

Review Article

A Review on Biocompatibility Characteristics of Dental Implant's Titanium Surface Treatment Methods, Focusing on SLA and SLActive Procedures

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Abstract

The implant's metal base is not considered a foreign body when placed inside the jawbone and is compatible with the patient's jaw environment. This is due to its non-magnetic properties and high resistance to oxygen, acidic compounds, and salt. The implant's structure and the surface will also affect the interaction between the metal and living tissues. One of the main reasons for the implant's surface changes is the reduction of coalescing time and their integration with the jawbone. Since strong bone formation is crucial in dental implants treatment, with this operation, the bone formation in the pores of the fixture is done better, and the fixture fuses more to the bone. Implant surface coating increases bone deposition on the implant, which includes: mechanical changes (machining or sandblasting), chemical changes (acid pickling), electrochemical changes (anodic oxidation), vacuum changes, and heat or laser treatments. These changes control the growth and metabolic activities of bone cells. In this study, a review of various implant treatment methods, including sandblasting (SLA) and sandblasting with acid washing (SLActive), has been performed. Finally, it was concluded that SLA, SLActive, and HA surface treatment methods bind to the patient's jawbone faster than other methods in post-surgery weeks. In the meantime, the adsorption rate of the implant to the bone in the SLActive process compared to the SLA method increases by about 20 to 22% in the period of two to eight weeks after surgery, which is due to the integration speed of this method.

Keywords: Implant Prosthesis, Implant Titanium Surface Treatment, SLA, SLActive.

1. Introduction

A prosthesis is an artificial organ or limb that replaces a lost one in the body. The dental prosthesis also means artificial teeth or tooth replacement [1]. Different types of dental prostheses include: removable dentures, fixed dentures, and dental implants, and each of them has different types [2]. An implant is a set of surgically fixed components inside the jaw, and a denture is placed on it, so it gets a natural tooth's shape. Implant placement in the jaw consists of four parts: implant, abutment, abutment screw and crown. The implant base, or so-called fixture, is placed in the upper or lower jawbone and will act as the tooth's artificial root [3]. After implementing the fixture, a cover screw is set to prevent saliva, blood, or any infection and bacteria from entering the implant [4]. This screw is removed after placing the abutment. An essential procedure in the human body is the formation and integration of new bone. Integration is an important step in the dental implant replacement process [5]. The fixture, placed under the gum tissue inside the jawbone to act as the root of the natural tooth, coalesces due to its integration with the body. In fact, the body experiences the same condition as its repairing a broken bone.

Integrity is the body's natural response to implant positioning. Integration is a procedure that allows the implant to become a permanent part of the jaw [6,7]. Due to its non-magnetic properties and high resistance to oxygen, acidic compounds and salt, this metal base is not considered as a foreign object inside the jawbone and is compatible with the patient's dental environment.

Early implants include stainless steel implants that were compatible with bones, but they did not integrate and therefore had to be removed after a while due to looseness or corrosion and wear [8]. Today, implants are made of a titanium base or sometimes zirconia, which does not cause allergies due to its compatibility with the dental environment. Implant surgery is performed in three ways: normal surgery, immediate surgery, and no surgery in the jaw. In the conventional dental implant procedure, the minimum time to complete the implant course, including surgery and permanent crown placement, is about five months in the case of the mandible and approximately six months in the maxilla. In this method, two surgeries with a time interval of 3 to 6 months are required. In the immediate implant procedure, which is rarely used, the dentist can perform all the implant steps in one session. This can be done in special time conditions, higher cost, and good bone conditions of the patient, which, of course, will increase the risk of treatment failure 20 percentage [9,10].

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In the third method, which is known as flapless implant surgery, first by using oral scan images, the patient's jaw is simulated in the software, and the most appropriate position for implant placement is determined by knowing the patient's jaw type and sinus and nerve location. Then a piece is designed that will be used as a surgical guide or navigation. According to the pictures taken, this piece identifies the design and places that the fixture needs to be implanted and drilled.

The navigation is fixed inside the patient's mouth, and the dentist begins surgery. In this method, the fixture's location is punched with high accuracy to its diameter [11]. In general, dental implant surgery has a specific age range of 15 years old in women and 18 years old in men, when the jaw is fully developed. When there is enough bone in the jaw to hold the fixture well, surgery is ready for the first stage, including implant placement.

A small slit is made in the gum (where the fixture is to be placed). Then, a hole is made with a special drill, and the fixture is placed with its cover screw, and the gum is sutured. After a period of 4 to 7 months, the bone and the fixture are combined, and integration is made between them; in other words, they are welded. After the recovery period of the first surgery, it is time for the second surgery [12].

A new slit is made in the gum to expose the implant's head. After the appearance of the implant's crown, a collar, or so-called healing cap (a round piece of metal that holds the gum away from the fixture head) is screwed into the upper part of the fixture to help the repairing of tissues around the gums. Collar stays on the fixture for 10 to 14 days [12,13]. After the gingival tissue around the healing cap was repaired, the healing cap is removed. Then the impression coping is closed on the fixture to be molded. Finally, the impression coping is opened, and the abutment is screwed firmly onto the fixture.

After connecting the abutment to the fixture, the temporary crown will be placed on the abutment. In some cases, after the fixture head's appearing in the second surgery, the temporary abutment and the tooth's crown can be implanted simultaneously, and a healing cap is no longer required. The temporary crown will stay for 4 to 6 weeks [14].

The surrounding gums heal and will become like the gums around the normal teeth. The temporary crown is made of softer materials comparing to the permanent crown.

Softer materials help protect the implant from chewing pressure and give the jawbone a chance to become stronger and stronger gradually [15]. Once the temporary crown is in the mouth, the permanent crown is molded in the laboratory, and finally, after three weeks, the permanent crown will be implanted. With the new advances in science and technology, new methods have replaced the use of artificial teeth. In addition to maintaining the teeth' beauty, they are a good alternative to solve artificial

teeth problems in the past. In fact, dental implants are stabilizers that can replace the root of a lost natural tooth.

The bone around the implant plays a key role in supporting and maintaining the implant's stability, and its gradual loss reduces its stability [16,17].

Research has shown that maximal bone resorption can be minimized by increasing the level of contact between the bone and the implant [17].

Fortunately, today, with the help of new artificial dentistry methods, dental problems have been solved more appropriately.

Dental implants are also one of the latest dentistry advances that can restore lost teeth in a guaranteed way. Dental implants are considered an effective and safe method with a higher score than conventional dental prostheses, both in terms of functionality and predictability [18]. Dr. Branmark first used titanium metal dental implants in 1965 as a material with biocompatibility and integrity in the human mouth [19].

Since then, many types of research and studies in the world in this field was formed. Implants have been developed in Iran since the 1980s due to its need after the Iran-Iraq War and veterans and wounded need to replace missing teeth. Due to the reception of its performance today, its significant growth and development can be seen in Iran's medical and scientific communities [20].

This growing growth is due to the fact that patients have gradually come to accept that with the use of dental implants, not only the lost teeth are replaced in the best way, but also problems such as improper chewing, poor speech, and even lack of self-confidence, Which is often seen in treatments such as complete or partial prosthesis, are adequately compensated [20,21].

On the other hand, it must be acknowledged that this growth for implant placement has led to an increasing number of dentists who wish to use this method in a private clinic. In the last 20 years, the number of dental implant treatments worldwide has reached more than one million implants each year. Numerous organizations have provided guidelines for standardizing the materials used in implant structures [22]. Numerous factors can affect a successful dental implant treatment. One of the most important factors is the effect of the implant's geometric design on the implant-bone joint strength and the mechanical properties of the material used in the implant construction.

Today, many types of research are being done to improve the mechanical properties of nanostructured implants. Understanding the implants' structure and loading systems in the oral environment is necessary to study the factors affecting the implants' strength from a geometric design and material selection perspective [23,24].

In general, fixed methods in dental implants have higher performance, durability, acceptability, and, of

course, cost comparing to mobile methods. Meanwhile, the dental implant prosthesis method's success is 97% compared to all fixed and mobile dental methods [25].

In 3% of cases, instead of a bone graft, the gingival tissue sticks to the fixture or the implant screw loosens, or the surface of the fixture gets corrosion, erosion, or fatigue, in which the dental implant must be removed and the new implant re-implanted [26]. The cause of this phenomenon is damage to the dental implant, which causes the implant to shake. Another case that may happen is that the patient's body reacts to the foreign object and rejects it, which is a very rare phenomenon. In this case, the implant operation can be repeated after two months, and the body usually accepts the implant transplant for the second time. To this date, many studies have been conducted in various fields of implants, including oral surgery, biomechanics, biomaterials, immunology and microbiology, dental neuroscience, post-implant surgery care, etc [27,28].

According to this study's purpose, different researches on dental implants from a biomechanical and biocompatibility perspective have been reviewed. In some cases, failure occurs at the junction of the implant to the abutment or at the implant's junction to the bone, which increases the need for studying mechanical loads [29].

2. Implant Surface Treatment Process

Titanium is a non-precious metal, and its high cost is due to the various stages of production, including surface treatment. First, the titanium reaches the desired grade by heating, or its alloy is prepared first, and then wires are made from it with the

required diameters, which are equal to the diameter of the implants that must be produced [30]. After this step, the wires are divided into desired lengths, which determine the dental implant length. From this point on, implant production costs increase because the cut parts must be connected to the CNC machine one by one, and their outer and inner surface must be turned [31].

After this step, due to the implant's smooth surface, they must be sandblasted using aluminum oxide. For better quality, the used powder enters the sandblasting tank from one side and is removed from the other side by suction after the operation.

The structure and surface of different types of fixtures will affect the interaction between metal and living tissues. One of the main reasons for the change in the implants' surface is the reduction of their Osseointegration time.

The fixture surface is the only part in contact with the body's biological environment (bone) and directly affects the bone response [32].

A particular surface layer on the fixture is required to increase the bone and fixture's functional area, so eventually, the stress and forces applied to the implant can be easily transferred to the bone [32].

This surface coating increases bone deposition on the implant, which includes mechanical changes (machining or sandblasting), chemical changes (pickling), electrochemical changes (Anodic oxidation), vacuum changes, heat treatments, and Or laser treatments [33]. These changes control the growth and metabolic activity of osteoblast cells. Surface roughness will increase (TGF-B), a growth hormone, and directly improve integration. Fig. 1. shows an example of a blasted sand implant surface up to a focus of five thousand times [33].

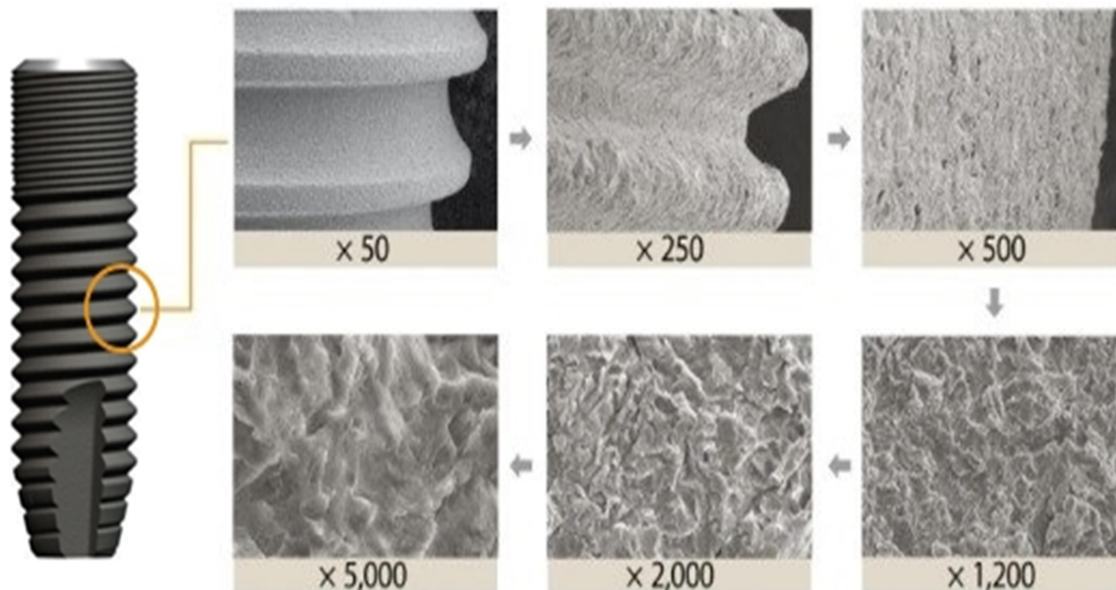


Fig. 1. An example of a sandblasted implant surface [33]

Since strong bone formation is crucial in the treatment of dental implants; with this operation, the construction of bone in the pores of the fixture is better, and the fixture fuses more to the bone, which, as mentioned earlier, is called the integration phenomenon [34].

In integrity, the engagement is so great that the titanium appears to be entirely attached to the bone. After the time of attachment of the fixture to the bone, about 400 Newton's are needed to separate the implant from the bone. Various methods for surface treatment have been tested to increase the implant's fusion and integration into the jawbone in recent decades. Among these, some of the most famous and practical examples are discussed below [35].

2.1. Implant Surface Treatment by SLA and SLActive Methods

The SLA surface is derived from Sandblasted Long grit Acid etched, which is a method for sandblasting the implants. The letter S stands for Sand Blast, which here means spraying alumina particles. The letter L stands for large grit, and the letter A stands for acid-etched, which means acid wash. In this method, the titanium is sent for acid washing after sandblasting. Acid washing is performed by hydrochloric acid and sulfuric acid. The result is ideal surface roughness, better bonding of the fixture to the bone, and material loss on the fixture surface. At this stage, in order not to damage the inside of the fixture, its inner surface must be covered with Teflon, which requires a lot of time and money [36,37]. In other words, the surface of the sandblasted titanium implant has increased roughness and surface irregularities.

Also, the subsequent acid etching procedure ensures that the roughness of the surface is increased on both macro as well as micro level. Also, the particle size plays an important role during sandblasting [38]. The SLA-treated surface results in increased bone-to-implant contact due to an elevated level of osteoblast proliferation and cellular adhesion at the surface of the dental implant. These factors play a significant role in the process of osseointegration. The rough surface has more surface energy when compared to a smooth surface. Thus, the SLA technique can accelerate as well as improve the process of osseointegration. This ultimately improves the mechanical stability of the implant. Thus, the strengthened bone-to-implant bond can sufficiently withstand the shearing forces as well as torsional forces, lengthening the longevity of the implant in the mouth. The techniques of early loading of implants like immediate implant placement or immediate-delayed implant placement have shown to be more successful when using an

SLA-treated implant [39]. Thus, the benefits of sandblasting, large grit, acid etching (SLA) technique for titanium dental implants are many, the most important being the increased bone formation on the implant surface, improvement in osseointegration and its clinical efficacy in early or immediate implant loading. In addition to this method, there is another method called SLActive, which is abbreviated to sandblasted Long grit acid-etched Active. In the SLActive surface treatment method, bone formation is accelerated more and bone connection with the implant (Bone Implant Contact) gets better by increasing mineralization [40]. Dental implants with SLA and SLActive coatings are produced in the same way. The only difference is in the last stage of their production process. SLA implants are dried and ready for use after sandblasting and acid etching. Whereas SLActive implants are stored under the protection of 0.9% N_2 gas and/or in a solution of NaCl (saline), which is isotonic (meaning that it neither causes the cells to swell nor shrink) after etching. The key to improving a dental implant is how the blood clot forms on the implant [41].

As shown in Fig. 2. Features such as high chemical activity and hydrophilicity of the SLActive surface provide a wider area for blood protein uptake and fibrin network formation. This is an ideal position to form a blood clot and start the healing process. This technology reduces the SLA recovery time from six to eight weeks to three to four weeks. Failure of a dental implant usually occurs in the early stages of recovery, the first two to four weeks after implant placement. SLActive surface can also accelerate osteoporosis, bone repair, and bone grafting in cases of osteoporosis [42,43].

As reported, both the SLA (Sandblasted with Long grit corundum followed by Acid etching with Sulphuric and Hydrochloric acid) surface, introduced in 1997, and the SLActive surface, introduced in 2005, have a strong track record of clinical success. Both SLA and SLActive surfaces are made of cold worked titanium (grade 2) and are produced with the same sandblasting and acid-etching technique, but they differ in that the SLActive implants are rinsed under nitrogen protection to prevent exposure to air and are then stored in a sealed glass tube containing isotonic NaCl solution as opposed to dry storage. As described by Rupp et al., [44] this contamination-reducing storage method allows the SLActive implant to have a higher surface energy and be more hydrophilic in nature than the SLA implant. Higher surface energy and hydrophilicity are important surface characteristics that facilitate a stronger cell reaction and bone tissue response in the early phase of bone healing [45].

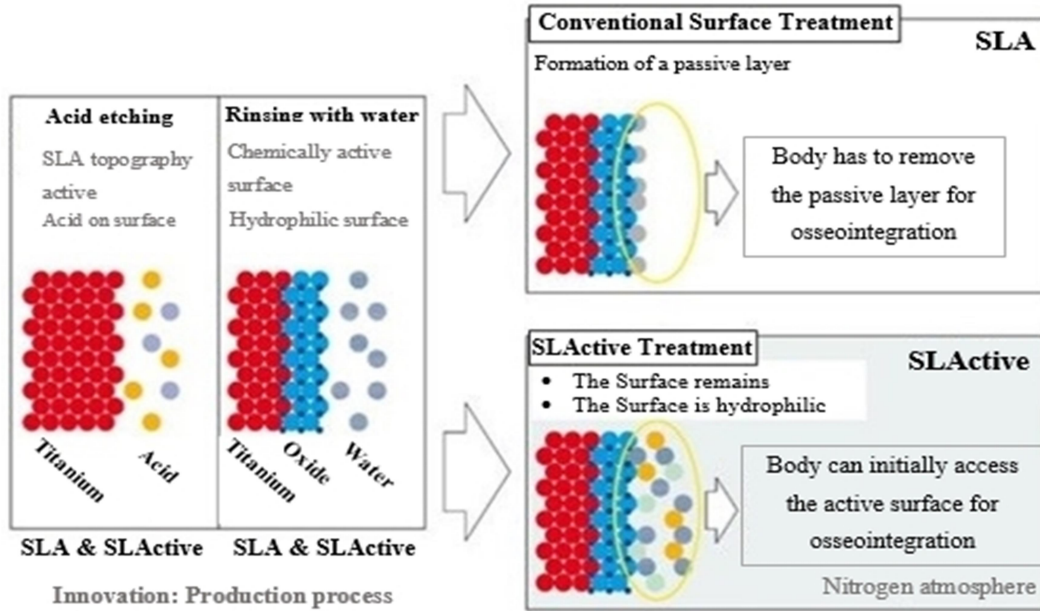


Fig. 2. Production process of SLA and SLA surfaces. The yellow and green circles represent different species in the sterile solution in which the SLActive surface is stored [42].

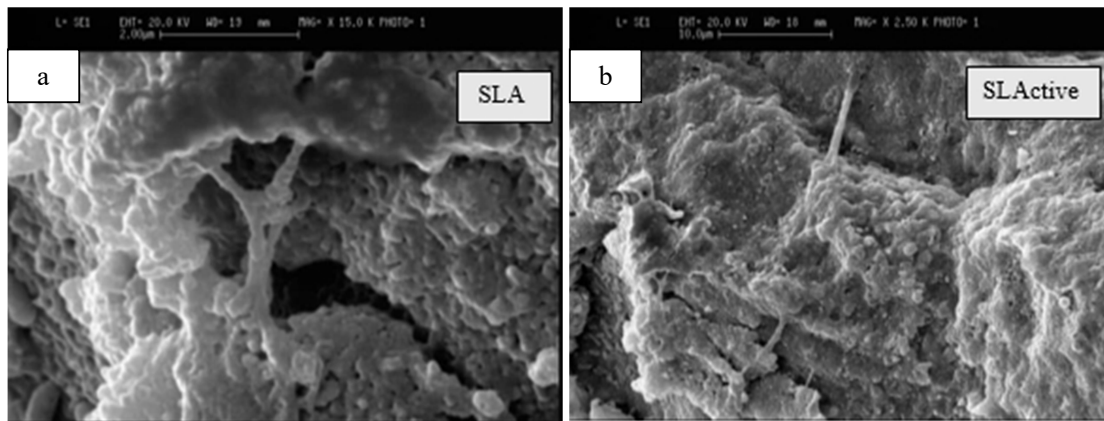


Fig. 3. Surface treatment by a) SLA, b) SLActive [50].

Biological responses to SLActive surfaces have been characterized in cell experiments. It has been claimed that the hydrophilic SLActive surface beneficially influences cell adhesion, stimulates maturation of osteogenic cells, promotes a bone forming microenvironment, and fosters neoangiogenesis [46]. Schwarz et al. [47] have studied the histological differences in osseointegration of SLActive implants compared to SLA implants in a dog model. For SLActive implants, a higher affinity of the initial blood clot to the implant surface, an enhanced neoangiogenesis, increased bone-to-implant contact, and greater bone density were described within the first 2 weeks of bone healing [47]. Buser et al [48]. Confirmed a higher BIC for SLActive compared to SLA implants 2 and 4 weeks after implant placement but not after

8 weeks, strengthening the theory that hydrophilic surfaces are beneficial in early phases of osseointegration. Accordingly, significantly greater removal torque values were measured for SLActive implants as opposed to SLA implants, suggesting a superior bone anchorage in early implant healing [49]. In Fig. 3., samples of SEM images corresponding to implant surfaces treatment by SLA and SLActive methods are shown. As it can be seen, osseointegration and bone purchasing properties of the SLActive sample are stronger and better and black areas of the image which indicate Lack of osseointegration are smaller than those in the SLA method.. Osseointegration of dental implants was previously characterized as a structural and functional connection between newly formed bone and the implant surface, which became a synonym

for the biomechanical concept of secondary stability [50]. Osseointegration comprises a cascade of complex physiological mechanisms similar to direct fracture healing. The drilling of an implant cavity resembles a traumatic insult to bony tissue leading to distinct phases of wound healing [51]. Initially, mechanisms of cellular and plasmatic hemostasis lead to fibrin polymerization and the formation of a blood clot, which serves as a matrix for neoangiogenesis, extracellular matrix deposition, and invasion of bone forming cells [52, 53]. New bone generates from the borders of the drill hole (distance osteogenesis) or by osteogenic cells on the surface of the implant (contact osteogenesis). In distance osteogenesis, osteoblasts migrate to the surface of the implant cavity, differentiate, and lead to the formation of new bone. Thus, bone grows in an appositional manner towards the implant. In contact osteogenesis, osteogenic cells migrate directly onto the implant surface and generate de novo bone [52]. The secondary stability of a dental implant largely depends on the degree of new bone formation at the bone-to-implant interface [54]. According to Wolff's Law, the subsequent phase of load oriented bone remodeling leads to a replacement of primary woven bone to realigned lamellar bone in order to optimize the absorption of occlusal load [52, 53] and to transmit the mechanical stimuli to the adjacent bone [53]. At the end of the remodeling phase, about 60–70% of the implant surface is covered by bone [55]. This phenomenon has been termed bone-to-implant contact and is widely used in research to measure the degree of osseointegration [56]. According to the concept of mechanotransduction, bone remodeling continues lifelong [53]. Research efforts have been focused on designing novel topographies of implant surfaces to optimize osteoblastic migration, adhesion, proliferation, and differentiation.

2.3. Implant Surface Treatment by RBM Method

The RBM method is derived from resorbable blast media, which means that the sandblasting operation is performed in a hot and pressurized environment that increases the impact of this operation and leaves a less sandblasting material residue on the fixture. The RBM technique was similar to the SLA technique, except that in this technique, hydroxyapatite derived from beta-tri calcium pyrophosphate and calcium pyrophosphate is sprayed on the surface of the fixture under extreme pressure [56,58]. RBM (Resorbable Blast Media) surface treatment is designed to roughen the implant surface without leaving the residual embedded blast particles or debris in the treated substrate. It resolves completely the issues which can occur with SLA, or other surface treatment and deliver impeccable results. The rough surface of the implant is crucial to achieving optimal osseointegration. It increases the success rate of Bone to Implant Contact (BIC),

the healing process and tissue growth around the implant while eliminating the unwanted possibilities of post-surgery infections. RBM plays the main role in roughened implant surfaces and provides increased retention strength. The topography, down to the micrometer, affects the attachment and the growth of new bone cells, more rapidly and more stable at the same time. The material used for the RBM process is Calcium Phosphate. This is a highly resorbable and biocompatible material. Usage of Calcium Phosphate as a blasting material eliminates the need for using strong acids for the removal of blasting material remnants. Such surface technology gives excellent results, reaching the optimal osseointegration and complete healing process with almost zero chance of abruption. Even the particles that are left are fully biocompatible, promote earlier bone in-growth and provide greater implant stability during the first critical weeks after placement [59,60].

2.4. Implant Surface Treatment by CA Method Taken From SA

To prepare the CA surface, a fixture is placed in a calcium chloride solution (CaCl₂) to activate the titanium surface after obtaining the sandblasted (SA) surface. This surface can absorb the blood and its proteins, which increases the attachment of bone cells and thus increases their desire for integration, proliferation, and ossification [61,62].

2.5. Implant surface treatment by HA method

The HA surface, derived from Hydroxyapatite-SA, is ideal for implant placement in weak, low-density bones, as well as immediate implantation in an extracted tooth cavity. Hydroxyapatite is a material with the ability to make a strong connection between bone and implant. The HA surface is a coating of hydroxyapatite with a thickness of 30 to 60 μm on the RBM surface. The advantages of this surface are its better biocompatibility as well as increased ossification compared to RBM. Hydroxyapatite is generally a layer of calcium and phosphate on an implant that can be applied to metal in various ways. Calcium phosphate and hydroxyapatite materials are used because of their similarity in chemical composition to bone tissue, their biocompatibility, not causing inflammatory reactions, and their tendency to produce bone cells. The BA level, which stands for Bio-Hydroxyapatite, is obtained by covering thin layers of hydroxyapatite at 10 nm or less on the blasted sand surface. This method increases ossification and hence increases the initial stability of the implant. This method improves ossification and thus increases the initial stability of the implant. Another advantage of this method is the adsorption and removal of hydroxyapatite coating and it's non-scaling in the long term [63,64].

2.6. Implant surface treatment by plasma spray method (TPS)

TPS, which stands for Titanium Plasma Spray, allows the implant to have a coating with approximately 40-50 microns thickness. This process is performed by injecting a titanium powder form into a plasma torch at very high temperatures. These particles eventually condense and attach to the surface of an implant, which stimulates osteogenic cells. The sandblasted and acid-etched surface of titanium plasma-sprayed implants has been compared in several animal studies. This study's radiological results showed that SLA implants performed better than TPS implants and that SLA surface increased bone contact in the early stages than TPS implants [65,66]. Plasma spraying technique generally involves thick layer of depositions, such as hydroxyapatite (HA) and titanium (Ti). The coating process includes spraying thermally melted materials on the implant substrates. A combination of HA coating on Ti alloys substrate has received many attentions due to their attractive properties such as good biocompatibility and mechanical properties [67]. The plasma spray substantially increased the surface area of the implants by increasing their surface roughness [68]. The potential of spray plasma spray coatings to enhance the mechanical behavior has been addressed by many studies [69, 70, 71]. Several techniques were proposed to adhere HA to titanium implants [69, 70, 72], but only the plasma spraying coating technique has been successfully used on commercial implants [72]. This deposition method is advantageous in that the temperature range achieved (the plasma core temperatures are between 8000 and 14000 K, while the plume can be down to about 2000 K at conventional spray distances) allows the coating of an extremely wide variety of materials with rapid deposition rate

[73,74]. Thermal spray processes to be reviewed are categorized as cold spray, combustion spray, electric arc spray, and plasma spray. Combustion spray methods discussed are high-velocity oxy-fuel spray and detonation gun spraying. Likewise, pertinent plasma spray processes are direct current blown arc spray, radio frequency inductively coupled spray, and plasma transferred wire arc spray. Cold spray involves the release of a high pressure gas through a convergent-divergent Laval nozzle, creating a supersonic stream which is used to accelerate coating powder at the work piece [75]. As the particles are not molten or semi molten, cold spray adhesion can be relatively high. High kinetic energy results in cleaning (removal of oxidation) and activation of the substrate. Each subsequent layer of coating sprayed further bonds the previous layer allowing excellent metallurgical bonding of the coating and substrate. Detonation gun spraying [76] has also been used to deposit coating on bone implants.

3. Conclusions

An essential procedure in the human body is building new bone and integrating it. Integration or biocompatibility is an important step in the dental implant placement process. The fixture, which is placed under the gum tissue inside the jawbone, acts as the root of a natural tooth and coalesces, due to its integrity and viability with the body. According to the cases previously studied and by reviewing the methods that have been used to prepare the surface of the titanium implant, all methods for surface treatment are shown in Fig. 4., based on the percentage of bone attachment to the implant (Bone Implant Contact), which is the biocompatibility of the titanium implant' surface with the patient's jawbone; in the weeks after implant placement I the patient's gum.

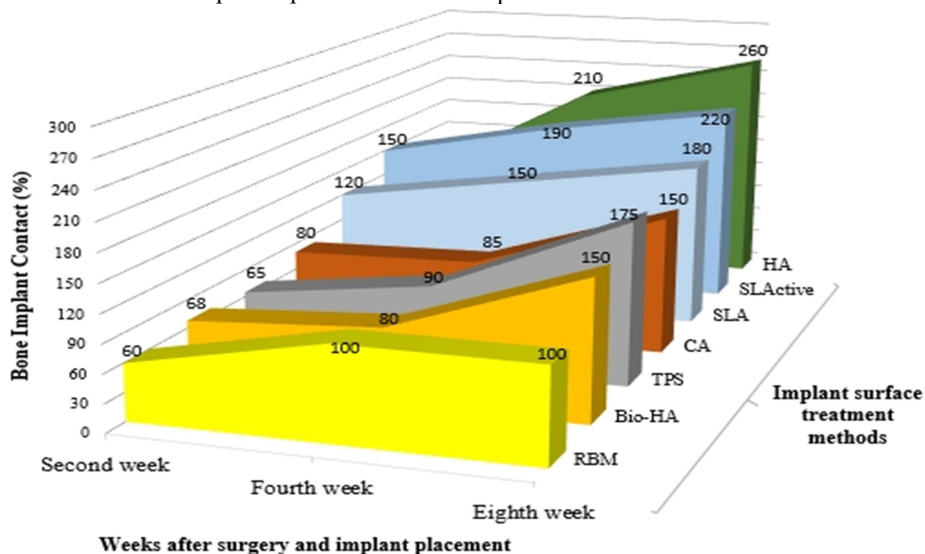


Fig.4. The bone tendency to attach in the weeks from implant placement percentage

As can be seen, the SLA, SLActive, and HA surface treatment methods bind to the patient's jawbone more rapidly after surgery than other surface treatment methods. Meanwhile, the SLActive surface treatment method is more appropriate due to its integration speed with the jawbone in the first two weeks, where the risk of surgery and implant loosening in the patient's mouth is higher. SLA and HA surface treatment methods are considered after the SLActive procedure. The bone's absorption rate of titanium implants in the SLActive procedure increases by about 20 to 22% in the two to eight weeks after surgery compared to the SLA method due to the high rate of integration and biocompatibility. However, after a critical period of two weeks and four weeks after surgery, it is the HA method that merges the titanium implant's surface to the jawbone more quickly. CA, TPS, Bio-HA, and RBM surface treatment methods are ranked next in terms of biocompatibility and the implant surface's attachment speed with the tooth.

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