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Effect of Different Types of Implant Coating and Surface Treatment on Implant Stability

Ola Abdelsamad Amin [1,*], Omar Mahmoud Elsherbiny [2], Fatma El-Zahraa Ayman Ahmed Hassab [3], Marina Maged Adly [4], Mohamed Hamdy Mahmoud Ismail [5]

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Abstract

Implant surface design has evolved to meet oral rehabilitation challenges in both healthy and compromised bone. For example, to overcome dental implant-related complications, peri-implantitis, and subsequent implant loss, implant surfaces were modified to introduce desired properties to dental implants and thus increase their success rate and expand their indications. Until now, a diversity of implant surface modifications, including different physical, chemical, and biological techniques, have been applied to a wide range of materials, such as titanium, zirconia, and polyether ether ketone, to achieve these goals. Ideal modifications enhance the interaction between the implant's surface and its surrounding bone which facilitates osseointegration while minimizing bacterial colonization to reduce the risk of biofilm formation. This review article aims to discuss currently available implant surface modifications in terms of their impact on osseointegration and biofilm formation, which is important for implantologists to choose the most suitable materials to improve implant success and survivability.

* **Corresponding author**.
E-mail address: oabdelsamad@msa.edu.eg
1 *Teaching Assistant of Oral and Maxillofacial Surgery, Faculty of Dentistry, October University for Modern Sciences and Arts*
2 *Student at Faculty of Dentistry, October University for Modern Sciences and Arts*
3 *Student at Faculty of Dentistry, October University for Modern Sciences and Arts*
4 *Student at Faculty of Dentistry, October University for Modern Sciences and Arts*
5 *Lecturer of Oral and Maxillofacial Surgery, Faculty of Dentistry, October University for Modern Sciences and Arts*

1 Introduction

Blasting, acid etching, anodic oxidation, fluoride treatment, and calcium phosphate coating are just a few of the extensively used methods for changing the topography or chemistry of titanium surfaces. The osseointegration of these changed surfaces is stronger and faster than that of turned, commercially pure titanium surfaces. [1]

Surface treatments are normally done to modify and maintain desirable properties of the substrate materials especially in the dental implant industry. The surface area can be increased remarkably by using the suitable modification techniques, either by addition or subtraction procedures. Surface treatment is used to modify the surface topography and surface energy, resulting in an improvement in wettability, increased cell proliferation and growth, and accelerated osseointegration process. [2]

Implant stability reflects implant osseointegration in that it requires certain objectives to be met during implant installation and healing. Stability can be divided into two categories: primary stability, which is assessed directly following implant implantation, and secondary stability, which is assessed following the healing of the implant's surrounding bone.

Secondary stability develops as a result of a series of processes, such as bone deposition and remodeling at the bone-implant interface, as opposed to primary stability, which is a mechanical phenomenon caused by the interlocking of bone to implant shortly following implant placement. The stability of implants is evaluated using a variety of techniques, including histologic examination, radiography, percussion testing, reverse torque testing, cutting torque resistance testing, periotesting, and resonance frequency analysis (RFA) devices. The secondary stability of implants is affected by a variety of factors, such as surface topography, bone quality, and patient-related factors. [3]

2 Review of literature:

2.1 Different types of implant stability and different techniques of measuring implant stability:

2.1.1 Different types of implant stability:

Functional dental implants require successful osseointegration, and successful osseointegration requires primary implant stability. Clinical mobility is not seen when an implant is stable. Implant instability may cause fibrous encapsulation and failure as a result. Primary implant stability upon placement is a mechanical phenomenon that depends on the type of implant utilized, the technique of placement, the quantity and quality of the surrounding bone. The improvement in implant stability caused by bone growth and remodeling at the implant/tissue interface and in the surrounding bone is referred to as secondary implant stability. [4]

The main determinants of implant stability are the mechanical properties of bone tissue at the implant site irrespective of how well the implant is engaged with bone tissue. Successful secondary stability is strongly correlated with good initial stability. Following implant insertion, secondary stability gradually rises by four weeks, and optimum stability takes three to six months of the non-loaded healing phase. The Branemark technique suggests placing implants once the alveolar bone has fully healed following tooth extraction, followed by three to six months of submerged healing. The quantity and quality of the alveolar bone, the implant design, the surface characteristics of the implant, primary stability, occlusal stress, and marginal bone loss are some of the aspects that can influence the prognosis of an implant placed in alveolar bone during this time. [3]

2.1.2 Different techniques of implant stability measurement:

Primary implant stability can be measured by either a destructive or non-destructive method. tensional test, push-out/pull-out test and reverse torque test are classified as destructive methods. Non-destructive methods include percussion test, cutting torque test while placing implants, Periotest® (SiemensAG, Benshein, Germany), and resonance frequency analysis (RFA). [5]

Destructive methods:

A. **Tensional test:** The interfacial tensile strength was originally measured by detaching the implant plate from the supporting bone. Bränemark later modified this technique by applying the lateral load to the implant fixture. [6]

B. **Push-out/pull-out test:** it is the most commonly used approach to investigate the healing capabilities at the bone implant interface. A cylinder-type implant is often inserted transcortically or intramedullary into bone structures and subsequently removed by exerting force parallel to the interface in a pushout or pull-out test. As a result, the maximum force can be divided by the area of the implant in contact with the host bone to determine the general loading capacity of the interface (or interfacial shear strength). [6]

C. **Reverse torque test:** by the application of a reverse or unscrewing torque to assess implant stability at the time of abutment connection, Implants that rotate under the applied torque are considered failures and are then removed. [4]

Non-destructive methods:

A. **Percussion test:** involves tapping of a mirror handle against the implant carrier and is designed to elicit a ringing sound from the implant as an indication of good stability or osseointegration. [4]

B. **Cutting torque resistance analysis:** relies on the concept of measuring the energy required for a current-fed electric motor in cutting off a unit volume of bone during implant surgery, the energy correlates to bone density, which is one of the factors determining implant stability. [4]

C. **Periotest:** is a device electrically driven and electronically monitored tapping head that percusses the implant a total of 16 times, The entire measuring procedure takes about four seconds. [4]

D. **Resonance frequency analysis:** yields a measurement scale called the implant stability quotient (ISQ), which has values that range from 1 to 100. [7] Higher ISQ values indicate higher implant stability. Clinically stable implants generally demonstrate ISQ values between 40 and 80. [8]

2.2 Different types of dental implants surface coating:

There are several factors that play a major role in the process of osseointegration for example, length of the implant, surface topography of the implant; thus, osseointegration of the titanium dental implant can be enhanced by making surface modification over the surface of the titanium dental implant. These modification in titanium dental implant are physical, chemical and mechanical.[10]

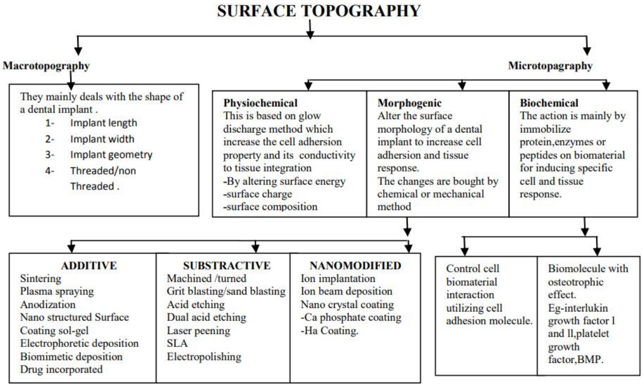

Figure 1. Different types of implant surface coating and treatment [9]

There are various principles through which surface modification could be achieved which are:

2.2.1 plasma spray coating:

By the deposition of a layer of thermally melted material, which is thick in consistency, for e.g. deposition of layer of hydroxyapatite on titanium implants. [10]

2.2.2 Grit blasting:

By projecting the particles of either silica or ceramic material over the surface of the implant at higher pressure. The process of grit blasting should always be followed by the process of acid etching. [10]

2.2.3 Acid etching:

It is a method of subtraction which is done to create surface roughness of the implant to help in cell adhesion over the implant surface and thus helps in faster bone formation,various acids such as nitric acid, hydrofluoric acid and sulphuric acid can be used. [10]

2.2.4 Dual acid etching:

By treatment of the implant surface via chemical or acid whether in sequence or with the combination of both. [10]

2.2.5 Sand blasting along with acid etching:

In this method, macro roughness and micro pits are simultaneously developed. Surface erosion is induced by the application of strong acid over the already blasted surface. In this process blasting is done by large grit particles along with acid etching that too sequentially. This process results in increasing of surface energy along with increased surface area over the implant surface, which leads to better implant osseointegration. [10]

2.2.6 Laser peening:

Neodymium-doped Yttrium Aluminum Garnet Nd:YAG lasers, CO_2 lasers, Nd:YVO_4 lasers, Yb:KGW lasers, Yb:KYW lasers, Yb:YAG laser, and femtosecond lasers are among those that can be used to modify titanium surfaces. The laser light can oxidize the surface through the diffusion of oxygen in the molten metal and generate morphologies with different surface characteristics, which can have a significant influence on the interactions between bone and implant. [11]

2.2.7 Anodization:

In this process films of oxide is deposited over the outer surface of the implant by the means of electro chemical deposition. Anodized surface results in better implant osseointegration. [10]

2.2.8 Biomimetic agent:

Various biomimetic agents like hydroxyapatite, calcium phosphate ions, bone morphogenic proteins, type collagen1, fluoride and chitosan polymer can be used as an biomimetic agent to increase the surface area. [10]

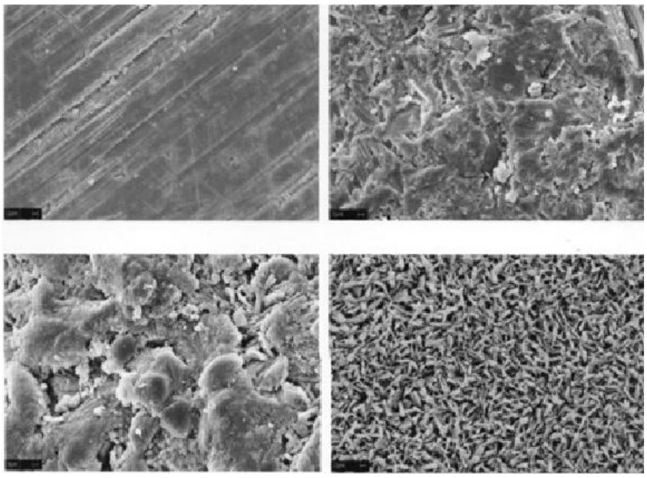

Figure 2. SEM picture showing the surface of the implant: (x 3.000). a) As-machined; b) Al_2O_3 blasted; c) Plasma-sprayed with titanium; d) Electrolytically coated with hydroxyapatite. [12]

2.3 Different types of dental implants surface treatment:

The design of dental implants and their surfaces have frequently changed and evolved over time to allow for improved osseointegration and better long-term implant survival rates. There are three distinct groups of methods through which implant surfaces can be modified at manufacture. [13]

2.3.1 Mechanical treatments: These include grinding, blasting and machining to create rougher or smoother surfaces. [13]

2.3.2 Chemical treatments: Conducted with acids, alkali, sol gel or through anodization, among other methods, chemical treatments alter the implant surface's roughness and composition and enhance surface energy. [13]

2.3.3 Physical treatments: These treatments include plasma spraying and ion deposition. [13]

Anodization, sandblasting, and acid etching are a few of the surface treatments for titanium implants that have become more popular in recent years. It has been demonstrated that anodization, which increases the implant's TiO_2 (Titanium dioxide) layer thickness, mildly roughens it, and improves osteoconductivity, improves osseointegration. [14-16] On the other side, sandblasting and acid etching remove some of the implant's material, producing minute irregularities and a roughened surface that may promote quick osseointegration. [17]

The effect of implant surface coating and surface treatment on implant stability:

Dental implants with hydroxyapatite (HA) coatings have the highest capacity to bind proteins to their surface, which is advantageous for interactions between cells and biomaterials. [18] As a result, HA coatings are regarded as a very effective way to increase the stability and osseointegration of titanium implants. [19]

Pimentel Lopes de Oliveira et al. conducted a randomized controlled clinical split-mouth trial to compare anodized implant surfaces and implant surfaces modified by acid etching regarding primary and secondary stability. According to ISQ analysis, the anodized (ANO) group had statistically lower values than the acid etched (AC) group. [20]

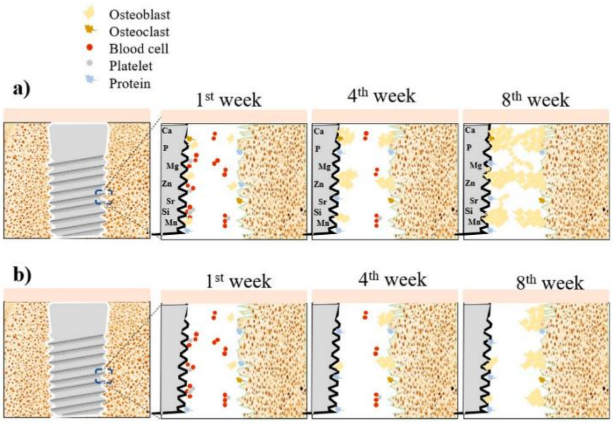

Figure 3. The difference between osseointegration in surface coated Titanium implants and Non-coated Titanium implants: a) Surface coated implants with bio-bonding materials; b) Non-coated Ti implants. [21]

A study by Kinga Körmöczi that compared between SA (alumina sandblasted and acid-etched), NH (bioabsorbable apatite nanocoating) and SLA (large-grit sandblasted and acid-etched) surface implants regarding primary stability and secondary stability after six weeks showed that all three groups could be safely used in case of early loading protocol after 6 weeks due to their higher osseointegration. The increase of the implant stability during the 6 weeks period was the lowest in case of SLA group and the highest in case of NH group. [22]

The SLActive surface has the potential to enhance osseointegration at an early stage and had the greatest impact on the primary stability of the implant, according to Chun-Ping Hao's network meta-analysis in animal models. [23]

3 Conclusion

Generally, the coating techniques contribute to important positive effects in dental implant application. Blasting is one popular technique for surface treatments which can easily roughen the implant surface but is inadequate to give credit to the important properties like bone implant contact, removal torque values, tissues response, and biocompatibilities. Ion implantation technique on the other hand is useful to harden the surface of titanium but not applicable for dental implant. [2]

Up till now, ceramic coatings (calcium phosphate, HA, and TiO_2) still remain the most popular bioceramic materials in the surface treatments area. Nevertheless, HA is recognized as the best candidate in bioceramics compared to TiO_2. [24]

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