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Various Materials in Dental Implants: A Comprehensive Review

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Abstract:
Background: *Dental implantology has emerged as a transformative modality in oral rehabilitation, offering a durable and predictable solution for edentulism. Central to implant success is the choice of material, which significantly influences osseointegration, mechanical strength, aesthetics, and long-term clinical outcomes. Over the decades, continuous innovations have taken place in metallic, ceramic, and polymer-based biomaterials used in dental implants. A clear understanding of these materials is crucial for clinicians to select the most appropriate system tailored to individual patient needs and clinical conditions.*
Materials and Methods: *This comprehensive review examines various dental implant materials by evaluating their historical evolution, mechanical and biological requirements, classification, and physico-chemical properties. The article discusses the core materials used—primarily titanium and zirconia—highlighting their development, modifications, and performance in clinical use. Contemporary advancements in nanostructuring, surface treatments, and bioactive coatings are reviewed alongside the limitations and future directions of biomaterial science in implantology.*
Results: *Titanium continues to dominate due to its exceptional biocompatibility, corrosion resistance, and mechanical reliability. Zirconia, as a metal-free alternative, offers superior aesthetics and biocompatibility, though with some limitations in fracture resistance. Emerging polymer-based and composite materials show promise, particularly in load-sharing applications and patient-specific customization. Innovations in surface engineering have notably enhanced osseointegration and soft tissue response across materials.*
Conclusion: *The evolution of dental implant materials reflects a convergence of clinical demands, material science, and technological innovation. Titanium remains the gold standard, yet zirconia and hybrid materials are gaining traction in specific indications. A detailed understanding of these biomaterials will empower clinicians to make evidence-based decisions for enhanced patient outcomes.*
Key Word: *Dental implants; Titanium; Zirconia; Biomaterials; Osseointegration; Prosthodontics.*

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I.Introduction

The pursuit of suitable materials for dental implants dates back to ancient civilizations such as the Egyptians and Mayans, who used ivory, bone, and shells to replace missing teeth. However, modern implantology began in the 1950s with the discovery of osseointegration by Brånemark et al. [1]. Defined as the direct structural and functional connection between living bone and the surface of a load-carrying implant, osseointegration revolutionized implant materials research.Modern dental implant materials include metals (e.g., titanium and its alloys), ceramics (e.g., zirconia), polymers (e.g., PEEK), and bioactive coatings. The ideal material should exhibit biocompatibility, resistance to corrosion, favorable mechanical strength, and promote osseointegration [2,3].

II. Historical Development of Dental Implant Materials

The journey of dental implantology traces back thousands of years. Archaeological findings from ancient civilizations such as the Mayans and Egyptians reveal attempts to replace lost teeth using materials like carved stones, shells, and animal bones [4]. While rudimentary, these early prostheses were significant attempts at oral rehabilitation.

It wasn't until the 20th century that dental implants began evolving through scientific principles. Early modern implants like subperiosteal and blade-form implants were crafted from materials such as cobalt-chromium and stainless steel [5]. These systems, though moderately successful, were prone to failure due to poor osseointegration and inflammatory reactions.

A pivotal moment occurred in 1952 when Prof. Per-Ingvar Brånemark accidentally discovered that titanium, once inserted into bone, could not be removed due to a direct structural and functional connection with bone—a phenomenon he later termed osseointegration [1]. This discovery led to the first commercial use of endosseous titanium implants in the 1960s and 1970s.

Subsequent decades saw modifications to titanium surfaces, including acid-etching, sandblasting, anodization, and coating with hydroxyapatite (HA) to enhance bioactivity [6]. New ceramic materials, particularly zirconia, emerged in the 1990s to address the limitations of metallic implants, especially in aesthetic zones.

Today, the development of novel alloys (e.g., Ti-Zr), polymers (e.g., PEEK), and functionally graded materials continues to shape the future of implant dentistry, offering personalized treatment options tailored to clinical conditions and patient preferences [7].

III. Parts of Dental Implants

A typical dental implant system consists of three major components, each designed to fulfill a unique function:

A. Implant Fixture

Also referred to as the implant body or endosseous component, this is the screw-shaped structure that is surgically embedded into the alveolar bone. It provides foundational stability and must be designed to withstand physiological loads while promoting bone integration [8].

B. Abutment

The abutment connects the implant fixture to the final prosthesis. It can be prefabricated or custom-made using materials like titanium, zirconia, or PEEK. A precise fit between the abutment and implant body is crucial to prevent microleakage and peri-implant inflammation [9].

C. Prosthesis

The prosthesis is the visible component, such as a crown, bridge, or denture. It restores form and function and is typically fabricated from ceramics, metal-ceramic combinations, or zirconia [10].

The interface between these parts must ensure structural integrity, prevent bacterial infiltration, and allow for biomechanical compatibility under mastication.

IV. Ideal Requirements of Implant Materials

Dental implants are subjected to complex biological and mechanical environments. Therefore, the materials used must meet several stringent requirements to ensure success over the long term.

A. Biocompatibility

Implants must be biologically inert, meaning they should not elicit immune or inflammatory responses. This is vital for promoting proper healing and integration with the surrounding tissues [11]. Materials such as titanium and zirconia are widely used due to their excellent track record in clinical and histological studies.

B. Mechanical Strength and Fatigue Resistance

Dental implants must resist masticatory forces that range between 200–900 N. They should exhibit high tensile strength, compressive strength, and especially fatigue resistance since implants are load-bearing over extended periods [12].

C. Corrosion Resistance

The oral environment is hostile, with fluctuations in pH, enzymatic activity, and exposure to food and beverages. An ideal implant material must be resistant to corrosion to prevent the release of potentially harmful ions and maintain structural integrity [13].

D. Osseointegration Capability

Perhaps the most critical feature is the material's ability to integrate with bone. Surface topography, chemical composition, and roughness all influence osteoblast attachment and differentiation, facilitating strong and lasting bone contact [14].

E. Aesthetic and Functional Compatibility

For anterior restorations, materials like zirconia are preferred due to their tooth-like color. The material must also be machinable and compatible with prosthetic components for precise restoration [15].

V.Classification of Dental Implants

Implant materials are classified in multiple ways to aid selection based on clinical scenarios. Broadly, they can be categorized as follows:

A. Based on Material Composition

1. **Metals:**
   - Titanium (cpTi, Ti-6Al-4V)
   - Titanium–zirconium alloys
   - Cobalt–chromium
   - Tantalum

2. **Ceramics:**
   - Zirconia (Y-TZP)
   - Alumina
3. **Polymers and Composites:**
   - PEEK (Polyether Ether Ketone)
   - PMMA (Polymethyl Methacrylate)
4. **Bioactive Materials:**
   - Hydroxyapatite (HA)
   - Bioactive glass

B. Based on Implant Design

1. **Endosseous Implants:** Inserted into the alveolar bone; most commonly used today.
2. **Subperiosteal Implants:** Placed above the bone but beneath the periosteum; largely obsolete.
3. **Transosteal Implants:** Pass through the entire thickness of the mandible; rarely used due to surgical complexity [16].

VI.Properties of Implant Materials

The success of a dental implant also relies heavily on the inherent properties of the chosen material. These include:

A. Mechanical Properties

- **Titanium and its alloys** possess a high strength-to-weight ratio, corrosion resistance, and low density, making them ideal for intraoral use. The elastic modulus of titanium (~110 GPa) is closer to that of bone compared to other metals, reducing stress shielding [17].
- **Zirconia** is known for its high compressive strength and stiffness but is more brittle, making it less suitable for long-span prostheses [18].

B. Chemical and Surface Characteristics

- Titanium forms a passive oxide layer (TiO_2) that enhances corrosion resistance and biocompatibility [19].
- Surface treatments like **sandblasting, acid-etching, and anodization** improve surface roughness and energy, promoting osseointegration [14].

C. Biological Response

- **Titanium** is inert and well tolerated by peri-implant tissues. However, rare cases of hypersensitivity or allergic reaction have been reported [20].
- **Zirconia** shows excellent tissue compatibility and may exhibit lower bacterial colonization than titanium, making it advantageous in aesthetic zones [21].

VII.Materials Used in Dental Implants

- The success of dental implants is intrinsically linked to the materials used in their fabrication. Here's a breakdown of the most commonly used materials and their clinical implications:
- **A. Titanium and Titanium Alloys**
- Titanium (commercially pure, cpTi) remains the most widely used material in implantology due to its unmatched biocompatibility, corrosion resistance, and mechanical properties. Titanium alloys, particularly Ti-6Al-4V, are favored in high-load-bearing situations for their increased tensile and yield strength [1,12]. However, concerns regarding the release of aluminum and vanadium ions have led to the exploration of newer titanium alloys, such as titanium-zirconium (TiZr) [16].
- **B. Zirconia**
- Zirconia, particularly yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), offers an aesthetic and metal-free alternative to titanium [6]. Its white color and low plaque accumulation make it suitable for anterior restorations and patients with metal sensitivities. However, its brittleness and low flexural strength limit its use in posterior multi-unit applications [18].
- **C. Tantalum**
- Tantalum is a newer biomaterial characterized by excellent bioactivity and corrosion resistance. Its highly porous structure mimics trabecular bone, promoting vascularization and faster bone in-growth. Tantalum is also radiopaque, facilitating post-operative evaluation [22].
- **D. Polyether Ether Ketone (PEEK)**
- PEEK is a high-performance thermoplastic known for its radiolucency and elastic modulus similar to bone. While not bioactive by nature, it is used for abutments and temporary implants. Surface modifications like titanium coating or incorporation of HA particles are often required to improve its osteogenic potential [19].

- **E. Bioactive Ceramics and Coatings**
- Hydroxyapatite and bioactive glass are often used as coatings on titanium implants to improve early-stage bone contact. These materials are osteoconductive and bond chemically with bone, accelerating healing. However, delamination of coatings under stress remains a concern [20].
- **F. Emerging Materials**
- Recent research has turned toward graphene oxide coatings, magnesium-based degradable implants, and functionally graded materials. Graphene offers antibacterial properties and supports cell adhesion [21]. Magnesium, while biodegradable

VIII.Current Status of Oral Implantology

The field of implantology has matured significantly, now offering highly predictable outcomes with long-term success rates exceeding 95% [24]. Technological advancements such as CBCT imaging, CAD/CAM prosthetics, guided surgery, and digital impressions have enabled personalized treatment planning with higher precision.

- Surface modifications continue to evolve, with research focusing on nanostructures, bioactive peptides, and hydrophilic surfaces to accelerate osseointegration [14]. Additionally, zirconia implants are increasingly favored for aesthetic concerns, and Ti-Zr alloys combine strength and osseointegration advantages.
- Immediate and early loading protocols, once considered risky, are now standard in many cases, thanks to improved implant stability and prosthetic accuracy. However, peri-implantitis, systemic health factors, and poor oral hygiene continue to challenge implant longevity [25].

IX.Discussion

The material composition of dental implants remains a cornerstone in the long-term success of implant-based rehabilitation. As this review demonstrates, multiple material systems—including metals, ceramics, polymers, and surface-modified composites—have been studied extensively for their mechanical integrity, biological behavior, and prosthetic compatibility.

Titanium, both in commercially pure and alloyed forms, continues to be the most widely used implant material owing to its high strength, corrosion resistance, and reliable osseointegration [1,11]. Its passive oxide layer plays a vital role in promoting biocompatibility and inhibiting corrosion in the oral environment [10]. However, rare cases of hypersensitivity or allergic reactions have encouraged exploration into alternative biomaterials such as zirconia and tantalum [17,22].

Zirconia has gained traction particularly in aesthetic zones and in patients sensitive to metals. Its tooth-colored appearance, excellent tissue response, and reduced bacterial adhesion are significant advantages [6,21]. Nevertheless, its intrinsic brittleness limits its application in high-load areas, and long-term data on full-arch zirconia implants remain limited.

PEEK and other high-performance polymers are currently being studied for their lightweight properties and bone-matching elastic modulus [19]. However, their biologically inert nature demands surface modifications or composite integration to induce osseointegration. Similarly, bioactive ceramics such as hydroxyapatite are valuable as coatings but not as standalone implant materials due to brittleness and poor tensile properties [20].

Recent advancements have shifted focus toward biofunctionalization, where implants are not merely passive structural components but active participants in the healing process. Techniques like nano-roughening, protein coating, and incorporation of growth factors are now being developed to stimulate faster and more effective bone regeneration [14].

Another key area is the development of functionally graded materials (FGMs) that mimic the natural bone-implant interface with varying compositions across layers to enhance mechanical compatibility and reduce stress concentrations [21,23]. Although promising, such technologies still face manufacturing and clinical validation challenges.

Furthermore, digital dentistry is changing the paradigm of material application. CAD/CAM, 3D printing, and robotic-guided placement allow for customized implant design, better load distribution, and improved clinical workflow. These innovations enable clinicians to optimize both material and structural selection per patient-specific anatomy [24].

Despite these advancements, complications such as peri-implantitis, mechanical failure, and implant loss persist. These are often multifactorial—linked to patient habits, implant material, prosthetic design, and surgical technique [25]. Thus, interdisciplinary treatment planning remains essential.

In summary, while titanium remains the benchmark, materials like zirconia, tantalum, and advanced polymers are expanding clinical possibilities. Future trends will likely include smart biomaterials with antimicrobial and osteoinductive properties, combined with AI-driven diagnostics and regenerative adjuncts for fully customized treatment protocols.

X.Conclusion

Dental implants have revolutionized modern prosthodontics, offering a durable and functional solution to tooth loss. The materials used in implant fabrication are central to clinical success, influencing everything from mechanical performance to biological integration and patient satisfaction.

Titanium remains the most reliable material, while zirconia offers promising results in aesthetic and metal-sensitive situations. Novel materials like PEEK, tantalum, and graphene-enhanced surfaces are expanding clinical options, especially with the help of digital workflows.

As the field continues to evolve, future dental implants will likely integrate smart materials, improved surface bioactivity, and customization through 3D printing, leading to faster healing and better clinical outcomes. For clinicians, understanding the properties and applications of these materials is essential for making evidence-based decisions that ensure long-term implant success.

References

[1]. Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallén O, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. J Prosthet Dent. 1983;50(3):399–410.

[2]. Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand. 1981;52(2):155–70.

[3]. Elias CN, Lima JHC, Valiev R, Meyers MA. Biomedical applications of titanium and its alloys. JOM. 2008;60(3):46–9.

[4]. Linkow LI. The blade-vent implant. J Oral Implantol. 1998;24(1):16–36.

[5]. Wennerberg A, Albrektsson T. Effects of titanium surface topography on bone integration: A systematic review. Clin Oral Implants Res. 2009;20(Suppl 4):172–84.

[6]. Andreiotelli M, Wenz HJ, Kohal RJ. Are ceramic implants a viable alternative to titanium implants? A systematic literature review. Clin Oral Implants Res. 2009;20(Suppl 4):32–47.

[7]. Gahlert M, Rohling S, Wieland M, Sprecher C, Kniha H, Milz S. Osseointegration of zirconia and titanium dental implants: A histological and histomorphometrical study in the maxilla of pigs. Clin Oral Implants Res. 2009;20(11):1247–53.

[8]. Misch CE. Dental Implant Prosthetics. 2nd ed. St. Louis: Elsevier Mosby; 2014.

[9]. Zipprich H, Weigl P, Lauer HC, Lange B. Micromovements at the implant–abutment interface: Measurement, causes, and consequences. Implantologie. 2007;15(1):31–46.

[10]. Hanawa T. Titanium–tissue interface reaction and its control with surface treatment. Front Bioeng Biotechnol. 2019;7:170.

[11]. Geetha M, Singh AK, Asokamani R, Gogia AK. Ti-based biomaterials, the ultimate choice for orthopaedic implants–A review. Prog Mater Sci. 2009;54(3):397–425.

[12]. Long M, Rack HJ. Titanium alloys in total joint replacement—a materials science perspective. Biomaterials. 1998;19(18):1621–39.

[13]. Hallab NJ, Jacobs JJ. Biologic effects of implant debris. Bull NYU Hosp Jt Dis. 2009;67(2):182–8.

[14]. Coelho PG, Granjeiro JM, Romanos GE, Suzuki M, Silva NR, Cardaropoli G, et al. Basic research methods and current trends of dental implant surfaces. J Biomed Mater Res B Appl Biomater. 2009;88(2):579–96.

[15]. Scarano A, Piattelli A, Caputi S, Favero GA, Piattelli M. Bacterial adhesion on commercially pure titanium and zirconium oxide disks: An in vivo human study. J Periodontol. 2004;75(2):292–6.

[16]. Jemat A, Ghazali MJ, Razali M, Otsuka Y. Surface modifications and their effects on titanium dental implants. Biomed Res Int. 2015;2015:791725.

[17]. Siddiqi A, Payne AG, De Silva RK, Duncan WJ. Titanium allergy: Could it affect dental implant integration? Clin Oral Implants Res. 2011;22(7):673–80.

[18]. Dubey N, Ferreira J, Malda J, Bhaduri SB, Bottino MC. Insight into biomaterials for orthopedic applications: Past, present and future trends. Adv Drug Deliv Rev. 2020;161–162:94–112.

[19]. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials. 2007;28(32):4845–69.

[20]. Hench LL. Bioceramics: From concept to clinic. J Am Ceram Soc. 1991;74(7):1487–510.

[21]. Zreiqat H, Ramaswamy Y, Wu C, Paschalidis A, Lu Z, James B, et al. The effect of surface composition of ceramic particles on the proliferation of human osteoblasts. J Mater Sci Mater Med. 2006;17(4):377–85.

[22]. Levine BR, Sporer SM, Poggie RA, Della Valle CJ, Jacobs JJ. Experimental and clinical performance of porous tantalum in orthopedic surgery. Biomaterials. 2006;27(27):4671–81.

[23]. Staiger MP, Pietak AM, Huadmai J, Dias G. Magnesium and its alloys as orthopedic biomaterials: A review. Biomaterials. 2006;27(9):1728–34.

[24]. Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: A systematic review. Int J Oral Maxillofac Implants. 2014;29(Suppl):25–42.

[25]. Renvert S, Polyzois I, Claffey N. How do implant surface characteristics influence peri-implant disease? J Clin Periodontol. 2012;39(Suppl 12):202–7.

[26]. Wang G, Zreiqat H. Functional coatings or films for hard-tissue applications. Materials. 2010;3(1):399–428.

[27]. Roehling S, Schlegel KA, Woelfler H, Gahlert M. Zirconia compared to titanium dental implants in preclinical studies – A systematic review and meta-analysis. Clin Oral Implants Res. 2019;30(5):365–95.

[28]. Osman RB, Swain MV. A critical review of dental implant materials with an emphasis on titanium versus zirconia. Materials. 2015;8(3):932–58.

[29]. Sagomonyants KB, Jarman-Smith M, Devine JN, Aronow MS, Gronowicz GA. Porous tantalum stimulates the proliferation and osteogenesis of osteoblasts from elderly female patients. J Orthop Res. 2011;29(4):609–16.

[30]. Schwitalla AD, Müller WD. PEEK dental implants: A review of the literature. J Oral Implantol. 2013;39(6):743–9.

[31]. Minagar S, Berndt CC, Wang J, Ivanova E, Wen C. A review of the application of plasma spray coatings for enhancing the performance of metallic implants. Surf Coat Technol. 2012;233:147–58.

[32]. Stadlinger B, Pilling E, Huhle M, Mai R, Bierbaum S, Scharnweber D, et al. Effect of biological implant surface coatings on bone regeneration. Bone. 2008;43(4):741–6.

[33]. Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers: Current status and potential application in prosthetic dentistry. J Prosthodont. 2019;28(2):146–58.

[34]. Parthasarathy J, Starly B, Raman S. A design for the additive manufacture of functionally graded porous structures with tailored mechanical properties for biomedical applications. J Manuf Process. 2011;13(2):160–70.

[35]. Berglundh T, Armitage G, Araujo MG, Avila-Ortiz G, Blanco J, Camargo PM, et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop. J Clin Periodontol. 2018;45(Suppl 20):S286–91.
[36]. Yu W, Jiang G, Zhang Y, Liu D, Xu Q, Li K, et al. Intelligent dental implant materials with antibacterial and osteogenic capabilities. J Biomed Mater Res B Appl Biomater. 2021;109(8):1104–20.