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REVIEW PAPER

Surface Roughness of Dental Implant and Osseointegration

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Abstract
Introduction Dental implants are a usual treatment for the loss of teeth. The success of this therapy is due to the predictability, safety and longevity of the bone–implant interface. Dental implant surface characteristics like roughness, chemical constitution, and mechanical factors can contribute to the early osseointegration. The aim of the present article is to perform a review of the literature on surface roughness of dental implant and osseointegration.
Methodology This work is a narrative review of some aspects of surface roughness of dental implant and osseointegration.
Conclusion Despite technological advancement in the biomaterials field, the ideal surface roughness for osseointegration still remains unclear. In this study about surface nanoroughness of dental implant and osseointegration, the clinical relevance is yet unknown. Innovative findings on nanoroughness are valuable in the fields of dental implantology, maxillofacial or orthopedic implant surfaces and also on cardiovascular implants in permanent contact with patient's blood.

Keywords Dental implants · Surface roughness · Nanotechnology · Osseointegration

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Introduction

The development of dental implants has broadened therapy possibilities for partially or completely edentulous patients. The high success rate of this treatment option is due to the predictability, safety and longevity of the bone–implant interface.

Oral implant surface characteristics like microroughness and nanoroughness, chemical constitution, and mechanical factors can contribute to the early osseointegration [1]. However, clinical researches are essential to investigate surface roughness of dental implant and osseointegration.

The aim of the present article is to perform a review of the literature on surface roughness of dental implant and osseointegration.

Osseointegration

According to the American Academy of Implant Dentistry, osseointegration is defined as "Contact established without interposition of nonbone tissue between normal remodeled bone and an implant entailing a sustained transfer and distribution of load from the implant to and within the bone tissue." [2] Clinically, osseointegration corresponds to the stability and ankylosis of an implant in bone [3].

Long-term survival rates of dental implants are outstanding. Despite the high success rates in edentulous patients, failures can occur during or after osseointegration in a small quantity of patients [4]. Primary implant failure due to insufficient osseointegration occurs in 1–2% of patients [5]. Secondary failure is often caused by peri-implantitis several years after successful osseointegration in about 5% of patients [5, 6].

In patients with diabetes mellitus, osteoporosis, using bisphosphonates or in radiotherapy, the osseointegration is still a challenge for dental implant therapy [7]. New technologies as implant surface modifications are needed in order to enhance osseointegration after insertion [7].

Surface dental implants characteristics promote biological processes during osseointegration by mediating the direct interaction to host osteoblasts in bone formation [8]. There are approximately 1300 implant systems with distinct shape, dimension, bulk and surface material, thread design, implant-abutment connection, surface topography and chemistry, wettability, and surface modification [9].

Surface Modifications

Several surface changes have been applied on implants by subtracting and additive methods including physical (turning, blasting), chemical (acid etching, alkali), electrochemical (electropolishing anodizing), deposition (plasma-spraying, sol–gel), and biochemical (proteins) [10, 11].

Some advancements in dental implants have been obtained through roughening the surface of the implant (e.g. sandblasting, acid etching) [12, 13]. Furthermore, alterations aiming to increase corrosion resistance (anodization) [14], change surface energy or vary the surface composition by adding different elements [15, 16] have been proposed.

Surface Topography

Based on the scale, the dental implant topography can be divided into macro-, micro- and nanoscale. Scientific researches were mainly emphasized on micro- and nanogeometry. Surface topography is fundamental for adhesion and differentiation of osteoblasts in the initial stage of osseointegration [9, 13].

Macrotopography of an implant is based on its visible geometry (millimeter scale). A proper macrogeometry associated with adequate dental implant drill hole preparation is fundamental for success in dental implantology [17].

Microtopography is related to microroughness on micrometer scale (1–100 μm). Over the last few decades, dental implants had mainly machined surfaces [18] which indicates a turned, milled, or polished manufacturing process [19]. In these surfaces, irregularities allow osteogenic cells to join and deposit bone, producing bone-to-implant interface. Depending on the anatomical position and bone quality, the healing time of machined implants is about 3 to 6 months [20]. Microtopography of implant surface acts at the cellular level of osseointegration [21].

Techniques for modifying microsurface are well documented in the literature. In systematic review, Wennerberg et al. [22] verified that survival rate of implants and marginal bone loss with different surface roughness was 82.9 to 100% after 10 or more years in function and the marginal bone loss was less than 2.0 mm (average) for turned, titanium plasma sprayed, blasted, anodized, blasted and acid-etched implant surfaces. Fischer and Stenberg [23] investigated 24 patients treated with full-arch prostheses on 139 SLA implants. The patients were followed up for 10 years with satisfactory long-term results (survival rate of 95.1% and mean bone loss of 1.07 mm). Buser and colleagues [18] evaluated the clinical outcomes of 511 SLA implants in 303 patients over a 10-year period with a success rate of 97.0% and an implant survival rate of 98.8%.

Changes of implant surface at the nanoscale level have been developed. Nanotopography can affect cell orientation, alignment, differentiation, migration, and proliferation by regulating cell behavior [24]. In dental implants, nanotopography has an effect on cell–implant interactions at the cellular and protein level, allowing to a better and faster osseointegration by acting on the differentiation of the osteoblasts [25].

Biomedical engineers have emphasized the nanoscale of implant surface design [17]. Companies have found that their implants present aspects of nanotopography [26, 27]. Alterations in nanotopography produce effects at a physical, chemical, and biological level [9], resulting in increased adhesion of osteogenic cells [28] and potentially stimulating osseointegration. Nevertheless, researches are needed to verity if nanometer scale surface topographies improve the osteogenicity of titanium implants [29].

Surface Roughness

Roughness is an important factor determining dental implant osseointegration. Furthermore, rough surfaces increase bone-to-implant contact [30].

Various studies have been carried out aiming to find a surface roughness that maximizes the response of bone cells during healing of the tissue surrounding dental implant. The results show a relation between surface roughness and cell behavior [31, 32]. However, the ideal surface roughness for osseointegration and primary stability still remains unclear [33].

Since the 1990s, the main method to obtain moderately rough surface was removing material or rearranging the superficial surface layer applying blasting, blasting plus etching or oxidization [1].

Considering that osseointegration depends on biochemical bonding, the original turned surface has been substituted by surfaces with moderate roughness, since those have showed improved bone anchorage [12]. A study comparing surfaces with microroughness corroborated favorable effects of moderately rough surfaces on osteoblast differentiation and migration [34].

Currently, studies about roughness on dental implants indicate that isotropic and moderately rough surface has been well documented. A meta-analysis revealed that anodized surface has a lesser likelihood for implant failure in relation to turned surface [35]. Wennerberg et al. [22] observed that oxidized surfaces have lowest probability for failure in relation to other moderately rough surfaces, minimally surfaces, and rough surfaces.

Surface Nanoroughness

Nanotechnology has gained wide attention in scientific media and can be defined as science engaged in design, synthesis, characterization and application of materials and devices whose smallest functional organization at the nanometer scale (1 to 100 nm; one billionth of meter) [36]. Nanostructured surfaces are capable of inducing bone cell adhesion, bone cell growth and differentiation, by promoting specific protein interactions [37, 38].

Nanostructures can be applied on a surface implant with nanosized hydroxyapatite or TiO_2 particles. However, research has showed that nanostructures can also spontaneously appear on titanium surfaces [39]. In vitro [40] and in vivo studies [41] presented more bone cells to proliferate and stronger bone tissue integration when implants contain these nanostructures. Despite this, there are controversies in the literature and the clinical relevance remains unrevealed.

Some benefits of nanoroughness on titanium dental implants include increase in surface area, improvement of cell attachment and biomechanical interface of implant with bone [24]. Traini et al. [42] investigated the fibrin clot extension associated with the contact angle, the micro- and nanoscale roughness between anodized and non-anodized titanium surfaces. The authors verified that titanium anodized surface significantly increases blood clot retention and nanoroughness, and favors osseointegration.

Coating technologies have been introduced for applying hydroxyapatite and calcium phosphates on implant surfaces [43]. Nanohydroxyapatites present nanostructured surface with higher surface area and higher reactivity, letting them to bind to bone creating a biomimetic coating on implants [44]. However, more investigations are needed to develop an effective implant due to the interaction of cells and biomaterial surface after dental implant surgery.

In spite of technological development at the nanoscale level, there is a lack of clinical evidence about surface nanoroughness on dental implant and osseointegration. Innovative findings on nanoroughness are valuable in the areas of dental implantology, maxillofacial or orthopedic implant surfaces and also on cardiovascular implants in permanent contact with patient's blood [45].

Conclusion

Despite technological development in the biomaterials field, the ideal surface roughness for osseointegration is still the challenge. Dental implants are successful in healthy patients. On the other hand, technological innovations such as surface nanoroughness are needed to accelerate osseointegration after implant insertion in medically compromised patients. In this study about surface nanoroughness of dental implant and osseointegration, the clinical relevance is still unknown.

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Compliance with Ethical Standard

Conflict of interest Dr. Geraldo Roberto Martins Matos declare that he has no conflict of interest.

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