Journal of Namibian Studies, 32 (2022): 1057-1075 ISSN: 2197-5523 (online)

"Advancements In Dental Biomaterials: Innovations For Restoration And Regeneration"

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Abstract:

Dental implants have revolutionized modern dentistry, offering a reliable solution for the replacement of missing teeth. Among the various biomaterials utilized in implantology, titanium has emerged as the gold standard due to its excellent biocompatibility, mechanical properties, and ability to osseointegrate with the surrounding bone. This abstract explores the role of titanium implants in contemporary dental practice, highlighting their advantages, challenges, and future directions. Titanium implants exhibit exceptional biocompatibility, eliciting minimal adverse reactions from the host tissue and promoting successful osseointegration, which is critical for implant stability and long-term function. Ongoing advancements in surface modifications, nanostructured coatings, and bioactive materials aim to further enhance osseointegration and mitigate risks associated with peri-implantitis and implant failure. However, challenges such as inflammation, foreign body reactions, and mechanical issues persist, underscoring the need for interdisciplinary collaborations to develop novel biomaterials with superior properties. Furthermore, personalized treatment planning is paramount in implant dentistry, considering individual factors such as bone quality, systemic health, and patient preferences. This holistic approach ensures optimal outcomes and patient satisfaction, paving the way for the era of personalized and precision dentistry. As research progresses and technologies evolve, the future of dental implantology holds immense promise, with continued advancements poised to further elevate standards of care and improve the quality of life for countless individuals worldwide.

Key Words: Biomaterials, Dental, Implants, Titanium, Features.

Introduction:

Biomaterials are synthetic or natural materials that interact with biological processes to help improve, replace, or repair any tissue or organ in the body over time. Biomaterials are made up of several parts and pertain to every system in the body. It may be as basic as a urine catheter, or it could be more intricate, like an internal glucose sensor, or it could be a permanent device, like a cardiovascular stent or a stainless steel implant that replaces bone [1], [2], [3]. Biomaterials are designed to interact with living tissue for dentistry and medical purposes. These are frequently associated with hip replacement implants, cardio-vascular reinforcement implants, and dental fillings [4]. Numerous recipients of these applications benefit from improved quality of life, including the elderly with longer life expectancies and younger individuals with heart problems, traumas, or genetic abnormalities.

The initial biomaterials synthesis played a pivotal role in reducing tissue reactivity. A thin fibrous layer forms between these substances and the rest of the body when the body is unable to absorb them fully [6]. The success of this implant depends on the materials used to create it. Thus, the now-standard hip replacement, performed on over a million patients worldwide annually, started as a multi-component assembly made up of an acetabular cup made of polyethylene, a PMMA attachment, and an austenitic stainless-steel stem. With a ten-year or longer life expectancy, every material tested was bioinert [7], [8]. For both bio-active and bio-inert applications, the interface between body cells and the implant as well as the surface materials science of the biomaterial are critical. Bioactive materials are being created that have a favorable effect on the biological response, e.g., by promoting bonding to surrounding tissue to encourage the formation of new bone [9]. Bioinert materials are also being enhanced concurrently. Biocompatibility is arguably the most common feature of biomaterials' applicability.

The ability of a substance to function in a specific application while evoking the intended host response is known as biocompatibility. The complex process of determining a material's biocompatibility is governed by a number of factors. Under the right circumstances, this property determines whether or not the body tissue can absorb synthetic implants without experiencing negative immunological, allergic, inflammatory, or chronic effects; these materials are not carcinogenic [10]. Additionally, biocompatibility is greatly influenced by the type of application. The following are the main factors affecting biocompatibility [11]:

- **Interaction with the Environment:** It covers inflammatory processes, the degree of biodegradation, mutagenesis reactions, toxicological or allergic reactions, and chemical interactions with blood.
- **The duration of implant application**: implants can be categorized as long-term or short-term.
- **Surface biocompatibility:** This refers to how well the implanted surface fits in terms of biology, chemistry, and morphology.
- **Biocompatibility of the Structure**: This refers to the implant's ability to mechanically fuse as closely as possible with the host tissue.
- **Function:** This word includes the necessary friction coefficient and mechanical characteristics.
- **Form and Size Proportion**.
- **Material:** This refers to the degree of aggression that exists between the host tissue and the synthetic material.

History of Dental Biomaterials and Dental Implants:

Restoring the patient to normal function, speech, health, and appearance is the aim of modern dentistry, independent of the stomatognathic system's atrophy, illness, or damage. Single missing tooth replacement has never been easy for dentists, particularly when it comes to the anterior region. Patients' requests have made detachable partial dentures less common, and many are now against the preparation of their natural teeth for the creation of a fixed partial denture. A dental implant is an excellent illustration of the integrated system of science and technology involving several disciplines, including surface chemistry and physics, biomechanics from macro-scale to nanoscale manufacturing technologies, and surface engineering, among other dental materials and their successful applications. A wide range of materials with varying degrees of bodily involvement are used in dental implants. This contact, which results from friction and mechanical interlocking between the implant thread surface and the bone trabeculae, offers primary stability immediately following implant insertion. The peri-implant bone remodels and is replaced by newly produced bone during the course of the ensuing weeks [12, 13]. As a result, the majority of the final bone-implant contact is composed of freshly produced bone that grows from the nearby peri-implant bone and is applied osteoconductively to the implant surface [14, 15].

Approximately one million dental implantations are performed annually worldwide, a steady growth over the previous 30 years. Early osseointegration of dental implants is associated with their clinical success [16, 17]. For dental implants to be successful both in the short and long term, geometry and surface topography are essential [18-20]. Implants' past and current applications in dentistry Ancient Chinese, Egyptian, Greek, and Etruscan cultures all have the desire, which goes back thousands of years, to replace missing teeth with something resembling a tooth's root. A ferrous metal tooth from a skull discovered in Europe during the time of Christ. The Incas of Central America used seashell fragments to replace lost teeth in a manner akin to that of the ancient Chinese by tapping them into the bone [21]. Then, history demonstrates that it has always made sense to use an implant that closely resembles a tooth to replace a missing tooth.

Greenfield [22] unveiled the first hollow cylinder implant prototype, which was constructed of an iridium-platinum alloy, in 1906. The bone's response to metal implants and tissue tolerance received increased attention in the early 1930s. Cobalt-chromium-molybdenum alloy screw Vitallium was successfully anchored in bone by Strock [23], who then mounted a porcelain crown on the implant right away. Müller inserted the first implant, an iridium-platinum alloy, into the mouth cavity at the same moment. Many implantologists began developing implant treatments in the 1950s [24–27]. Per-Ingvar Brånemark, a physician doing in vivo research with titanium chambers inserted within bone, identified the specific bond that this metal could form within the recipient tissue, which marked the beginning of modern oral implantology [28]. Brånemark proposed a "bone-anchored bridge" in 1965 as a means of treating mandible edentulousness. Two seminal papers [1, 16] introduced and expanded upon the idea of osseointegration. Specifically, Brånemark noted that a titanium fragment inserted into rabbit bone solidifies and becomes challenging to extract [29]. After a year of surveillance, the peri-implant bone showed no signs of inflammation; in the meantime, soft tissue had grown to adhere to the titanium and the metal [30]. Despite the fact that many people considered osseointegration to be unachievable and did not recognize it as a clinical breakthrough [31], the Brånemark dental implant system was unveiled in 1971 [20]. Also check the references [32–45] for additional information on the history of dental implants. Titanium is currently the most often utilized implant material. Titanium has emerged as the benchmark material for implant dentistry as a consequence of Brånemark's comprehensive research. However, a new, difficult path in implantology has been made possible by the significant revolution in the field of ceramic materials with the use of zirconium dioxide and other materials.

Features of Biomaterials and Dental Implants:

An artificial tooth root called a dental implant is inserted into the jaw to support a crown, or replacement tooth. The implant mimics the root's form. Over time, the implant is surgically integrated into the bone to serve as a strong foundation for crowns. Dental implants can support partial or complete dentures, or they can be used to replace one or more teeth. Three components can be distinguished: (a) the implant fixture that will be the subject of this discussion; (b) the abutment that is positioned over the fixture to support the crown; and (c) the crown that is attached to the abutment by either cement or screw. Screw-type and cylinder-form implants are two types of implants that differ in their general shape. "Straight (parallel-walled) implants" and "tapered root-form implants" are included in the first, which is the most popular. It can be inserted into smaller sockets and effectively transfers biting force to the bone. The cylinder-form implant fits into the jawbone with ease and has a cylindrical shape without screw threads. However, due to the reduced surface area compared to screw-type implants, it does not demonstrate sufficient primary stability.

Osteointegration is the process by which an implant and the jawbone form a robust biomechanical relationship. The osseointegration was defined by Brånemark as direct contact (under a light microscope) between the implant and living bone. The direct anchoring of an implant by the development of bone tissue surrounding it, without the establishment of fibrous tissue at the bone–implant interface, is known as osseointegration, according to histology. There isn't a complete bone-to-implant contact. Regarding the criteria for defining the term and the degree of bone-to-implant contact necessary for the link to be accepted as osseointegration, no consensus could be reached. Despite all the ambiguities in the term, an oral implant that integrates successfully must fulfill specific requirements that have been documented in other sources [46–51]. The patient's health, smoking habits, bone quality, bacterial contamination, rapid loading, and implant surface features are among the several variables that affect osseointegration success [40]. The minimal requirements for implant success include success rates of 85% or above after a 5-year observation period and 80% after a 10-year period [52-54].

Classification of Biomaterials and Dental Implants:

Alloys and metals

Because of their exceptional mechanical properties, these materials have long been used for load-bearing body parts like knees, teeth implants, and bones. The metallic biomaterials that are used most frequently are Fe alloys (such as stainless steel), Mo, Ti, and Co-Cr [12]. Although metallic biomaterials have remarkable mechanical properties, once they are transplanted into the host, they quickly corrode [13]. Additionally, stress shielding may happen as a result of metallic implants' significant stiffness compared to the host bone, which could lead to bone resorption [14]. The previously described traits eventually affect the living thing wherever they are grafted [15]. When these conditions come together, they can eliminate the transplant's characteristics, weakening the grafts and reducing their compatibility with living things [16].

Ceramics:

Ceramics are resistant to breaking down and compressing, and they have low thermal and electrical conductivities. Medical grafts have historically been the primary application for bioceramics [17]. It produces new bone tissue more effectively and with less toxicity. High-stiffness bioceramics called hydroxyapatites are mostly utilized in dental implants. Numerous small, non-metallic components make up bioceramics [18]. Bioceramics have a high compressive strength, a low tensile strength, and are stiff, brittle, and chemically inert.

Materials made of polymers:

Biopolymers are generally accepted as the most appropriate material for use in biomedicine among other types of biomaterials. Compared to other materials, metallic alloys and bioceramics are examples of synthetic biopolymers that are commonly used. Man-made polymers find application in dental materials, bandages, prosthesis, drug delivery systems, grafts, and skilled tissue products [19]. Compared to bioceramics or metallic biomaterials, synthetic biopolymers provide a number of advantages, such as the ability to be produced in a variety of shapes (such as films, fibers, sheets, and latex), simple secondary processing steps, affordability, and simplicity of achieving specific mechanical capabilities [20]. Important characteristics of synthetic biopolymers include their flexibility, biocompatibility, low weight, resilience to biological attacks, and, most importantly, their ease of biodegradation [21].

Biocomposites:

Materials with different physical, chemical, and morphological properties that are biologically relevant are combined to generate biocomposites [22]. Biocomposites have been created in a variety of ways, depending on the characteristics of the constituent parts, to produce materials with mechanical, chemical, and physical properties tailored to certain uses. Because of this, the applications for composites have steadily increased over the past forty years, and today's composite materials have a wide range of non-medical uses, such as in the naval, automotive, and aerospace industries. Recently, a number of biocomposites have been investigated and confirmed for use in biomedicine [23]. Because of their benefits over conventional materials, some of these materials are now available in consumer markets.

Biomaterials testing:

Following such developments in medicine, it's critical to guarantee the security and effectiveness of medical devices and technologies. Biomaterials are put through a variety of tests based on mechanical and biological criteria in order to achieve these requirements.

Needs for biocompatibility:

Data on biological interaction can be promptly and reasonably obtained through evaluation in vitro, or "in glass" circumstances. The material is, in theory, placed close to the cell, grown in vitro, and after a few days, its cellular composition is examined [36]. Following the completion of in vitro testing, these examinations may include skin, hemocompatibility, and implantation testing. The duration of a test might vary, ranging from three weeks to several months, contingent on the required test date. Mammals such as guinea pigs, rats, mice, and hamsters are utilized. The mechanical testing of these biomaterials includes fatigue testing, pressure pulsation models of stent materials, compression and bending testing of complete devices, and static, dynamic, and tensile testing of individual metals and alloys. Another important test is corrosion testing, in which the implants are subjected to a highly corrosive environment that includes blood and other body fluids that contain a variety of substances, including proteins, plasma, water, salt, chlorine, amino acids, and, in the case of saliva, mucin.

Dental Implants such as Titanium:

Numerous materials, including metals, alloys, ceramics, polymer-based materials, glasses, and carbon, have been tested over the lengthy history of dental implants [42–44]. The qualities listed in the preceding paragraph—biocompatibility, biofunctionality, availability, and osseointegration capacity—are necessary for the production of dental implants. One of the most crucial aspects of material selection is biocompatibility, which describes how materials interact with the biological tissues they are intended for [45]. The mechanical and physical characteristics of an implanted device that allow it to work under the forces placed on it in the oral cavity are referred to as biofunctionality. The term "availability" describes how easily the implants may be made and sterilized [45].

Due to their widespread application and many advantageous physical, mechanical, and biological characteristics, pure titanium, its alloy Ti6Al4V, and zirconium dioxide (Zirconia) will be the primary subjects of this review. A brief portion will be devoted to the materials that the field's ongoing research is generating, with some of the limitations of the current technology serving as inspiration.

Thanks to Brånemark's research, titanium—once thought to be a rare metal—is now one of the most significant metals in the business and the most widely used implant material in dentistry. Although Klaproth didn't call this element after the mythological Titans, the earliest sons of Earth, until 1795, Gregor made the initial discovery of it in England in 1790 [46]. After iron, magnesium, and aluminum, titanium was the fourth most prevalent metallic element and the ninth most abundant element in the crust of the planet. Titanium, being a transition element, has an electronic structure with an incompletely filled d shell [46]. There are two allotropic types of titanium. It possesses a body-centered cubic structure (bcc), designated β, above around 883 °C, although in its elemental form it has a hexagonal closed packed crystal structure (hcp), generally known as α [47].

To change its qualities, titanium can be alloyed with a wide range of elements. The major goals of this process are to increase the metal's strength, creep resistance, high-temperature performance, reaction to aging heat treatments, and formability [48]. Depending on the type of alloying elements, pure titanium's α to β transition temperature can either rise or fall. The addition of alloying elements like Al, O, N, and C—which tend to stabilize the α phase—raises the β transus temperature. On the other hand, the addition of elements like V, Mo, Nb, Ta, Fe, Cr, Fe, W, Si, Co, Mn, and H—which stabilize the β phase—is known as a β-stabilizer and lowers the β transus temperature. Neutral elements (Zr and Sn) are some of the elements that form solid solutions with titanium but do not significantly affect the stability of either phase. However, research by Tang et al. [50] and Geetha et al. [49] has demonstrated that Zr addition stabilizes the β phase in the Ti–Zr–Nb system.

Titanium alloys can be categorized as α, near-α, α + β, or metastable β based on their microstructure at room temperature [51]. α alloys are defined as alloys with solely α stabilizers and that are made completely of α phase. Near α alloys are defined as those that include between 1% and 2% of β stabilizers and between 5% and 10% of β phase. α + β alloys are alloys with increased concentrations of β stabilizers, which lead to a microstructure with 10–30% β phase. Metastable β alloys are alloys with even higher β stabilizers that allow for the retention of the β phase via rapid cooling. As these alloys age, they break down into α + β. The composition, relative amounts of the α and β phases, thermal treatment, and thermo-mechanical processing parameters all affect the material's characteristics. Additionally, the β alloys have the special qualities of having a low elastic modulus and excellent corrosion resistance [52, 53]. Commercially pure titanium (cpTi), which is graded from 1 to 4 depending on the amount of oxygen, carbon, and iron present, is typically used to make dental implants. Since grade 4 cpTi is stronger than other grades, it is utilized most frequently. Commercially, the α + β alloy Ti–6Al–4V with 6% aluminum and 4% vanadium is also available. It has better yield strength and fatigue characteristics than pure titanium and is often employed in an annealed state [54].

Surface roughness of titanium:

For dental implants, a variety of titanium surfaces are offered by businesses. Clinical efficacy for the majority of these surfaces is established. But these surfaces have been developed empirically, without the need for standardized testing. Moreover, it is uncommon to do comparative clinical trials using several implant surfaces. It is still unclear exactly how surface topography and chemistry affected the initial stages of osseointegration [8]. Depending on the size of the features, surface roughness can be categorized into three levels: macro-, micro-, and nano-sized topologies. A number of techniques have been developed to increase the osseointegration of titanium dental implants by roughening their surface. The most often utilized techniques are anodization, acid etching, ceramic particle blasting, and titanium plasma spraying [8].

Titanium powder is injected into a plasma torch at a high temperature in titanium plasma spraying (TPS). Particles of titanium are directed onto the implant's surface, where they condense and combine to form a 30-µm-thick coating. For the thickness to be uniform, it must reach 30–50 µm. The resultant coating improves the implant's surface area and has an average roughness of about 7 µm. Research has demonstrated that the tensile strength at the interface between the implant and bone was enhanced by this three-dimensional pattern . Nonetheless, titanium particles have occasionally been seen in the bone next to implants . It has also been documented that metallic wear particles from endosseous implants are present in the spleen, liver, tiny clusters of macrophages, and even the para-aortic lymph nodes. Because of their potentially dangerous local and systemic carcinogenic consequences, metal ions released from implants owing to wear, dissolution, and fretting may be cause for concern. However, not everyone is aware of the detrimental implications that the release of titanium ions can have both locally and systemically.

Surface coating of titanium:

Metal implants can now be coated using a variety of techniques, including electrophoretic deposition, sputter deposition, sol-gel coating, plasma spraying, and biomimetic precipitation. For titanium dental implants, however, only the plasma-spraying coating technique has been applied in clinical settings. Coatings deposited by plasma spraying can have a thickness of a few micrometers to a few millimeters. Because one of the primary issues with this technique is coating delamination, implant roughening—such as via blasting—is frequently linked to plasma-sprayed coating. For a variety of reasons, inorganic components as coatings are thought to be very intriguing. Since calcium adsorbs to the TiO2 surface in its ionized form and then to macromolecules with a high affinity for Ca2+, it plays a significant role in the binding process of physiologically active proteins from the peri-implant milieu. Calcium phosphate coatings are a rather old method of incorporating calcium and phosphates onto implant surfaces. It is commonly known that, compared to untreated Titanium implants, calcium phosphate Ca10(PO4)6(OH)2 (HA hydroxyapatite) coatings have produced longer-term clinical success rates. A higher initial rate of osseointegration is the cause of these long-term success rates [55].

Large crystalline HA particles contained in a highly soluble amorphous calcium phosphate phase make up the majority of HA coatings applied by plasma spraying. Furthermore, covering small dental implants with intricate shapes is a difficult task for the plasma-spraying method to accomplish. Clinical issues have also been linked to dental implants with HA coatings that were plasma-sprayed. As previously mentioned, even if the coating is firmly bonded to the bone tissue, one of the main issues with plasma-sprayed coatings is the potential for the coating to delaminate from the Titanium implant's surface and fail at the implant-coating interface. Implant clinical failure has resulted from delamination and particle release caused by differences in the breakdown rate of the coating's constituent phases. There have been reports of coating delamination in dental settings where the size of the dental implants limits the effectiveness of plasma spraying. Additionally, reports of coating loosening have been made, particularly in cases where dense bone surrounds the implants [55].

The clinical application of dental implants coated with HA and plasma-sprayed is restricted for the aforementioned reasons. For HA-coated implants, numerous clinical trials have been published. Compared to uncoated, they achieve direct bone bonding, accelerate bone attachment, and have a better integration rate. Regarding the long-term prognosis of coated dental implants, there are numerous disagreements. For instance, an 8-year clinical retrospective investigation of titanium plasma-sprayed implants coated with hydroxyapatite revealed that the survival rate of HA-coated implants was greater at first but sharply declined after 4 years of implantation. Inflammatory reactions were the main cause of long-term failures. Low crystallinity and poor mechanical strength of the HA coating are caused by certain metastable and amorphous phases that emerge in the coating during the plasma-spraying process, as reported by Tsui et al. A meta-analytic evaluation did not demonstrate that long-term survival rates for dental implants covered with plasma-sprayed HA were worse than those of other dental implant types, despite the implants' unfavorable reputation in dental practice [55].

A glass-reinforced HA composite has been published and developed by Santos et al. throughout the last ten years. This material was patented and recently registered as Bonelike®. It is made of CaO-P2O5-based glass that is incorporated into the microstructure of HA using a straightforward liquid phase sintering process. This technique enables the addition of several ions, including fluoride, sodium, and magnesium, producing a bone graft with a chemical makeup resembling that of the mineral phase of bone. This new biomaterial has improved mechanical qualities and increased bioactivity than the HA that is currently sold commercially because of its regulated chemical phase composition of HA, α, and β-tricalcium phosphate (TCP) and its microstructure. The direct bone bonding and osseointegration of commercially pure (cp Ti) implants coated with Bonelike® were assessed by Lobato et al. after the implants were placed in a 40-year-old patient's jaw. Scanning electron microscopy was utilized to assess the interfaces between new bone and the Bonelike® coating and dental implants. Significant bone remains were found along the covering surface of dental implants coated with Bonelike®, according to microstructure observations. Additionally, there was an improvement in the coated implants' main stability, indicating that Bonelike® might be a major factor in the process of new bone creation surrounding the dental implants [55].

Prospects for Titanium dental implant surfaces in the future:

A few recent evaluations [6, 8] have suggested several tactics to improve the rate and quality of titanium dental implant osseointegration. These future directions include:

(1) modifying surface roughness at the nanoscale level to facilitate cell adhesion and protein adsorption; (2) applying biomimetic calcium phosphate coatings to improve osteoconduction; (3) incorporating biological drugs to hasten the process of bone healing in the vicinity of implants; and (4) adding organic components, such as polysaccharides and chlorhexidine, to nanoparticles to enhance osteoconduction. One strategy that is currently of attention is the use of nanotopographical changes on the implant surface to promote intrinsic osteoinductive signaling of the surface adhering cells. Data currently available demonstrating the significance of nanotopography imply that nanoscale surface alteration of the implant can regulate important stages of osseointegration. These modifications affect how ions, proteins (adsorption, configuration, bioactivity, etc.), and cells interact with the implant's surface [55].

These interactions have the potential to positively impact cellular and molecular functions as well as modify the osseointegration process. Currently, a variety of methods and strategies are employed to create endosseous implant nanotopographic alterations. A few of these techniques include chemical treatments, novel sandblasting/acid etching, optical lithography, galvanostatic anodization, crystal deposition, physical methods of compaction of ceramic particles to yield surfaces with nanoscale grain boundaries , and monolayers to expose functional end groups that have specific functions. The fact that several of these techniques involve random processes makes it challenging to regulate the homogeneity and dispersion of nanostructures on implant surfaces.

(2) Researchers have created a novel coating technique that draws inspiration from the organic process of biomineralization. Using simulated body fluids (SBF), the calcium phosphate apatite crystals precipitated onto the titanium surface in this biomimetic technique, forming a covering at room temperature. Several techniques have been devised and reported elsewhere to speed up the deposition of coatings from aqueous solutions. Preclinical comparison models have been used to study the osseointegration of titanium implants covered with biomimetic calcium phosphate. Preclinical models have not yet been used to compare the osseointegration of titanium dental implants coated biomimetically with other surface treatments [55].

(3) To accelerate the localized repair of bone, growth factors or other bone-stimulating agents may be applied to the surface of titanium dental implants. Some of the most promising possibilities for this purpose are members of the transforming growth factor (TGF-) superfamily, specifically bone morphogenetic proteins (BMPs), TGF-1, platelet-derived growth factor (PDGF), and insulin-like growth factors (IGF-1 and 2). The requirement for the active product to be released gradually rather than all at once is the limiting issue.

(4) According to recent studies, applying bioactive compounds to the implant surface may improve its osteogenic qualities. It has been suggested that bioactive implants may cause a bonding process that is more than just physical, involving the titanium implant surface and bone tissue . An implant surface that has the capacity to stimulate many molecular interactions and maybe create a chemical link between the implant surface and bone is referred to as bioactive. Promising bioactive molecular candidates with a high osteogenic potential are proteins or peptides with bioactive capacity, such as fibronectin, type I collagen, arginine-glycine-aspartic acid (RDG peptide), bone morphogenetic proteins (BMPs), and fibroblast

growth factor (FGF). Combining RGD peptides (arginine, glycine, and aspartate) with acrylate anchors and the nanomechanical anchorage of collagen I fibers has been used in preliminary matrix engineering approaches, leading to increased bone-implant contact and bone density during early stages of peri-implant bone formation already after one month. The ability of arginylglycylaspartic acid tripeptide to stimulate cell adhesion through integrins, transmembrane receptors essential for cell-extracellular matrix interactions, has been thoroughly studied in vitro and in preclinical animal models [55].

Conclusion:

In conclusion, biomaterials, particularly titanium, have revolutionized the field of dental implants, offering remarkable biocompatibility, durability, and osseointegration properties. Titanium implants have become the gold standard due to their ability to fuse seamlessly with the surrounding bone, providing stable anchorage for prosthetic restorations. This has led to significant improvements in patient outcomes, with enhanced functionality, aesthetics, and longevity of dental prostheses. Moreover, ongoing research and advancements in biomaterial science continue to refine implant materials and designs, aiming to optimize performance, minimize complications, and broaden the scope of applications. Innovations such as surface modifications, nanostructured coatings, and bioactive materials hold promise for further enhancing osseointegration, reducing healing times, and mitigating risks of peri-implantitis and implant failure.

However, despite the remarkable success of titanium implants, challenges persist, including biological responses such as inflammation and foreign body reactions, as well as mechanical issues like fatigue and corrosion. Addressing these challenges necessitates interdisciplinary collaborations among materials scientists, engineers, clinicians, and biologists to develop novel biomaterials with superior properties and better understanding of host-material interactions. Furthermore, the pursuit of patient-centric approaches in implant dentistry underscores the importance of individualized treatment planning, considering factors such as bone quality, systemic health, and patient preferences. This holistic approach ensures optimal outcomes and patient satisfaction, fostering a paradigm shift towards personalized and precision dentistry. In conclusion, biomaterials, particularly titanium, have transformed the landscape of dental implants, offering unparalleled functionality, reliability, and aesthetics. As research progresses and technologies evolve, the future of dental implantology holds immense promise, with continued advancements poised to further elevate the standards of care, benefiting countless individuals worldwide.

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