REVIEW ARTICLE

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Surface structure characteristics of dental implants and their potential changes following installation: a literature review

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Abstract (J Korean Assoc Oral Maxillofac Surg 2023;49:114-124)

Dental implants have been utilized for many years to treat individuals with missing teeth. To optimize the long-term success rate of such implants, new designs, surfaces, and materials have been analyzed. It is important for the clinician to have a background in the field of implant surface design, to be familiar with the strengths and limitations of the available options, and to be aware of the alterations in surface structure that may occur following installation. This article provides a detailed review of the structure and the surface characteristics of dental implants, the modifications of implant surface, as well as the methods of evaluating implant surface structure. Moreover, it provides information concerning the structural changes that may take place at the time of dental implant placement. It is important for clinicians to be aware of such changes to plan and execute implant procedures with the highest possible success and implant survival rates.

Key words: Confocal laser scanning microscopy, Dental implants, Scanning electron microscopy

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I. Introduction

Dental implants are utilized to replace missing teeth in patients with partially or fully edentulous areas to improve function and appearance and enhance the patient's quality of life[1]. Titanium is a silver-colored transition metal used for dental implants due to its physical and mechanical strength, corrosion resistance, chemical stability, and high biocompatibility. Titanium can become integrated with bone in a process known as "osseointegration," which is necessary for long-term durability of dental implants[2,3].

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Studies have confirmed the high survival rates of implants over the last 50 years. The use of improved designs, surfaces, and materials has been a priority. Nevertheless, modern implants have increased roughness. This leads to having more prominent points on their surface, which are likely to break and detach from the implant body, during insertion into the bone.

Wennerberg et al.[4] presented a method to quantitatively assess the outer surface of the fixture of dental implants. They examined roughness metrics before and after insertion for determining the degree of wear[4]. The shape of the implants and the heterogeneity of the bone tissue both have an impact on the shear forces created by friction of self-tapping implants on bone tissue to cause a dynamic shift of stresses along the implant fixture[5].

There have been concerns about deterioration of dental implant material, allergic reactions, and chronic peri-implant inflammation, all of which can lead to implant failure[6]. Within the first 15 years after insertion, more than 11% of dental implants fail and must be removed[7,8]. Dental implants can fail for a variety of reasons, both biological and mechanical. These include peri-implantitis (inflammation around the implant that causes bone loss), degradation of structural materials and/or connections, flaws in the implant design, loss of patient bone density, surgical and/or prosthetic complications, and patient-specific conditions[8,9].

Moreover, because placement precision is subjective, this operation requires a highly experienced practitioner. In difficult areas, such as regions of dense bone or zones of restricted vertical bone height, correct placement of the implant may not occur upon the first attempt, necessitating a screw-out and reinsertion.

This review provides a summary of dental implant structures and surface modifications, commercially available surface treatments, methods of evaluating dental implant surfaces, and possible changes in implant structure upon insertion.

II. Dental Implant and Osseointegration

Osseointegration, first described by professor Brånemark and colleagues, is direct contact (at the light microscope level) between living bone and the implant; "secondary implant stability" is another term for this biomechanical concept[10].

Trauma to bone tissue occurs during the creation of an implant cavity and is followed by several stages of wound healing. Fibrin polymerization and formation of a blood clot are the initial results of the cellular and plasmatic hemostasis mechanisms. The blood clot acts as a scaffold for bone-forming cells, extracellular matrix (ECM) deposition, and neo-angiogenesis[11,12].

Davies[13] claimed that textured surfaces increase blood clot adherence and bone growth (contact osteogenesis) on the implant. This is most likely because a clot contracts away from a perfectly smooth machined surface, producing a micro-gap. When a micro-gap is present, new bone starts to form distant from the implant, as the osteogenic cells are unable to reach the implant surface (distant osteogenesis)[13]. Thus, osseointegration occurs more quickly on textured surfaces[14,15]. The quantity of new bone growth at the bone-to-implant interface largely determines a dental implant's secondary stability[16]. By the end of the remodeling phase, bone has covered roughly 60%-70% of the implant surface[15]. The term "bone-to-implant contact" (BIC) represents this coverage and is frequently used in studies concerning osseointegration.

Conforming to the notion of mechano-transduction, bone remodeling occurs throughout one's life[12]. The focus of research has been on creating novel topographies for implant surfaces that will improve osteoblastic migration, adhesion, proliferation, and differentiation.

III. Surface Modifications of Dental Implants

Recently, dental implants have been widely used for substitution of missing teeth. Titanium has proven to be a viable material for implant fabrication through a long history of usage[17]. For dental implants to successfully osseointegrate, pri-

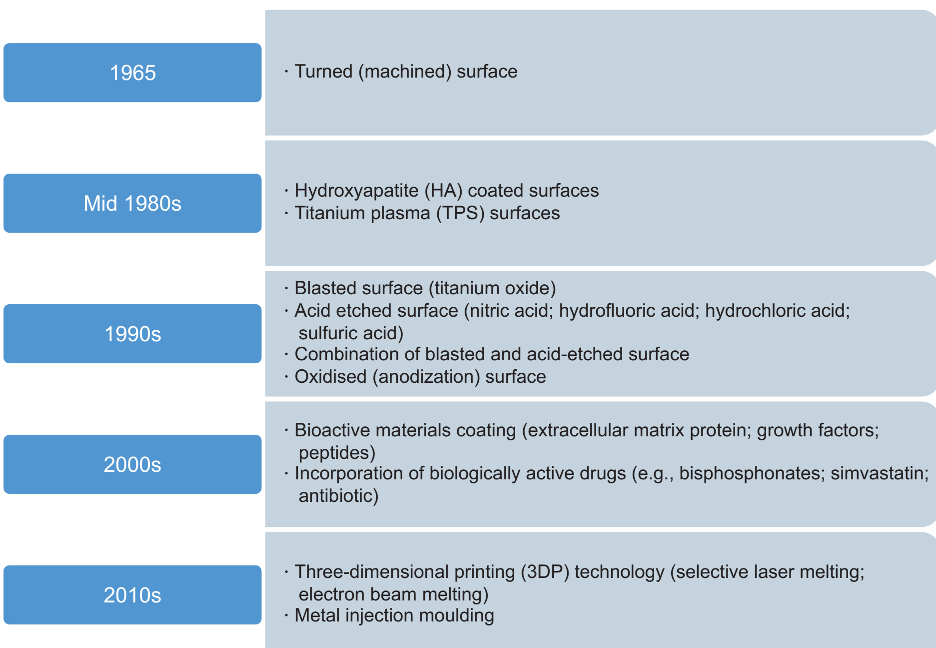

Fig. 1. Evolution of implant surface modifications.

Pitchaya Aneksomboonpol et al: Surface structure characteristics of dental implants and their potential changes following installation: a literature review. J Korean Assoc Oral Maxillofac Surg 2023 mary implant stability is crucial and is affected by the implant surface. Therefore, several strategies for modifying implant surface structures and features have been implemented to improve primary implant stability and reduce bone healing time. The healing time has been shortened from 12-24 weeks to 6-8 weeks because of developments in implant surface technology[18]. Fig. 1 summarizes the evolution of dental implant surface modifications, which has been ongoing since 1965.

Beginning in the year 2000, dental implant research concerning the cellular interactions between implant surfaces and bone contact has been ongoing. Bioactive materials such as growth factors, peptides, and ECM protein, as well as biologically active drugs such as bisphosphonates, simvastatin, and antibiotics have been added to dental implants to enhance the interaction of the patient's bone cells with the implant surfaces and to accelerate osseointegration.

Biomaterial research concerning dental implants has three therapeutic goals: (1) to increase stabilization of the implant by encouraging natural osseointegration, (2) to improve peri-implant soft tissue integration, and (3) to reduce peri-implantitis by inhibiting the adherence of bacteria to the surface of the implant. An important criterion is that the surface coating must not disintegrate during fixture insertion[19].

Another method is incorporating surface porosities via three-dimensional printing technology (such as selective laser melting, electron beam melting, or metal injection molding[20]). Porous implants have provided improved implant stability through osseointegration and osteo-conduction into the pores of the implants[21]. However, implant surface alterations using three-dimensional printing and metal injection molding are empirical and are largely at the laboratory stage, with only limited clinical results recorded.

As shown in Fig. 2, dental implant surface treatments can be classified as additive (e.g., hydroxyapatite-coated, titanium plasma sprayed) or subtractive (e.g., blasting, acid-etching, and oxidization)[22]. These procedures result in fixtures with

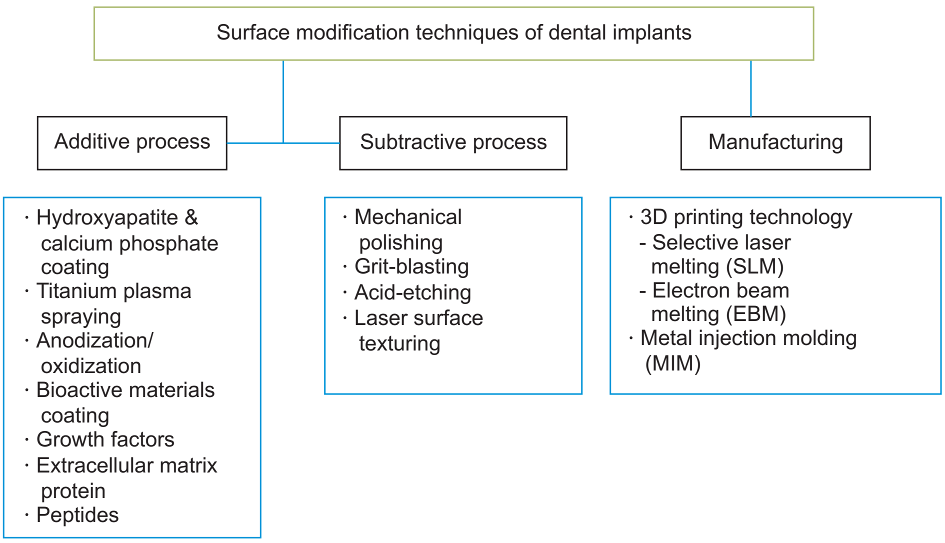

Fig. 2. Surface modification techniques used for dental implants.
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Table 1. Dental implants with varying surface roughness (Sa)

Sa category	Sa value (μm)	Implant system
Smooth surface	0.0-0.4	"Machined" experimental implants
Minimally rough surface	0.5-1.0	• Most implants used before 1995 • Turned (machined) surface implants (e.g., Brånemark System, Nobel Biocare AB, Southern Implant System)
Moderately rough surface	1.0-2.0	• Most currently marketed implants • Blasted surface (e.g., AstraTech TiOblast and Zimmer MTX) • Acid-etched surface (e.g., BIOMET 3i Osseotite and NanoTite) • Blasted and acid-etched surface (e.g., Straumann SLA and SLActive) • Oxidized surface (e.g., Nobel Biocare TiUnite) • Laser-microtextured surface (e.g., BioHorizons Laser-Lok)
Rough surface	>2.0	• Titanium plasma-sprayed (TPS) implants (e.g., Straumann TPS, Zimmer TPS, and BIOMET 3i TPS) • Hydroxyapatite (HA)-coated implants (e.g., Zimmer Calcitek Integral, Omnilock, and BioHorizons HA-coated)

Pitchaya Aneksomboonpol et al: Surface structure characteristics of dental implants and their potential changes following installation: a literature review. J Korean Assoc Oral Maxillofac Surg 2023 varied surface roughness (Sa), as categorized in Table 1 and detailed in the following section. Surface modifications of dental implants can be classified into macro-, micro-, and nano-roughness[23].

1. Macro-roughness

Macro-roughness ranges from millimeters to microns. This scale is directly related to the shape of implants, including macro porous and threaded screws.

2. Micro-roughness

The micro-roughness range is from 1 to 100 microns. A micro-rough surface can be altered by processes such as machining, acid-etching, anodizing, sandblasting, and grit-blasting, as well as other coating treatments. A micro-rough surface affects the osseointegration process at the cellular level. A systematic review by Junker et al.[11] noted that suitable surface structure at the micron level results in improved bone development and interlocking at the implant interface. Micro-topography is defined by pits, grooves, and protrusions, which affect biological processes at the bone-implant contact. Surface area may increase as a result of microtopography changes. BIC level has been found to be higher on micro-rough surfaces[24].

1) An overview on commercially available dental implants with micro-rough surfaces

(1) Sandblasted and acid-etched implants: a. Roxolid implants with SLA (sandblasted, large grit, acid-etched) surfaces (Straumann Holding AG) and b. Camlog Promote implants (Camlog), Dentium, and Osstem

The Straumann Holding AG surface mentioned above is created using grit sandblasting at 5 bar with 0.25-0.5 mm corundum particles to produce SLA macro-roughness[25]. The microtopographic surface structure is produced via high-temperature acid etching with HCl/H_2SO_4, which yields an active surface area with equal roughness and acceptable cell adhesion.

The Camlog, Dentium, and Osstem implants use a similar method. As mentioned above, they have surface roughness values in the micro-rough range, and the Sa value is 1.3 microns[26].

(2) Grit-blasted, acid-etched, and neutralized implants: (e.g., implants using the FRIADENT plus surface (DENTSPLY Implants)

The FRIADENT plus surface is formed via large grit blasting (354-500 microns) in a temperature-controlled environment, followed by etching in hydrochloric, sulfuric, hydrofluoric, and oxalic acid and a special neutralizing technique. The micro-topography of the FRIADENT plus surface has a mean roughness of Ra=3.19 microns and spans numerous magnitude levels[27]. As a result of grit blasting, macro-roughness and amorphous micropores can be observed, with both 2- to 5-micron diameter micropores and a second layer of much smaller micropores.

The FRIADENT plus surface alters its wettability dynamically. When it comes into contact with ECM proteins, the originally hydrophobic surface transforms into a hydrophilic state with a 0° water contact angle[28].

3. Nano-roughness

A current trend in dental implants is the use of nano-rough surfaces with ranges from 1-100 nanomicrons (0.001-0.1 microns). Such surfaces are modified using techniques such as discrete crystalline deposition (DCD), laser ablation, anodic oxidation, and titanium oxide blasted and acid-etched implants.

Implant roughness is believed to increase protein absorption and osteoblast adhesion, resulting in improved osseointegration[29]. This roughness value is expected to affect interactions between cells and implants at both the cellular and protein levels[30].

Variations in both surface chemistry and surface roughness contribute to an increase in surface energy[31]. Consequently, changes in nano-topography have physical, chemical, and biological effects that may enhance osseointegration and result in improved osteogenic cell adhesion[11,12]. To improve outcomes in challenging clinical scenarios (such as cases involving immediate implantation after tooth extraction, early loading protocols, and patients who have compromised bone-healing or wound-healing abilities), additional advancements in dental implant surface design are needed[32].

1) An overview on the commercially available dental implants with nano-rough surfaces, according to modification technique

(1) DCD: 3iT3 dental implant (BIOMET 3i) and Osseotite surface (BIOMET 3i)

• Surface: A dual acid-etched titanium alloy implant modified using a nanoscale manufacturing strategy. This double acid-etched surface is coated with 20 to 100 nanometer-sized calcium phosphate (CaP) particles using the DCD solgel process. Compared to earlier CaP deposition methods, the CaP particles have better adhesion to the implant surface. With this method, the CaP particles cover nearly half the surface area. The Osseotite surface is more prone to bacterial adhesion than the NanoTite surface (BIOMET 3i)[33,34].

(2) Laser ablation: Laser-Lok implant (BioHorizons) and PDL surface treatment (BiomateSwiss)

• Surface: With this implant type, the implant collar is fabricated with nanoscale roughness to improve how well the dental implant blends in with the nearby soft tissue. On the neck of the Laser-Lok implant, laser micromachining produces a pattern of micro- and nanoscale microchannels. It has been proposed that these microchannels act as a biologic seal by promoting connective tissue and bone adhesion and inhibiting epithelial downgrowth[35].

A high energy density laser (up to 1,700^{o}C) is used in the BiomateSwiss PDL laser surface treatment. This is a thermal processing method and is used to melt and evaporate a metal surface. This approach may generate unique three-dimensional pores with micro-nano and microchannel texture on the implant surface. The method is suited for adhesion and growth of osteocytes to improve the contact area of the bone and fixture, maximizing cell proliferation and osseointegration.

(3) Anodic oxidation: TiUnite (Nobel Biocare Holding AG)

• Surface: Anodic oxidation is a surface modification technique that electrochemically alters the TiO_2 layer in standard titanium implants and increases its thickness range from 17-200 nanometers to 600-1,000 nanometers. A porous surface microstructure is created with pore sizes ranging from 1.3 to 2.0 mm^2, a porosity of approximately 20%, and a small proportion of Sa=1 microns. Such an implant surface is referred to as "titanium porous oxide" (TPO) or "anodized titanium surface implants" (ASI)[36]. Anodic oxidation requires an electrical connection, with the implant acting as the anode. The nanoscale surface characteristics of the TPO implants, such as TiUnite, have been established. According to findings from cell research, anodic oxidation may provide a tight soft tissue seal by successfully transferring to the implant's neck[35]. Titanium surfaces with nanostructures created via anodic oxidation promote human gingival fibroblast proliferation and adhesion, as well as ECM deposition[35].

(4) Titanium oxide blasted and acid-etched implants: OsseoSpeed implants (DENTSPLY Implants) and TiOblast implants (DENTSPLY Implants)

• Surface: In 2004, the OsseoSpeed implant was made available for purchase by DENTSPLY Implants in Mannheim, Germany. This implant product is manufactured with consecutive subtractive processes, resulting in a unique surface roughness. Microscale surface roughness is produced by titanium oxide blasting. The nanostructure of the implant is subsequently sculpted using hydrofluoric acid etching. Surface fluoride accumulation is a pleiotropic side effect, encouraging early osseointegration in the host-implant contact area[37]. Cell experiments have shown that, in comparison to TiOblast implants, the OsseoSpeed surface improves mesenchymal stem cell osteogenesis and osteo-induction, as well as the branching cell shape of osteoblasts and the osteogenic gene expression profile (DENTSPLY Implants)[36,38].

IV. Surface Wettability

In addition to implant structure and surface roughness, implant surface wettability (or hydrophilicity) is an essential feature of osseointegration. The water contact angle, which varies from 0° with extremely hydrophilic surfaces to greater than 90° with hydrophobic surfaces, is an important variable. Protein structure and function are preserved by hydrophilic surfaces, whereas protein denaturation has been associated with conformational changes in hydrophobic implant textures. Protein adsorption is responsible for the cells' capacity to bind more strongly to a hydrophilic implant surface than to a hydrophobic surface[12]. Implants with a dual surface and enhanced hydrophilicity were comparable to those with SLA surfaces in short-term osseointegration[39].

V. Measurement of Surface Roughness

Wennerberg et al.[40] introduced quantitative assessment of the surface structure of dental implants in 1995. The current recommended instruments for measuring the surface structure can be divided into optical profiling instruments and scanning probe microscopes (SPM).

1. Optical profiling instruments

In general, optical profiling instruments are faster and have higher resolution than mechanical contact instruments. The two methods most suited for topographic characterization of oral implants are confocal laser scanning microscopy (CLSM) and a white light interferometer.

The authors of this review use CLSM with a special focus detecting system. With this system, the reflected light and the XYZ position of the helium-neon laser (He-Ne laser) are measured at the same time. The system adjusts the focus point by point regardless of previous measurements, reducing integration mistakes. The light entering the detector from out-of-focus details is reduced by two pinholes, resulting in fine vertical resolution. Furthermore, the CLSM approach is unlikely to overestimate surface roughness. The accuracy and reliability of this instrument have been investigated, and it was determined to be well-suited for topographic assessment of oral implants and other biomaterials[41]. The benefit of CLSM is that a large numerical aperture can be used, which is useful when measuring porous and/or inclined surfaces.

In a white light interferometer, a light beam is divided into two, one reflected from a reference plane and the other reflected from the surface of the sample to be measured. Surface irregularities induce phase changes in the reflected light; some waves will be augmented, while others will cancel each other out. The dark and light fringes are not straight and evenly spaced (as they are for optically flat surfaces) and the degree of fringe modulation is related to the surface height. Each point on the surface is measured independently, reducing integration errors. The main benefit of a white light interferometer is the potential to view and analyze implant structure features that are as tiny as a protein molecule. Such analysis allows investigation of the links between surface roughness and biological processes. Measurements can be performed in either air or liquid.

2. Scanning probe microscope

With an SPM, the contact between a sharp tip and the sample surface is measured. The tip is attached to a cantilever, the vertical movement of which during surface scanning is recorded. The most popular SPM techniques are scanning tunneling microscopy and atomic force microscopy (AFM), which are the best techniques for topographic analyses. AFM is the sole option for analysis of non-conductive surfaces and employs a very fine tip (radius 6 to 60 nano-microns) that is drawn across the surface at a consistent speed and pressure. There is also a tapping mode in which the tip oscillates above the surface, contacting it only at the bottom of its swing. A detection system monitors the position of the tip.

For many implant surfaces, the measurement area and the maximum measurement range in the vertical direction are insufficient for proper analysis. This implies that measurements are not always possible, or that they must be selective, limiting generalization of the measurement over the entire surface. Furthermore, because the threaded portion of dental implants cannot be examined non-destructively, such analysis is unsuitable, hindering evaluation of the most regularly used form of oral implants[42]. The SPM can be used in such situations to analyze structures as fine as a protein molecule based on the extremely high resolution of this technique. This method allows investigation of the links between surface roughness and biological processes. Measurements can be performed in either air or liquid[27].

3. Scanning electron microscopy

Using scanning electron microscopy (SEM) for structure evaluation provides the ability to investigate structures with a high aspect ratio, a wide depth of field, and high spatial resolution (down to the nanoscale range)[43]. SEM produces high-quality images and is better suited for morphologic rather than topographic analysis. SEM is primarily utilized as a comparison tool for topographic characterization, making it susceptible to subjective interpretations. A stereo pair of SEM images can be used to obtain height information, but this technique may reduce the high resolution that is otherwise the main advantage of this technology[27].

VI. Optimal Surface Roughness

The most important factor in cell response is surface roughness[44]. It is believed that the ideal surface for bone integration can only be achieved with a very accurate surface structure with an Ra value between 1 and 2 microns[24]. In addition, Shalabi et al.'s systematic evaluation[45] discovered a beneficial effect of Ra/Sa from 0.5 to 8.5 microns on bone response. Although they were unable to provide a conclusive reason for this discrepancy, surface roughness measurements on oral implants are highly complicated. The numerous methods used in the available literature can lead to different outcomes[45].

VII. Bone Density

When evaluating an edentulous site for future implant placement, it is essential to look at the available bone volume overall. in addition, assessing the bone density or quality should be taken into consideration as well. The amount of

Table 2. Misch bone density classes, with associated bone quality description and density

Bone density classification	Bone quality description	Density (Hounsfield units)
D1	Dense cortical bone	1,250
D2	Thick dense to porous cortical bone on crest and coarse trabecular bone within	850-1,250
D3	Thin porous cortical bone on crest and fine trabecular bone within	350-850
D4	Fine trabecular bone	150-350

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Table 3. Common anatomical sites by bone density type (% occurrence)

Bone density type	Maxilla		Mandible	
	Anterior	Posterior	Anterior	Posterior
D1	0	0	6	3
D2	25	10	66	50
D3	65	50	25	46
D4	10	40	3	1

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accessible bone in an edentulous area affects treatment planning, implant design, surgical technique, healing time, and early progressive bone loading with prosthetic restorations. Researchers have been examining the classification of bone density and how it relates to dental implant therapy for the past three decades. In 1970, Linkow and Cherchève[46] classified bone density into three groups: (1) Class I bone formation: Contains trabeculae with small, cancellated, evenly distributed spaces. (2) Class II bone formation: Reduced homogeneity in an osseous pattern, with noticeably larger cancellated spaces. (3) Class III bone formation: Considerable marrow-filled spaces between bone trabeculae, resulting in unsatisfactory implant stability (i.e., a loose-fitting implant).

Both Class I bone and Class II bone are suitable for implants, and Class I bone is considered ideal for implant restoration.

Four bone types have been presented, based on both radiographic inspection and the surgeon's perception of resistance during implant preparation[47]. In contrast, Misch[48] created four categories of bone density based on macroscopic cortical and trabecular bone characteristics. The Misch classification of bone density separates and categorizes four sections of the human jawbone.(Tables 2, 3) Furthermore, the density based on computed tomography scan is in Hounsfield units and can be used to quantify bone quality[49,50]. The bone type influences the design, drilling process, and insertion torque of dental implants.

The density and hardness of the bone, the size of the drill bits used, and the implant design all have an impact on the energy needed to install an implant. In dental implantology, this energy is called insertion torque and is measured in Newton centimeters (Ncm). The insertion torque needed to secure the implant into bone is based on the instrument tip and the friction created during insertion[51].

The density and hardness of the bone, the size of the drill bit, and the implant design all have an impact on the insertion torque. Torque and bone density are related, with the D-1 bone type possessing the highest bone density. Use of drill bits with smaller dimensions and implants with tapered geometries can result in good stability and local compression[52]. Although a drill bit with a much smaller diameter than the implant may ensure initial primary stability, it can cause bone necrosis due to bone remodeling, which reduces primary stability[53].

As they are placed into the bone, tapered implants cause higher compression than parallel implants. Tapered implants also require higher insertion torque than parallel implants due to lateral bone compression along the entire length of the implant during insertion.

In implant macro-designs with cutting edges, insertion torque is minimized[54]. The ideal insertion torque as well as its minimum and maximum limits have been the subject of numerous studies. To prevent over-compression or metallurgical issues, several implant manufacturers recommend the ideal insertion torque for quick loading and its upper limit of their implants.

Neugebauer et al.[55] stated that insertion torques larger than 50 Ncm were excessive and should not be exceeded, and that 35 Ncm was ideal for initial loading. In addition, Duyck et al.[56] hypothesized that insertion torques greater than 50 Ncm are more likely to result in peri-implant bone loss.

VIII. Damage to Implant Surface during Insertion

Implant installation causes stress on the bone and implant itself. According to the abrasion theory, abrasion occurs when two dissimilar surfaces collide with velocity and is affected by surface hardness, roughness, and velocity. Because bone has a lower hardness than titanium, it is more easily eroded, although titanium is not invulnerable at the micro level. Both compressive and tensile stress play a part in larger-scale thread abnormalities during the torquing process. Thread pitch and design (including form, width, depth, pitch, face, and helix angle) have an impact on insertion torque (angle and width). The amount of bone deformation caused by insertion torque is influenced by the amount of bone surrounding the implant and the degree of bone apposition. These factors will affect bone remodeling and the overall success of the implant[57]. For predictable results, the insertion torque should typically be greater than 30 Ncm to prevent implant micromovement and connective tissue formation[56,58]. When installing implants in dense bones, an extremely high insertion torque (above 50 Ncm) may occur, exerting compression stress on the neighboring bone and affecting osseointegration[59]. Additionally, some studies have found that shear force during implantation may change the characteristics of the surface of the implant[60,61]. Awareness of the biological response of soft tissue and bone (i.e., soft tissue adaptation and osseointegration) raised concerns about titanium wear during insertion. Comparison of roughness characteristics before and after insertion is a valid method for determining the level of wear[62]. A study with rabbits found after 12 weeks of healing a change in surface structure of unscrewed implant, demonstrating a reduced roughness after the removal of high-roughness implants[4]. In addition, studies on several types of implants have indicated loose titanium particles in the recipient bone. For instance, Meyer et al.[63] found a detectable amount of titanium around titanium-plasma-sprayed surfaces but smaller amounts of residue adjacent to SLA, and smooth surfaces. In addition, Franchi et al.[33] noted the presence of titanium particles around titanium plasma-sprayed implants 14 days after installation. Similar findings were seen in human studies, in which, six months postoperatively, titanium particles were noticed in the tissue covering implant fixtures[64]. These results indicate that a certain degree of implant wear occurs after placement in the oral cavity.

With regard to surface damage on dental implants after insertion into fresh cow rib bone, SEM images showed chipping of the porous structures along the surface, associated with fissures on the surface modification layer. In addition, delamination was observed when the exposed bulk of titanium was located along the sharp edges of the cutting threads. After implantation, the sharp peaks on the grit-blasted and acid-etched implants were diminished or removed, leaving smooth, flattened areas. Portions of the thick oxide coating were peeled from anodized implants, mostly in the apical region and on top of the threads, along with loose titanium particles[60].

In another study, interferometer results revealed a decrease in the roughness of all dental implants[61]. A study from Salerno et al.[65], on the other hand, reported no significant change in structure using AFM. In the authors' opinion, AFM is ineffective for evaluating the structure of a dental implant because the probe cannot reach some areas around the thread, and AFM is more appropriate for analysis at the nano level, as it might not provide detail at the micro level, the functions of which are related to cell attachment and BIC[65].

Another important by Franchi et al.[33] noted that the threads of several implant fixtures were deformed in areas where the recipient bone showed fractures. This indicates that proper site preparation and avoidance of excessive insertion torque maintain both the bone and the implant since they hinder potential damage to the host bone (via fracture) and to the implant (via thread deformation).

IX. Conclusion

A dental implant is a unique apparatus designed to replace missing teeth and to restore appearance and function to a level that is as close to normal as possible. It is important for the clinician to be familiar with the complex structure of dental implants. In addition, surgeons should be aware of the preferred drilling and insertion methods, as well as the possible changes in implant structure that may occur during the procedure. This knowledge will help to maximize the success and survival rates of dental implants.

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Authors' Contributions

P.A., B.M., and N.A. wrote the manuscript. P.N.N. and P.L.

collected the information for Figures 1 and 2 and participated in writing the relevant paragraphs. T.K., N.W., and N.A. provided the idea of this article, supervised on the project, and critically revised the manuscript.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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