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SURFACE TREATMENTS ON DENTAL IMPLANTS: WHAT DO WE STILL NEED TO KNOW?

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Abstract: The literature review on the different surface treatments of titanium and zirconia dental implants revealed a variety of techniques that aim to improve osseointegration and promote initial stability superior to untreated implants. The data found highlights that in both titanium and zirconia implants, the surfaces can be modified to improve biological performance, accelerating the initial healing process. Although there is variability in the types of treatment, with some being common for both titanium and zirconia implants, the changes have proven to be effective, allowing loading in shorter times. However, regarding zirconia implants, although studies are promising, more long-term research is needed. To date, there is not enough data to clearly and safely indicate the use of these implants, except in cases of proven allergenicity to titanium. Therefore, although surface treatments offer promising opportunities to improve osseointegration and the success of dental implants, it is essential to continue investigating and evaluating these techniques, especially in the context of zirconia implants. Long-term longitudinal studies are needed to further validate the efficacy and safety of these treatments, thus ensuring better clinical outcomes for patients.
Keywords: Surface treatment; Dental Implants; Dentistry.

INTRODUCTION

Planning oral rehabilitation with implants is a complex and crucial process for the success of the treatment. One of the most important results is osseointegration, which is fundamental to the stability and functionality of dental implants. Osseointegration occurs in two phases: primary stability, which is the initial mechanical stability of the implant in the prepared socket, and secondary stability, which is the ability of the implant to remain stable after deposition and regeneration of peri-implant living tissue.

These phases are influenced by several factors, including the macro and microgeometry of the implant, the patient's bone quality, surgical planning, and the skill of the dentist. Furthermore, the implant surface properties play a crucial role in the osseointegration process.

Both titanium and zirconia implants have been widely used in dental practice. Titanium is considered the gold standard due to its biocompatibility and osseointegration capacity. However, in recent years, zirconia implants, especially yttrium-stabilized polycrystalline tetragonal zirconia (Y-TZP), have gained popularity due to their excellent biomechanical properties, chemical stability, and lower bacterial adhesion. Furthermore, zirconia has a similar color to natural teeth, which makes it a preferred choice in aesthetic areas and for patients with thin gingival biotypes and a high smile line.

The surfaces of implants, both titanium and zirconia, can be modified to improve biological performance, without altering the fundamental properties of the materials. These modifications include changes in surface roughness and the application of bioactive coatings, which promote biochemical union and accelerate the initial stages of bone tissue formation.

In this sense, the success of osseointegration in dental implants depends on a variety of factors, including the characteristics of the materials used, treatment planning, and modifications made to the implant surfaces. A comprehensive understanding of these aspects is essential for developing successful treatment protocols and achieving predictable and long-lasting results in oral rehabilitation with implants. Therefore, the present study aims to expose, through a literature review, surface treatments of dental implants.

MATERIAL AND METHODS

A bibliographic search was performed in the main health databases PUBMED (www.pubmed.gov) and Scholar Google (www.scholar.google.com.br), in which articles published from 1955 to 2024 were collected. Laboratory studies, case reports, systematic reviews, and literature reviews, which were developed in living individuals, were included. Therefore, articles that did not deal with the use of finite element analysis and strain gauge were excluded, as well as their use in computational studies with greater validity and reproducibility

Through bibliographic research, 60 articles were selected, 55 articles from PUBMED (www.pubmed.gov) and 5 from Scholar Google (www.scholar.google.com.br) (Table. 1). The following titles of specific medical subjects and keywords were used: Surface treatment; (DeCS / MeSH Terms), Dental Implants (DeCS / MeSH Terms), Dentistry (DeCS / MeSH Terms).

Database	Mean ± Stardard Deviation	Total Studies (1955-2024)
Pubmed	2,03 ± 1,89	55
Google Scholar	0,78 ± 0,90	5

Table. 1 - Mean ± standard deviation of the number of studies in the main health databases.

RESULTS

According to Table 1, it can be seen that the average publication of articles in the period from 1955 to 2024 from the Pubmed database was 2.03 with a standard deviation of 1.89. While at Scholar Google, the average was 0.78, and the standard deviation was 0.90. Thus, it is possible to verify that there was a significant variation in the number of articles, in both databases.

OSSEOINTEGRATION

Osseointegration is a crucial process for the success of dental implants and plays a fundamental role in the stability and functionality of these devices. This phenomenon refers to the direct formation of a structural and functional connection between the living bone and the implant surface, without the presence of interposed fibrous connective tissue. Osseointegration lies in the fact that it allows the efficient transfer of chewing loads to the bone, replicating the natural function of the teeth. Furthermore, successful osseointegration promotes long-term stability, load resistance, and prevention of peri-implant bone loss.

For patients, osseointegration is essential to ensure effective oral rehabilitation, restoring chewing function, aesthetics and self-confidence. For dental professionals, successful osseointegration is an indication that the implant is stably and healthily integrated into the surrounding bone tissue, which is crucial for planning and executing successful dental treatments. Therefore, understanding the mechanisms underlying osseointegration and employing strategies to promote it are essential aspects in the practice of implant dentistry, aiming to guarantee predictable and lasting results for patients who require oral rehabilitation with dental implants.

In recent years, there have been significant advances in dental implant surface treatment technology, intending to improve osseointegration and, consequently, the success of implant procedures. These advances have been driven by the search for more effective implants, with higher osseointegration rates and faster recovery for patients. Here is some context on these advances and their role in improving osseointegration:

One of the main advances has been the development of new materials for dental implants, in addition to the traditional titanium. Zirconia, for example, has favorable biomechanical and aesthetic properties, and advances in surface treatment technology have contributed to improving its osseointegration.

Studies have shown that adequate roughness on the implant surface can promote faster and more effective osseointegration. New surface treatment techniques have been developed to control and optimize roughness, providing a surface more conducive to cell adhesion and bone formation. Bioactive coatings, such as hydroxyapatite and calcium phosphate, have been applied to the surface of implants to promote a more favorable interaction with the surrounding bone. These coatings can stimulate bone formation and improve osseointegration, especially in patients with compromised bone quality. In addition to bioactive coatings, physical and chemical stimuli have been used to modulate the biological response to the implant surface. This includes techniques such as plasma spraying, laser, thermal, and chemical treatments, which can alter surface properties to promote more effective osseointegration.

Advances in nanotechnology have allowed the creation of implant surfaces with specific nanometric characteristics, aiming to improve interaction with bone cells and accelerate osseointegration. These promising approaches are increasingly being explored in dental implant research and development. Generally speaking, these advances in dental implant surface treatment technology have played a crucial role in improving osseointegration. By optimizing the properties of the implant surface, it is possible to promote a more favorable biological response and faster and more stable integration with the surrounding bone. These developments have contributed significantly to the success and longevity of dental implant procedures, benefiting both patients and dental professionals.

MACHINED IMPLANTS

Machined implants refer to dental implants manufactured using a machining process, in which titanium is transformed, polished, or milled to obtain the desired shape. This manufacturing method results in smooth or machined surfaces but microscopically presents a certain roughness due to the grooves and grooves formed during the machining process. These grooves cannot induce osseointegration by themselves but have been observed as places where new bone formation occurs towards this roughness, which is characteristic of distant osteogenesis.

Although machined implant surfaces have an average surface roughness value between 0.53 and 0.96μm, they do not receive additional chemical or mechanical treatment to improve osseointegration. However, cleaning and disinfection processes can change the surface energy of the machined implant, making it more attractive for cell adhesion. It is important to note that, although machined implants have surface roughness resulting from the machining process, this roughness is not sufficient to promote optimal osseointegration. Therefore, additional surface treatment techniques, such as the application of bioactive coatings or chemical treatments, are often employed to improve the implant's ability to integrate with the surrounding bone.

PRINTED IMPLANTS

Printed dental implants, also known as dental implants manufactured using 3D printing or additive manufacturing, represent a significant innovation in the field of dentistry. This manufacturing method allows for the creation of highly precise, customized implants based on each patient's specific needs. Unlike traditional implant manufacturing methods, in which the material is molded or machined from a solid block, 3D printing builds the implant layer by layer, based on a previously designed digital model. This offers unparalleled flexibility in customizing the shape, size and surface characteristics of the implant, allowing it to be adapted to the patient's individual anatomical conditions.

Printed dental implants can be manufactured from a variety of materials, including titanium alloys, ceramics, and biocompatible polymers. Each material has its advantages and limitations, and the choice depends on the specific needs of the patient and the clinical demands of the case. One of the main advantages of printed dental implants is the ability to optimize osseointegration. Precision in implant design, along with the ability to design surfaces with specific textures to promote cell adhesion and bone formation, can significantly improve clinical outcomes and reduce healing times.

Additionally, on-demand manufacturing and customization of printed implants can result in more efficient and less invasive procedures, reducing surgery time and improving the patient experience. However, it is important to highlight that 3D printing technology in dentistry is still constantly evolving, and more research is needed to validate its long-term effectiveness and its applicability in different clinical situations. Printed dental implants represent a promising evolution in the field of implant dentistry, offering a personalized and precise approach to replacing missing teeth. With continued innovation and improvement in technology, these implants are expected to play an increasingly important role in modern dental practice.

ZIRCONIA IMPLANTS

Zirconia Implants Zirconia (ZrO2) has gained prominence in dentistry due to its properties favorable to osseointegration and aesthetics. However, despite the growth in its use in dental implants, it has not yet become routine in dental practice. This is partly because when aesthetics is the main consideration, especially in cases of thin gingival biotype, the use of a zirconia abutment may be sufficient to meet the aesthetic needs of patients. However, research on zirconia and its potential modifications in macro and microgeometry is ongoing, aiming to expand its applications and improve its effectiveness. These modifications may include surface treatments that aim to improve osseointegration and biocompatibility of zirconia implants. Although some of these modifications to the surface of zirconia implants may be similar to those applied to titanium implants, there are also approaches specific to zirconia. These modifications may include chemical, physical or mechanical treatment techniques, aimed at improving surface characteristics, such as roughness and surface energy, to promote better interaction with bone tissue and more efficient osseointegration. Although some of these modifications have not yet been commercialized, promising research results suggest that they may play an important role in advancing the use of zirconia implants in dentistry. The use of machined zirconia and titanium implants can result in similar bone-implant contact (BIC) values, as noted by Hafezeqoran & Koodaryan (2017). However, in terms of microbial adhesion, studies show that zirconia tends to have a lower number of bacteria compared to titanium. This was confirmed by Roehling et al. (2017), who observed a significant reduction in in vitro oral biofilm formation on zirconia surfaces compared to titanium. Even the simple process of polishing the surface of the zirconia implant can result in roughness ranging from 8 to 200 nm, providing better adhesion of fibroblasts without altering the chemical surface, as stated by Karthigeyan et al. (2019). Furthermore, zirconia surface modification can be accomplished in several ways, including laser treatment, which decreases roughness while increasing surface energy and wettability, promoting cell adhesion. A specific example is the ZLA surface (Straumann® Pure Ceramic ZLA™), which follows the same principle as the SLA treatment (blasting followed by double acid etching) applied to titanium implants, but is made on the surface of zirconia implants. This combines the benefits of zirconia with a well-established surface modification in the literature (Barfeie et al., 2015; Gahlert et al., 2016). Furthermore, the application of bioactive coatings on the zirconia surface, such as silica, magnesium, nitrogen, carbon, calcium phosphate hydroxyapatite, dopamine, and graphene, can further enhance the biocompatibility, bioactivity, and antibacterial potential by inducing the formation of hydroxyapatite in a biological environment. These coatings can be developed to promote osseointegration and reduce bacterial adhesion, contributing to the long-term success of zirconia dental implants.

SUBTRACTION PROCESS

The subtraction process, particularly acid etching, is a widely used method to modify the surface of dental implants, aiming to improve osseointegration. Different types of acids like hydrofluoric acid (HF), nitric acid (HNO_3)and sulfuric acid (H_2ONLY_4), or combinations of these acids are used for this purpose. Acid etching aims to clean the implant surface and change its roughness on a microscale, both for titanium and zirconia implants. Implants treated with acid attack have demonstrated an increase in cell adhesion and bone formation, thus promoting more effective osseointegration. The homogeneous wear process resulting from acid attack does not depend on the size or shape of the implant, but rather on the acid concentration, temperature and treatment time. It is important to control these parameters to avoid undesirable chemical changes on the implant surface. A common approach is double etching, which involves combining two acids to remove and stabilize the oxide layer on the implant surface. Mixtures of nitric acid and hydrofluoric acid, or hydrochloric acid and sulfuric acid, are the most used. These acids can promote roughness on the implant surface, increasing surface energy and improving wettability and protein absorption. This accelerates the osseointegration process, allowing faster prosthetic rehabilitation. An advantage of acid etching compared to other methods is its ability to prevent surface contamination by abrasive particles or delamination of anodized layers. However, it is important to carefully select and control the acids used, as well as the process parameters, to ensure effective and safe results. Sandblasting is a surface modification method used in dental implants, which involves the pressurized projection of particles of ceramic materials or other materials, such as silica, sand, hydroxyapatite, alumina, and titanium dioxide (TiO_2), followed by an acid attack to remove residual particles. The resulting roughness depends on particle size, time and jet pressure. Blasting associated with acid etching is an even more advanced technique. This method promotes physical (roughness) and chemical (surface energy) changes to the implant surface. This results in better osseointegration during the healing phase by increasing the contact area between the implant and the surrounding bone, which in turn improves mechanical fixation. One of the best-known surfaces produced by this method is SLA (Sandblasted, Large-grit and Acid etching). In this process, the implant surface is treated with Al2O3 particles, approximately 250 to 500μm in size, to create macro-roughness. Then, a double acid attack occurs (generally with 1% hydrofluoric acid and 30% nitric acid), to form micro-roughnesses on the implant surface. Another variation of this method is the SLActive® surface, developed by the company Straumann®. In addition to blasting followed by acid etching, the implant is stored in an isotonic 0.9% sodium chloride (NaCl) solution. When in contact with blood during surgery, this surface has high hydrophilicity and a high degree of wetting. This promotes rapid hydroxylation of the surface, improving its protein adsorption capacity and favoring early osseointegration. The SLActive® surface was designed to optimize implant stability in a reduced osseointegration time, reducing the risk of implant loss in the early stages of the process. In short, blasting associated with acid attack is an effective technique for improving the osseointegration of dental implants, offering significant advantages in terms of mechanical fixation and healing time. These modified surfaces have been widely adopted in clinical practice due to their proven results in terms of long-term implant success. Changing the surface of dental implants through the use of lasers has several significant advantages. One of the main advantages is that this method does not require the use of different chemical elements, thus avoiding contamination of the oxide layer. Furthermore, laser treatment offers precise control over the angulation of the roughness produced, resulting in the creation of regularly oriented micro-retentions on the implant surface. These roughnesses can vary in size and shape depending on the pulse intensity of the laser emitting source. Several types of lasers can be used for this process, with the diode laser being a common example. The diode laser is a type of semiconductor laser that converts electrical energy into photons and is widely used due to its effectiveness and versatility. Comparative studies, such as those carried out by Jemat et al., demonstrated superior results in laser surface modifications compared to machined or sandblasted surfaces. For example, the removal torque of implants with laser-modified surfaces can be significantly greater, reaching up to 52N compared to 35N on machined surfaces, after a 12-week healing period. However, it is important to highlight that laser treatment alone may not be sufficient to guarantee an ideal surface for osseointegration. Some authors emphasize that other surface treatment methods must be combined to optimize results. Therefore, although laser treatment offers several advantages, its effectiveness can be enhanced when combined with other surface modification techniques.

ADDITION PROCESS

Biomimetic treatment with hydroxyapatite (HA) is a technique used to modify the surface of dental implants, aiming to improve osseointegration. The process consists of covering the implant surface with a uniform layer of HA, similar to the natural biological layer. This layer is formed through the heterogeneous precipitation of calcium phosphate, using a solution of ions similar to blood plasma, under physiological conditions of temperature and pH. HA presents high biocompatibility and bioactivity, combining the mechanical advantages of metals with the biological properties of HA. The molecules integrated into the material's structure are gradually released, promoting osteoconductivity and enhancing bone formation around the implant. Furthermore, calcium phosphate has biocompatibility and osteoconductivity properties, contributing to the regeneration of bone tissue. This method is considered attractive for improving the quality of the bone-implant interface, especially in the early stages of healing. Some additional advantages of biomimetic HA treatment include low cost, deposition on implants of any geometry, processing at low temperatures, and the ability to incorporate organic molecules, such as proteins, into the formed crystals. On the other hand, HA and Ti plasma spray, although it has been used in the past, is out of favor due to concerns about displacement of HA from the implant surface and accumulation of particles in surrounding tissues, which can lead to biomechanical complications and biological. Currently, implants with nanometric HA particles are used as an alternative. Anodizing is another surface treatment method that promotes an increase in the titanium oxide layer on the implant. This increase in the oxide layer, together with the addition of other elements such as phosphate, improves osseointegration. Anodizing changes the topography and composition of the surface, increasing the adhesion of bone cells and contributing to better implant fixation. Studies have shown that implants with porous anodized surfaces have satisfactory long-term cumulative success and survival rates, associated with good oral hygiene. These results highlight the effectiveness of anodization as a method to improve osseointegration and stability of dental implants.

CLINICAL CONSIDERATIONS AND FUTURE DIRECTIONS

For clinicians, appropriate selection of implants and surface treatments must take into account several considerations specific to the patient and clinical situation.

- Patient Assessment: Before selecting a specific type of implant or surface treatment, it is crucial to carefully assess patient needs and patient characteristics. This includes factors such as general health, oral health, underlying medical

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conditions, oral hygiene habits, history of prior dental treatment, and patient expectations regarding treatment.

- Treatment Goals: Understanding the specific treatment goals is essential to determining the most appropriate implant type and surface treatment. Objectives can range from basic functional restoration to optimizing aesthetics and osseointegration.

- Bone Type: The quality and quantity of bone available at the implant placement site will influence the choice of implant type and surface treatment. In cases of compromised or deficient bone, bone augmentation techniques or specific implants may be necessary to improve stability and osseointegration.

- Primary Stability: Achieving primary implant stability is critical to long-term success. Depending on bone density and the surgical technique used, it may be preferable to select implants with a design and surfaces that promote good primary stability.

- Biological Compatibility: Considering the biocompatibility of the implant material and surface treatment is crucial to minimize adverse reactions from the body and promote a favorable tissue response. Materials such as titanium and zirconia are widely recognized for their biocompatibility.

- Aesthetic Needs: In cases where the patient's aesthetic needs are a priority, such as in the anterior jaw region, it may be preferable to opt for implants and surface treatments that provide natural integration with the surrounding tissues and improved dental aesthetics.

- Predictability and Scientific Evidence: Basing treatment decisions on scientific evidence and clinical studies is critical to ensuring the predictability and long-term success of treatment. Consulting guidelines and recommendations from dental societies and experts can help clinicians make informed decisions.

- Interdisciplinary Collaboration: In complex cases, especially those involving full oral rehabilitation or advanced surgical procedures, it is beneficial to collaborate with other healthcare professionals, such as oral and maxillofacial surgeons, periodontists, prosthetists, and implant dentists, to ensure a comprehensive, multidisciplinary approach. Identifying gaps in knowledge and proposing suggestions for future research in the area of dental implant surface treatment is essential to advancing the field and improving clinical outcomes.

- Long-Term Effects: Many studies focus on the immediate or short-term results of implant surface treatments. Longitudinal research on Long-term studies is needed to evaluate the long-term effects of these treatments, including implant stability, osseointegration, peri-implant health, and long-term implant survival.

- Direct Comparison between Treatments: Although there are many studies investigating individual surface treatments, there is a need for more direct comparative research between different surface treatments. This would help clinicians make informed, evidence-based choices about which surface treatment is most appropriate for certain clinical situations.

- Standardization of Assessment Protocols: The lack of standardization in assessment protocols makes it difficult to compare results between studies. Future research should focus on establishing standardized assessment protocols to measure osseointegration, implant stability, biofilm formation, and other relevant variables.

- Impact of the Surface on the Aging Process: With the increase in the elderly population, it is important to understand how surface treatments of dental implants can influence the aging process of the bone and surrounding soft tissues. This includes investigating the effects of surface treatments on elderly patients and conditions such as osteoporosis.

- Treatment Personalization: Future research could explore personalized surface treatment approaches, taking into account individual patient characteristics such as age, general health status, bone density, and oral hygiene habits. This could lead to better clinical outcomes and a more holistic approach to dental implant treatment.

- Development of New Materials and Technologies: Continued research into developing new materials and technologies for dental implant surface treatments can open up new possibilities and further improve clinical outcomes. This may include the use of bioactive materials, antimicrobial coatings and advanced manufacturing techniques.

- Economic Impact Assessment: In addition to clinical aspects, it is important to consider the economic impact of dental implant surface treatments. Future research could investigate the cost-effectiveness of different surface treatments in relation to clinical outcomes and patient quality of life.

- Integration of Digital Technologies: With the advancement of digital technologies in dentistry, there is an opportunity to integrate these technologies into the development and evaluation of dental implant surface treatments. This includes using 3D printing, computational modeling and data analysis to optimize surface treatments and predict clinical outcomes. By addressing these areas of research, researchers can significantly contribute to advancing knowledge and improving implant surface treatments. dental care, resulting in better patient outcomes and a more effective and personalized dental practice.

DISCUSSION

The different surface treatments of dental implants are of great relevance in dentistry, since adequate osseointegration is fundamental to the long-term success of the implants. Surface treatments aim to improve the interaction between the implant and the surrounding bone tissue, promoting faster and more effective osseointegration. In this discussion, we will explore the main types of surface treatments, their advantages and disadvantages, as well as their clinical implications. One of the most common surface treatments is particle blasting, which consists of projecting abrasive particles onto the implant surface to create microscopic roughness.

These roughnesses increase the contact area between the implant and the bone, facilitating initial fixation and promoting osseointegration. However, this method can result in an uneven and rough surface, which can increase plaque accumulation and the long-term risk of peri-implantitis. Another common treatment is anodizing, which involves passing an electrical current through the implant in an electrolyte solution to form an oxide layer on the surface. This oxide layer can improve implant biocompatibility and promote osseointegration. However, the effectiveness of this method may depend on the uniformity of the oxide layer formed and the manufacturing technique. Additionally, acid treatment is often used to condition the implant surface and promote the formation of a hydroxyapatite layer, which is similar to the composition of natural bone.

This can facilitate cell adhesion and promote osseointegration. However, the use of acids can result in changes in the chemical composition of the implant surface and affect its biocompatibility. Recently, more advanced techniques, such as laser treatment and biomimetic surface modification, have been developed to further improve the osseointegration of implants. Laser treatment can create precise and controlled surface patterns, while biomimetic modification can promote cell adhesion through the immobilization of biomolecules on the implant surface. In terms of clinical implications, the choice of the most appropriate surface treatment must take into account the patient's characteristics, such as oral health, bone quality, and aesthetic needs.

Additionally, it is important to consider factors such as cost, availability, and scientific evidence regarding the effectiveness of each treatment. Dental implant surface treatments play a crucial role in promoting osseointegration and the long-term success of implants. By understanding the different treatment options available and their clinical implications, dental professionals can make more informed decisions and provide the best possible care to patients.

CONCLUSION

IT CAN BE CONCLUDED FROM THIS STUDY THAT:

The effectiveness of surface treatments in accelerating osseointegration in both titanium and zirconia implants is a significant advance in implant dentistry. These treatments have been able to reduce the time needed to load implants, providing faster recovery and more satisfactory clinical results. The relationship between the levels of hydrophilicity and wettability generated by surface treatments plays a crucial role in this process, facilitating interactions between the implant and the surrounding bone tissue. When choosing the appropriate surface treatment, it is essential to consider several factors, such as the patient's bone quality, their systemic conditions, and the previously established loading plan. These elements can directly influence osseointegration and the long-term success of dental implants.

Despite the promising results observed in preclinical and short-term clinical studies, it is essential to conduct long-term longitudinal studies to evaluate the survival of zirconia implants and their surface treatments. These studies should address both the mechanical and biological aspects of osseointegration, providing more comprehensive information on the stability and durability of these implants over time. Furthermore, it is important to continue investigating and refining existing surface treatments, as well as developing new approaches that can further improve osseointegration and reduce the risks of long-term complications. Continuous research in this area is essential to advance the field of implant dentistry and offer patients increasingly safe and effective treatment options.

CONFLICT OF INTERESTS

The authors declare they do not have any conflict of interest.

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