts a complex microbiome. The material's surface characteristics significantly influence the adhesion and proliferation of bacteria, leading to biofilm formation. Materials with high surface energy and roughness are more prone to plaque accumulation, increasing the risk of secondary caries, gingivitis, and peri-implantitis.

Understanding and controlling these events at the biological interface is paramount for the long-term success of any fixed prosthesis.

A Comparative analysis of prosthetic materials - Metal Alloys: The Traditional Workhorse For decades, metal alloys (especially noble and base metal alloys) have been the standard for fixed prosthodontics due to their excellent mechanical strength, durability, and fracture resistance.

Biological concerns: The primary drawback of base metal alloys (e.g., Nickel-Chromium, Cobalt-Chromium) is their susceptibility to electrochemical corrosion in the moist, fluctuating pH environment of the oral cavity. This degradation process leads to the release of metallic ions. As Wataha (2000) extensively documented, ions such as Nickel (a potent allergen), Cobalt, and Chromium can elicit a range of adverse biological responses, including localized inflammation, contact dermatitis, cytotoxicity, and even systemic hypersensitivity reactions. The research by Okazaki (2003) further confirmed that the accumulation of these ions can inhibit the function of critical cells like fibroblasts, impairing soft tissue healing.

Titanium as an alternative: Commercially pure titanium and its alloys have become a superior alternative due to the spontaneous formation of a stable, passive, and bioinert titanium dioxide (TiO₂) layer on their surface. This oxide layer provides excellent corrosion resistance. However, under high mechanical stress, this layer can be disrupted (fretting corrosion), potentially releasing titanium particles that may cause a low-grade inflammatory response in some individuals.

Advanced ceramics and zirconia dioxide - The biocompatible revolution ceramic materials have revolutionized aesthetic and restorative dentistry due to their superior biocompatibility and tooth-like appearance.

Exceptional Biocompatibility: Materials like lithium disilicate and, particularly, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), are characterized by extreme chemical inertness. As demonstrated by Piconi and Maccauro (1999), zirconia exhibits virtually no cytotoxicity and does not negatively impact fibroblast proliferation, allowing for excellent soft tissue response.

Mechanical Superiority and Microbial Resistance: Zirconia possesses flexural strength (900-1200 MPa) comparable to some metals, allowing for its use in long-span bridges. Its fine-grained,



smooth surface has a low surface free energy, which, as shown in studies by Rasulova et al. (2022), reduces bacterial adhesion and biofilm formation by up to 40% compared to metals. This property is critical for maintaining periodontal health around the restoration. Furthermore, research by Zhang et al. (2019) has highlighted that controlling the surface topography of zirconia can further optimize cellular adhesion and guide tissue integration.

Potential Challenges: Despite its advantages, early generations of zirconia were prone to low-temperature degradation (aging) and had a high modulus of elasticity, which could create stress concentrations. Modern formulations have largely mitigated these issues.

Polymer and composite materials - The Aesthetic Option Resin-based composites are widely used for direct restorations and as veneering materials due to their excellent aesthetics and conservative preparation requirements.

The monomer problem - The primary biocompatibility concern with composites is the incomplete polymerization of the resin matrix, leading to the leaching of residual monomers such as Bis-GMA, TEGDMA, and HEMA. As established by Schmalz and Garhammer (2002), these molecules can diffuse into adjacent tissues, where they can induce oxidative stress, trigger inflammatory pathways, and exhibit cytotoxic effects on pulpal and gingival cells.

Physical limitations: As Peutzfeldt (1997) noted, composites suffer from physical limitations such as polymerization shrinkage (which can lead to microleakage), higher water sorption, and a coefficient of thermal expansion that does not match tooth structure, all of which can compromise long-term marginal integrity and durability.

The frontier of bioactivity: engineering the future of dental materials - The most exciting advancements in dental materials science are focused on moving beyond passive biocompatibility towards active biological integration.

Advanced Surface Modification: The goal is to engineer the material's surface to elicit a specific, favorable biological response.

Plasma Treatment: As demonstrated by Matsushita et al. (2020), treating titanium surfaces with plasma can create a nano-structured, highly reactive TiO_2 layer. This not only improves corrosion resistance by 1.8 times but also significantly enhances fibroblast adhesion and integration.

Bioactive Coatings: Applying coatings of materials like hydroxyapatite (HA) or other calcium phosphates can make a surface osteoconductive. These coatings mimic the mineral component of bone, actively encouraging osteoblast attachment and accelerating osseointegration, which is particularly relevant for dental implants supporting fixed prostheses.

Nanotechnology in Dentistry: The incorporation of nanoparticles is enhancing material properties on multiple fronts. As pioneered by Mitra et al. (2003), adding nano-fillers (e.g., nano-silica, nano-zirconia) to resin composites improves their mechanical properties (wear resistance, polishability) and reduces polymerization shrinkage. Furthermore, incorporating nanoparticles of silver or zinc oxide can impart potent, long-lasting antimicrobial properties to the material.

Smart and Functional Biomaterials: The future lies in "smart" materials that can sense and respond to their environment. This includes developing materials that can release therapeutic ions (e.g., fluoride for remineralization, strontium for osteogenesis) or antibacterial agents in response to a drop in pH, thereby actively preventing disease. As Boskey (2020) envisioned, these bioactive materials will no longer be passive scaffolds but active participants in tissue healing and maintenance.

CONCLUSION



The selection of a material for a fixed dental prosthesis has evolved from a simple choice based on strength and aesthetics to a complex decision grounded in a deep understanding of cell and tissue biology. The comprehensive analysis of available materials clearly indicates that while metal alloys remain functional, advanced ceramics like zirconia dioxide offer a superior combination of strength, aesthetics, and, most importantly, biocompatibility. Zirconia's resistance to corrosion and microbial adhesion makes it an exemplary material for maintaining long-term oral health.

However, the ultimate goal is to bridge the gap between artificial restorations and living tissue. The ongoing research into bioactive surfaces, nanotechnology, and smart materials signals a paradigm shift towards a new era of regenerative dentistry. The development of materials that not only replace lost tissue but also actively promote its healing and integration will define the future of prosthodontics, leading to more predictable, durable, and biologically harmonious clinical outcomes for patients worldwide.

References:

1. Boskey, A. L. (2020). Current concepts of biomineralization and bioactive materials. *Journal of Dental Research*, 99(6), 599-601.
2. Flemmig, T. F., & Beikler, T. (2014). Biocompatibility of polymer-based dental materials. *International Journal of Prosthodontics*, 27(5), 411-413.
3. Gao, Y., Li, Y., & Li, W. (2018). Plasma modification and fibroblast adhesion on titanium-based biomaterials. *Surface and Interface Analysis*, 50(5), 589-596.
4. Geis-Gerstorfer, J. (1994). Corrosion of dental alloys. *Clinical Oral Investigations*, 1(1), 1-2.
5. Hench, L. L. (1998). Biomaterials: a forecast for the future. *Biomaterials*, 19(16), 1419-1423.
6. Manicone, P. F., Rossi Iommetti, P., & Raffaelli, L. (2007). An overview of zirconia ceramics: basic properties and clinical applications. *Journal of Dentistry*, 35(11), 819-826.
7. Matsushita, T., Hanawa, T., & Ota, M. (2020). Surface modification of titanium and its alloys by plasma treatment. *Surface and Coatings Technology*, 399, 126131.
8. Mitra, S. B., Wu, D., & Holmes, B. N. (2003). An application of nanotechnology in advanced dental materials. *The Journal of the American Dental Association*, 134(10), 1382-1390.
9. Okazaki, Y., & Gotoh, E. (2003). Comparison of metal release from various metallic biomaterials in vitro. *Biomaterials*, 24(7), 1167-1172.
10. Peutzfeldt, A. (1997). Resin composites in dentistry: the monomer systems. *European Journal of Oral Sciences*, 105(2), 97-116.
11. Piconi, C., & Maccauro, G. (1999). Zirconia as a ceramic biomaterial. *Biomaterials*, 20(1), 1-25.
12. Rasulova, Sh., & Abdug'afforov, A. (2022). Og'iz to'qimalarining biomateriallarga biologik javobi [Biological response of oral tissues to biomaterials]. *Stomatologiya jurnali*.
13. Schmalz, G., & Garhammer, P. (2002). Biological interactions of dental materials. *Clinical Oral Investigations*, 6(3), 121-127.
14. Wataha, J. C. (2000). Biocompatibility of dental alloys. *The Journal of Prosthetic Dentistry*, 83(2), 223-234.
15. Zhang, Y., & Lawn, B. R. (2019). Novel zirconia materials in dentistry. *Journal of Dental Research*, 98(2), 140-147.