

Titanium-based nanocomposite materials for dental implant systems

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16.1 Introduction

A “dental implant” is a surgical component that interfaces with the jaw bone/skull to support a dental prosthesis such as a crown, bridge, denture, or facial prosthesis, and to act as an orthodontic anchor. The basis for modern dental implants is “osseointegration,” in which implant materials form a bond with the bone through a biologic process in which the bone eventually fuses tightly to the surface of specific materials, such as titanium and some ceramics. The integration of the implant and bone can support physical loads for decades without any failure [1]. The concept of implants emerged in the 20th century, and materialized with the development of a variety of components. In 1913, one of the earliest successful implants developed was the “Greenfield implant system” (Greenfield crib or basket) [2]. Greenfield’s implant was an iridio-platinum implant attached to a gold crown, which showed evidence of significant osseointegration [2]. The first use of titanium as an implantable material was by Bothe, Beaton, and Davenport in 1940, who carried out a detailed study on bone growth patterns along titanium screws [3]. In 1951, Gottlieb Leventhal implanted titanium rods in rabbits [4]. Leventhal’s positive results led him to believe that titanium represented the ideal metal for surgery [4].

Leonard Linkow, in the 1950s, was one of the first to insert titanium and other metal implants into the bones of the jaw with artificial teeth attached to these pieces of metal [5]. The dental implants were developed in 1952 by a Swedish doctor, Branemark, who reported that titanium, in contact with bone in an uninterrupted condition, allowed the bone to grow right against the surface, making the titanium objects unmovable without cutting out the bone around the titanium. That idea was used to develop modern dental implants. In 1965, Brånemark first attempted to place a titanium dental implant into a human body. He termed the clinically observed adherence of bone with titanium as “osseointegration” [6]. Dental implants are usually of three types: (i) root form implants, (ii) zygoma implants, (iii) or small-diameter implants. Root-form implants are the most common, and can be used for all purposes [7]. Zygoma implants are long, and can anchor to the cheek bone by passing through the maxillary sinus to retain a complete upper denture when bone is absent. Though zygomatic implants offer a novel approach to severe bone loss in the upper jaw, it has not been shown to offer any advantage over bone grafting, functionally. It’s a less invasive option, depending

on the size of the reconstruction required [8]. Small-diameter implants with a low diameter and one construction piece (i.e., implant and abutment) are sometimes used for denture retention and orthodontic anchorage [9]. Most of the implant placements are done after the removal of an infected root canal. In permanent implanting procedures, materials are securely fitted into the jaw effectively for those patients with good bone structure, and showing no serious health issues that could interfere with the remedial process. This chapter aims to cover details of the dental implants with an emphasis on the titanium-based implants. The utilization pattern, recent developments, and future prospects of the titanium-based implants are summarized in this chapter.

16.2 Theory of dental implants and associated risk factors

When natural teeth are damaged or compromised, the damage goes well below the surface of the tooth, and even the gum line. When the damage goes deep into the roots, the roots are destroyed and lost, and the bone that once supported and surrounded those roots starts to deteriorate, which is termed as “bone resorption.” Hence, a replacement of the tooth root with a dental implant has become so vital, along with the replacement of the visible part of the tooth (the crown) (Fig. 16.1). Typically, the implant is designed like a titanium screw (resembling a tooth root), with either a roughened or smooth surface, which is embedded in the bone to preserve it. With time, the bone gradually forms a bond to the implants, and functions as a natural tooth root, providing a permanent foundation for biting and chewing. Dental implant treatment is much advantageous over other traditional treatment options. Outmoded routes require grinding down adjacent teeth for a bridge, and safeguarding a partial denture to natural adjoining teeth with catches that gradually loosen the natural teeth and cause serious damage to the gum line. Dental implant treatments have no such problems associated with gum line damage, and implants are a permanent solution for missing teeth [10].

Implant techniques differ, depending on the extent of the damage (Fig. 16.2). In the case of single tooth missing, the two most common treatment options are either a traditional tooth-supported bridge (3-unit bridge), or an implant-supported crown. While a tooth-supported bridge is used to replace one missing tooth, the bridging process destroys natural enamel and tooth structure, but is essential for fitting the new

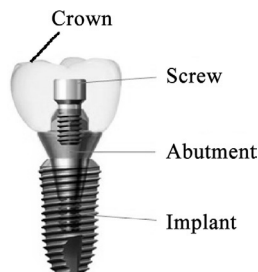


Fig. 16.1 Dental implants and different parts of dental implants.

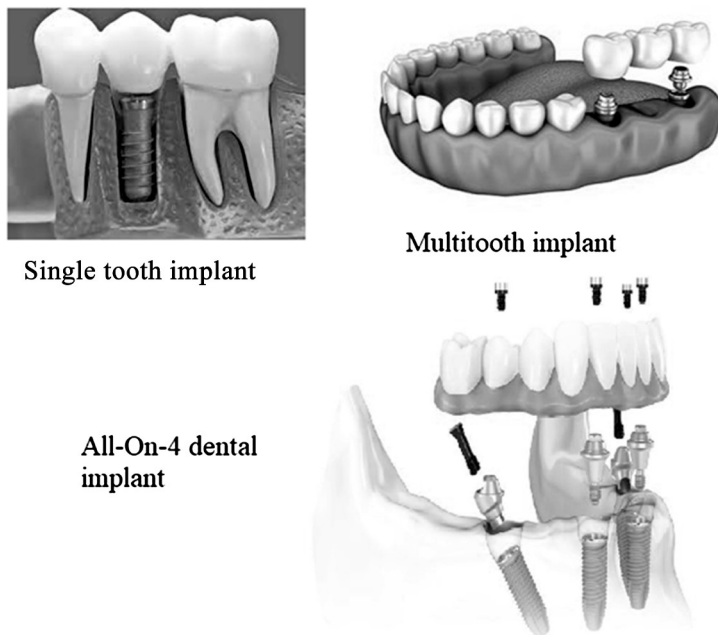


Fig. 16.2 Illustrations of different types of dental implants.

cemented bridge in place. Though a “3-unit tooth-supported bridge” remains operative for many years, the compromised teeth (healthy teeth cut down to support the bridge) frequently develop deterioration, periodontal bone loss, and ultimately require root-canal treatment. In case of multiple missing teeth, treatment options may include (i) a removable partial denture, (ii) a multiple-tooth-supported fixed bridge, and (iii) an implant-supported bridge. A removable partial denture employs clips that grasp onto adjacent healthy teeth to hold the denture in place. The clips, which are designed to fit comfortably onto the healthy teeth, put an excess load on the underlying gums, resulting in a frail jaw bone, and additional tooth loss. A multiple tooth-supported fixed bridge tooth replacement option has all the same complications, compromises, and risks of a single-tooth bridge, only to a much greater degree. The problems of root canal infections, decay, periodontal bone loss, and bone atrophy are very prominent because, in the case of multiple teeth, there is an increased probability of a falling bridge. The implant-supported bridge technique has several advantages over “partial denture” and “multiple tooth supported fixed bridge” techniques such as (i) dental implants virtually stop the bone resorption process (deterioration), (ii) the implants are much more comfortable and stable than partial dentures, (iii) the integrity of the facial structure is maintained (no sagging jaw line), (iv) the gum line stays intact, (v) natural biting and chewing capacity is restored, (vi) adjacent natural teeth are preserved, (vii) dental implants are like natural teeth in look and feel, and performance, and (viii) dental implants permanently overcome the need for messy adhesives or cleaning solutions. With the advancements of implant dentistry “All-on-4” (AO4) techniques have been introduced as a cost effective, optimal solution [10].

The risks and complications related to implant therapy are categorized in three types; risk may occur during surgery (such as excessive bleeding or nerve injury); risk may arise in the first 6 months (such as infection and failure to osseointegrate) of surgery, and risk that may ensue in the long-term (such as peri-implantitis and mechanical failures). It has been reported that in the presence of healthy tissues, a well-integrated implant can have more than 5-year survival rates from 93% to 98% [1–3], and 10- to 15-year life spans for the prosthetic teeth [4].

16.3 Necessity of dental implants

The dental implant is the new standard of care for tooth replacement. A tooth mislaid is a very obvious dental problem and a serious health concern. The condition also leads to bone loss in the jaw, the abnormal shifting of other teeth, as well as bite problems. Missing teeth cause the jaw bone to melt away (resorption), causing cheek bones to collapse inward, the nose to droop and point downward, and increase widow lines and wrinkles. Dental implants have become the viable treatment option to replace missing teeth, and are now referred to as the standard of care for replacing missing or failing teeth. Implants act as a substitute for the tooth root, where the natural tissues in the bone bonds to the implant, forming a stable foundation for permanent replacement teeth that feel, look, and function like natural teeth. In reality, dental implants preserve the bone by providing the stimulation that was previously provided by natural tooth roots maintaining the facial structure integrity [11].

A dental implant is described as a small titanium device that serves as a replacement for the natural root portion of missing teeth (Fig. 16.1). Titanium is labeled as the best material for dental implants because of its significant strength and biocompatibility. Dental implants can be placed in either the upper or lower jaws, and the living bone tissue in the jaw adheres to the implant surface itself, allowing the implant to merge with the bone. Titanium implants, being biocompatible, mimic the true root appropriately, and the jaw bone fuses with it as it would with the natural tooth root, creating a perfect anchor for a replacement tooth, or even a full set of replacement teeth that are strong, stable, pain-free, worry-free, and permanent. Over and above this, with five decades of clinical experience and over a million patients treated, statistical analysis has confirmed the success rate of dental implants to be about 95%–98% [11].

Dental implants protect natural healthy teeth, which is not possible in the case of tooth replacement with traditional tooth-supported bridges, which requires grinding down the teeth adjacent to the missing tooth/teeth, to smoothen the process of bridge cementing in the proper place. The natural tooth structure, once ground down, is irreversible, and the long-term health of these teeth is compromised. Partial dentures have clasps that hook onto adjacent teeth, putting pressure on those teeth as the metal framework rocks back and forth. Furthermore, the clasps erode at the remaining gum tissue, causing more harm. In due course, those teeth can loosen and fail as a result of the effect of unequal pressure. Replacing missing teeth with implant-supported crowns/bridges does not implicate the adjacent natural teeth; hence, those are not compromised,

damaged, or destroyed. Dental implants help to reduce periodontal disease tendency, and bacterially induced chronic infections and inflammatory diseases, which if remain unattended and allowed to aggravate, can lead to heart attacks, strokes, Alzheimer's disease, diabetes, and other chronic diseases. Studies have reported that poor oral health can also lead to cardiovascular issues (Periodontal Health; www.perio.org). The potential effects of gum disease are associated with a greater risk of developing certain diseases or experiencing certain events such as coronary artery disease at about a 2–4 times higher rate; stroke at about a 2–3 times greater rate, and adverse pregnancy outcomes at about a 4–7 times greater rate, diabetes at about a 2–4 times greater rate, and chronic respiratory disease at about a 2–5 times higher rate [11].

16.4 Dental implant material

The concept of dental implants is known from ancient ages, with the use of various materials, including several metals, nonmetals, and even animal body parts. Before introduction of the titanium-based implants, vitreous carbon was the material that worked very well in fusing to bone, but being brittle and having other issues made it impractical for use as a dental implant. Typical commercial dental implants of four different grades, depending on percentage of carbon, nitrogen, oxygen, and iron were developed from pure titanium [12]. Cold work hardened CP4 (maximum impurity limits of nitrogen 0.05%, carbon 0.10%, hydrogen 0.015%, iron 0.50%, and oxygen 0.40%) is the most commonly used titanium for implants. Grade 5 titanium (titanium 6AL-4V) (signifying the titanium alloy containing 6% aluminum and 4% vanadium alloy) was slightly harder than CP4, and used in the industry mostly for abutment screws and abutments [13]. The advanced dental implants have a textured surface (through etching, anodic oxidation, and by various media blasting) to increase the surface area and osseointegration potential of the implant materials [14]. If CP titanium, or a titanium alloy, has more than 85% titanium content, it will form a titanium-biocompatible titanium oxide surface layer or veneer that encloses the other metals, preventing them from contacting the bone [15]. Because titanium dental implants have no allergy or reaction to the metal itself, is safe for people who have either an allergy or sensitivity to other metals (e.g., prevalence of nickel allergy is about 5%) and/or simply have concerns about any metals within the body. In order to alleviate the associated concerns, “metal-free” implants have been developed that are basically implants based on zirconium. Initially, zirconium-based implant materials were approved for use in Europe in 2008 and in Canada in 2013. For dental applications, zirconium was used in the form of oxide (ZrO_2), with traces of hafnium (Hf) and yttrium (another metal). Zirconium-based implants are hard enough to facilitate development of crowns and bridges with excellent fusing properties with bone, like titanium. Titanium-based implants are much more versatile than zirconia because of the flexibility of design of either one- piece or two-piece systems. The post, or abutment, is a part that sticks through the gums, and is used to support or attach the teeth. Two-piece implant systems are more versatile, with more options prosthetically. Zirconium implants are also adaptable, but are not as prosthetically ideal, as a

separate post is required. In some cases, slightly off-angle placed implants become obligatory, due to the volume and location of bone in the implant site. In practice, titanium implants are more versatile, and flexible as far as surgical placement. The primary limitation of zirconium implants, specifically the implant body and the post/abutment, is that they are made as one piece; hence, the only choice for the prosthetics is to cement the teeth into place. Also, surgical placement and volume of bone is absolutely critical; hence, very careful management is required to implant at an improper location or angle. Titanium implants are typically buried under the gums, and the area is simultaneously grafted. In the case of a zirconium implant, which protrudes above the gums, the ability to graft is reported to be reduced significantly, with minimum risk factors. Both types of implants require a few months for the bone to fuse or grow against the implant before placing the final teeth. With one-piece zirconia implants, the healing phase is trickier, as the implant can't be buried under the gum tissue and mild pressure or movement of the implant disrupts the process of osseointegration. The long-term strength is another important factor of concern in zirconia implants. Fracture of titanium implants with time has rarely been seen, but zirconia implants have been known to fracture, which, during removal, creates a large defect in the bone. Hence, for a patient with heavy function (clenching or grinding), zirconia is not an ideal implant material. Zirconia-based dental implants reportedly have several advantages, such as no dark color showing through the gums, fewer corrosion problems, no piezo-electric current developments between dissimilar metals inside the mouth, and an overall thermally nonconductive nature. Most dental implants are fabricated out of titanium to very specific and accurate tolerances. Titanium has been used as implant material for more than 35 years, and has proven to be the material of choice due to its long lifetime and highly biocompatible nature [16]. Some implants are coated with hydroxyl apatite (the actual bone and tooth material), in hopes that they will integrate at a faster rate, and more accurately when placed in the bone. The monolithic zirconium-oxide implants have been introduced as an alternative to titanium for those concerned about use of metal inside the mouth. The crown, or cap, is attached to the implant itself by means of an "abutment." The abutment is screwed into the implant itself, usually after the implant has integrated to the bone. The abutment part of the implant can be made out of metal, zirconium-oxide, or a combination of the two. Although metal has provided an excellent option for many years, the fact that it's dark colored limits what material the crown can be made of. The typical technique involves placing metal abutments in the back of the mouth, and then adding either a metal-reinforced crown, or an opaque all-ceramic crown on top of it. In the anterior of the mouth, where the aesthetic and natural appearance of the final result is paramount, usually a tooth-colored zirconium-oxide or a zirconium-oxide overlaid on a titanium base is used. Titanium is the first choice as a dental implant material with high efficiency in a variety of different medical applications. The prime complication related to titanium-based dental implants is that they are less aesthetically appealing than the natural tooth, due to their inherent grayish color. Titanium-based implants, although inert, are reportedly susceptible to allergies, while the ceramic implants provide metal-free restoration, reducing concerns of allergies and biocompatibility, and damage to the immune system. The metal-free dental implants have superior biocompatibility, are more aesthetically pleasing, and work just as well as the more traditional titanium

implants. Recent developments in implant materials have synthesized many other materials based on both ceramics and metal, with improved appearance and function. In the metal type, cobalt alloys, CP titanium, and Ti-6Al-4V alloys have been synthesized and applied as dental implant materials. In the ceramic category, inert ceramics such as alumina carbon zirconia have been used, and some bioactive ceramics, such as bioactive glasses and calcium phosphate, have been used as potential implant materials. Metallic implants undergo several surface modifications, such as passivation anodization and ion implantation to become suitable as implant material. The most commonly used titanium alloy is Ti-6Al-4V; the modulus of elasticity of which is closer to that of bone, which ensures more uniform distribution of stress along the bone implant interface. Some new titanium alloys have been developed with the aim of improved corrosion resistance, such as Ti-13Nb-13Zr and Ti-15Mo-2.8Nb [17]. The American Society of Testing and Materials recognizes four grades of commercially pure titanium and titanium alloys, namely Cp titanium grade I (0.18% oxygen), Cp titanium grade II (0.25% oxygen), Cp titanium grade III (0.35% oxygen), and Cp titanium grade IV (0.40% oxygen). Table 16.1 illustrates the materials used for fabrication of dental implants. Although the materials have a high degree of biocompatibility and strength, with excellent corrosion resistance, the high cost and difficulty in casting are major drawbacks associated with titanium alloys. Ceramic can also be used as an implant material. Two types of ceramic implants, bioinert aluminum oxide and bioactive hydroxyapatite, have been used frequently. Ceramics offer high compressive strength, less resistance to shear and tensile strength, and a high modulus of elasticity, with a crucial limitation being brittleness and low tensile stress for withstanding capacity. Alumina is considered the gold standard for ceramic implants because of its inertness, and no evidence of immune reaction in vivo. Zirconia also belongs to the category of bioinert implant material. Calcium phosphates as coating material for metallic implants promote bone-to-implant integration. A minimum of 50% crystalline hydroxyl apatite is considered an optimal concentration in coating implants. Dissolution of the ceramic coating occurs at a high rate with an amorphous hydroxyl apatite structure. The advantage of ceramic coating is the enhanced possibility of bone-to implant integration. Bio-glasses are another type of ceramic implant materials that usually provide a carbonated hydroxyapatite layer. The formed calcium-phosphorous layer stimulates osteoblasts to proliferate, stimulating the formation of bone, but being brittle, these are unsuitable as stress-bearing implant materials. Polymers are also potential implant materials, which were first introduced in the 1930s, but with limited application because of low mechanical strength and susceptibility to fracture during function, as well as high contamination propensity and sterilization difficulties (gamma radiation and ethylene oxide exposure). Physical properties of polymers are greatly influenced by changes in temperature, environmental condition, and compositional features. Selection of the implant material depends on the type of bone in which the implant is placed; for a high load zone, in posterior areas, high-strength materials such as CP grade IV titanium and titanium alloys are used. Currently, diverse types of implant systems are available, starting from pure titanium, to hydroxyl apatite-coated Ti. To overcome the problems associated with implant failure, implant bioacceptance and structural stabilization are the crucial factors to consider and optimize.

Table 16.1 Materials used for fabrication of dental implants (Osman et al., 2015) [18]

Metal		Ceramic		Polymer
Titanium	Cp titanium	Alumina	Al ₂ O ₃ , polycrystalline alumina or single-crystal sapphire	Polymethyl methacrylate
Titanium alloy	Ti-6Al-4V extra low interstitial (ELI) Ti-6Al-4V Ti-6Al-7Nb Ti-5Al-2.5Fe Ti-15Zr-4Nb-2Ta-0.2Pd Ti-29Nb-13Ta-4.6Zr Roxolid (83%–87%Ti-13%–17%Zr)	Hydroxyl apatite	HA, Ca ₁₀ (PO ₄) ₁₀ , (OH) ₂	Polytetrafluoroethylene
Stainless steel	SS, 316 LSS	β-Tricalcium phospahte	β-TCP, Ca ₃ (PO ₄) ₂	Polyethylene
Cobalt chromium alloy	Vitallium, Co-Cr-Mo	Carbon	C Vitreous, low-temperature isotropic (LTI), ultra-low-temperature isotropic (ULTI)	Polysulfone
Gold alloys	Au alloys	Carbon silicon	C-Si	Polyurethane
Tantalum		Bioglass	SiO ₂ /CaO/Na ₂ O/P ₂ O ₅	Polyether ether ketone
		Zirconia	ZrO ₂	
		Zirconia toughened alumina	ZTA	

16.5 TiO₂ as nanostructured titanium with improved performance

Titanium nanostructures have exhibited great potential for better bone integration and regeneration properties [19–21]. A number of studies have reported distinctive techniques to develop micro- to nano-range titanium implants, with detailed evaluation of the inherent effects on bone stem cells. Designs of micro/nano-hybrid titanium surfaces have exhibited superior implant surface properties [22–24]. Some studies of TiO₂ nanotube layers (70–100 nm) reported greater antibacterial activity against common bacterial pathogens [25]. A study reported that TiO₂ micro-nano-hybrid surfaces were produced and treated by UV light, and several papers emphasized the impact of UV light on titanium bioactivity promotion [26–28], and the results illustrated that titanium has higher antibiological aging properties [29]. Research has presented a promising outlook for having better dental implants with long-term stability and bone healing abilities, with fewer drawbacks.

16.6 Modification of titanium dental implants by nanotechnologies

Recently, many techniques based on nanotechnology principles have been attempted to improve dental implant performance, such as surface modifications with nanomaterials, surface functionalization to improve topography, and the use of nanocomposite materials for bone regeneration [30]. Nanotechnology is a promising field of study in regard to better dental implant materials. Many techniques have been adopted for better exploitation of effective modified materials in dental implantations. Sandblasted TiO₂ particles offer desirable qualities as dental composites [31, 32]. Another approach of improvement is changing the anodic polarization of the titanium surface [33]. Publications have established the dependence of physicochemical properties of implant surfaces on biological interactions. Hence, the coating of several organics or inorganics (thin calcium phosphate nanocrystals on titanium) on titanium's surface has been reported to enhance the nanostructural properties [34]. The surface area of titanium-based dental implants can be enhanced by surface modifications without altering their shape and form, thereby improving the biological properties of the biomaterial. A good biomaterial promotes enhanced cell adhesion and cell signaling. Vignesh et al. (2015) [35] reported a comparative study of cell adhesion properties of conventional titanium, laser-modified, and nano-modified titanium to determine the best osteoconductivity for nanoparticles and their potentially superior future prospects [35]. Electrochemical modification of titanium by anodic oxidation and hydroxyapatite (HA) electrochemical deposition are promising routes for synthesis of better implantation composites. To achieve better biocompatibility, nano-sized HA have been reported by Kim and Ramaswamy (2009) [36]. Another approach to reducing the probability of infection and failure of the dental implants is modification of titanium with silver nanoparticles [37]. Modification of titanium with silver can

be achieved using different techniques, such as deposition of silver nanoparticles on titanium, silver nanoparticle-filled hydrogen titanate nanotube layers on metallic titanium surfaces, and halogenated furanone-loaded poly(L-lactic acid) nanoparticles coated on microarc-oxidized titanium, which are promising methods for prevention of early peri-implant infection [38–40]. Family et al. in 2012 reported [41] the surface modification of Ti implants by coating them with a single layer of HA-Al₂O₃-ZrO₂. A single-layer hydroxyapatite-alumina-zirconia coated sample has shown the most homogenous morphology on the surface, and the greatest strength, as compared with single HA coating.

Surface modification is another approach of improving the process of osseointegration, because it accelerates the healing process, and offers high stability and durability of the dental implant. The development of surface-coarsening has been reported to improve the osseointegration of titanium-based dental implants, which is mostly done by sandblasting and/or acid etching and coating with other chemicals such as hydroxyapatite (HA). But this approach reportedly has several limitations; specifically, increased soft-tissue growth onto the bone-implant interface [15]. This approach adversely affects the contact between the implant and host bone. In the case of HA-coated implants, a layer often disintegrates under certain conditions, generating cracks on the implant's surface [15]. Metal surfaces with positive and negative charges are more hydrophilic than electrically neutral surfaces, which plays a pivotal role in guide bone-cell adhesion, and early stage bone mineralization in the bone-implant interfaces. Hence, surface modification is a promising methodology for improving the osseointegration process of an implant. A group of scientists have reported the surface modification by a special group of biomaterials such as bioglass and glass ceramics, which induce surface charges in a biological environment. Sandblasting is another approach of surface treatment to accelerate osteoblast attachment in biological environments, thus enhancing the process of osseointegration [15].

16.7 Conclusion and future perspective of Ti-based dental implants

These days, dental implantation is one of the most common practices for replacement of missing teeth; hence, many efforts have been made to improve the function of dental implants. The prime factor that determines the success of dental implantation is osseointegration, which is the stable port of an implant in living bone achieved by direct bone-to-implant contacts [42, 43]. Excellent osseointegration includes an accelerated healing process, high stability, and durability of the dental implant. Using current implant materials and techniques, a titanium-based dental implant requires a few months to osseointegrate with its adjacent bone. Therefore, the potential is there for the improvement of the surface quality of a titanium dental implant, with an accelerated rate and strength of its osseointegration. To achieve enhanced performance, the understanding of interactions between the host bones and the titanium implant in a living body is crucial. These interactions occur mostly in the bone-implant interface.

Both in vitro and in vivo studies have reported that such interactions depend principally upon the implant's surface characteristics [44]. Major aspects of the implant's surface characteristics include surface morphology, surface chemistry, and surface energy, which significantly affect the initial bone cells' response to the implant at the bone-implant interphase [45]. Application of nanotechnology in dental implants is an area of intensive research and development. Nanotechnological methods in dental implants help to fabricate more efficient materials with less allergy propensity, bacterial inflammation, and corrosion, even with bone healing properties. Titanium has been widely used in dental implants; hence, titanium nanoparticles' development, and nano-modified titanium surfaces with better characteristics than titanium in different perspectives have become an important topic of research [15]. Studies are ongoing to develop innovative fabrication design of titanium nano-modified titanium surfaces for long-term health of dental implants. Research is being conducted to produce new modified implant materials based on titanium with the ultimate aim of validating the aptness of new products, other than titanium itself, in various aspects. Until now, many techniques have been investigated for improving dental implants, such as surface modifications, functionalization and topography, nanocomposites for bone regeneration, and assessing implant osseointegration. It's still a technically challenging task to perceive consistent techniques for fabrication of dental implants [46]. Nanotechnology is a promising field of study for their potential to offer better materials for implantations [47, 48]. Another instance of titanium implants' modification is the changes in anodic polarization of the titanium surface [49]. Several methodologies have been attempted for appropriate exploitation of effective modified materials in dental implantations in various publications [50–52]. Hence, future performance of titanium-based dental implants may be developed by combining the prospects of nanocomposites with the knowledge of dentistry.

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