Investigation of Dental Implant's Titanium Surface Hydrophilicity Effect on Biocompatibility and Osseointegration

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Abstract. With the expansion of studies and research to recognize the mouth's biocompatibility properties, the components and types of implants have been examined in terms of different surfaces with respect to one another. The bone around the implant plays a crucial role in supporting and maintaining the stability of the implant after implantation in the gums, and its gradual loss will reduce the biocompatibility and, ultimately, the strength of the bond between the implant fixture surface and the gingival bone. In this study, the 3A implant characteristics have been investigated from the perspective of hydrophilicity, biocompatibility, and osseointegration of this implant's surface. So that the viability of the noted fixture's titanium surface, when the hydrophilicity has been established in it, should be examined with the time when it lacks the hydrophilicity. Finally, it was found that the adsorption rate of the implant's titanium surface to the gingival bone decreased from about eight weeks to about Four weeks, when the implant surface was hydrophilic compared to the time it lacked this property. This result indicates an acceleration in the process of adaptation of the 3A implant's titanium surface when it has biocompatibility.

Abbreviations

3A: Anodized **-** Acid etched – Active
SL2A (SLA): Sandblasted Large grit Acid etched
SL3A (SLActive): Sandblasted Large grit Acid etched Active
SEM: Scanning Electron Microscopy
CNC: Computer Numerical Control

1. Introduction

The complication of tooth loss and the many problems it causes for oral health also affect the appearance of beauty and smile. Until recent years, the only way to treat tooth loss was by using artificial teeth. But due to its unpleasant and unnatural appearance and other problems, it caused dissatisfaction among many patients [1]. Therefore, new methods of filling dental gaps are an essential step. With the advancement of science and technology, new methods have replaced the use of artificial teeth. In addition to maintaining the teeth's beauty, these techniques are an excellent alternative to solve the problems of artificial teeth in the past [2]. In fact, dental implants are stabilizers used as a substitute for the root of a lost natural tooth. The bone around the implant plays a crucial role in supporting and maintaining the implant's stability, and its gradual loss reduces its strength. Research has shown that by increasing the contact area between the bone and the implant, jaw bone resorption can be minimized [3]. The titanium base of the implant, or so-called fixture, is placed in the upper or lower jawbone and will act as the artificial root for the tooth. Immediately after implant placement, a cover screw is placed on it to prevent saliva, blood, or any other contaminants and bacteria from entering the implant. The screw is removed when the abutment is placed. Some patients have retained their titanium dental implants for more than 30 years [4]. Although there are no reports of the body reacting to titanium implants, some people may be allergic to other metals that come in contact with their bodies or may have concerns about the presence of metal in their bodies. Titanium and zirconia are biocompatible materials, and the body does not reject them, but each of these materials has its own characteristics compared to the other. Due to growing concerns about mercury in some amalgam fillings, some patients prefer to have no metal or metal fillings inside their mouths. To address this concern and find the right solution for these people, extensive research has been done on metal-free implants that have led to the development of zirconia implants [5]. But still, titanium implants are much more useful. An essential procedure in the human body is osseointegration. Integrity is an important step in the dental implant placement process. The fixture, placed under the gum tissue inside the jawbone to act as the root of a natural tooth, coalesce due to its integration with the body. In fact, the body experiences the same state as when repairing a broken bone. Integrity is the body's natural response to implant placement. Integration is a procedure that allows the implant to become a permanent part of the jaw [6]. Early implants include stainless steel implants that were compatible with the body's bone but did not integrate, and as a result, after a while, due to looseness or corrosion and fretting, they had to be removed. Today, implants are made of a titanium base or sometimes zirconia, which does not cause allergies due to its compatibility with the dental environment [7]. The micro-threads in the upper part of the fixture help the fixture penetrate and integrate better with the bone. In fact, these micro-screws in the fixture's neck area will organize the stress transferred to the gingival bone and reduce bone loss in the gingival crest area, ultimately leading to better integration of the fixture with the gums in this sensitive area. Implant design provides initial stability in the jaw [8]. It is effective in the fixture contact with the bone and the location of this contact for efficient transfer of forces to the bone. The success rate of surface treatment is directly related to the various fixture body designs. The threads are designed to maximize the fixture's initial contact with the bone, increase the contact surface, and facilitate the release of forces and stress distribution in the fixture's contact area to the bone [9]. The effective contact surface changes along the fixtures by three geometric properties: the slope of the thread, the shape of the thread, and the thread depth. As mentioned, fortunately, today, with the help of new methods in artificial dentistry, 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 [10]. Dental implants are considered an effective and safe method with a higher score than conventional dental prostheses in both functionality and predictability. Numerous factors can affect a successful surface treatment with a dental implant, the most important of which is the hydrophilicity and biocompatibility of the implant titanium surface on the joint's strength between the implant and the gingival bone [11]. This is important because increasing the implant fixture surface's quality and making it more ready when implant placement in the gums will increase the percentage of connection and osseointegration of the fixture with the gums and jawbone [12]. The term osseointegration is empirically described as the close contact between bone and implant in histological sections, and in clinical terms, as the stability of an implant in the bone. This biological stability is a prerequisite for dental implant prostheses and their long-term success [13]. Lack of osseointegration leads to implant failure or loosening, which can be related to various factors during and after implant surface treatment. In this regard, the researchers used various methods to increase the fixture surface pores and finally make this surface more active to connect better for osseointegration with the gums [14]. The difference between each of these methods is in the final surface treatment. Most of these methods are performed in the same way at the initial stages of surface treatment, such as sandblasting, etc. [15]. Methods such as RBM and SA were used in the past; But other new methods such as HA and SLActive, are receiving more attention today due to their higher speed and attachment percentage to gingival bone [16]. Today, a lot of research is being done to improve the surface treatment properties of titanium implants. In this regard, Dorin Kasht Mana Company in Iran began its work to optimize, update, and improve dental implants' production quality. In this study, the biocompatibility, hydrophilicity, and osseointegration properties of 3A implants have been investigated.

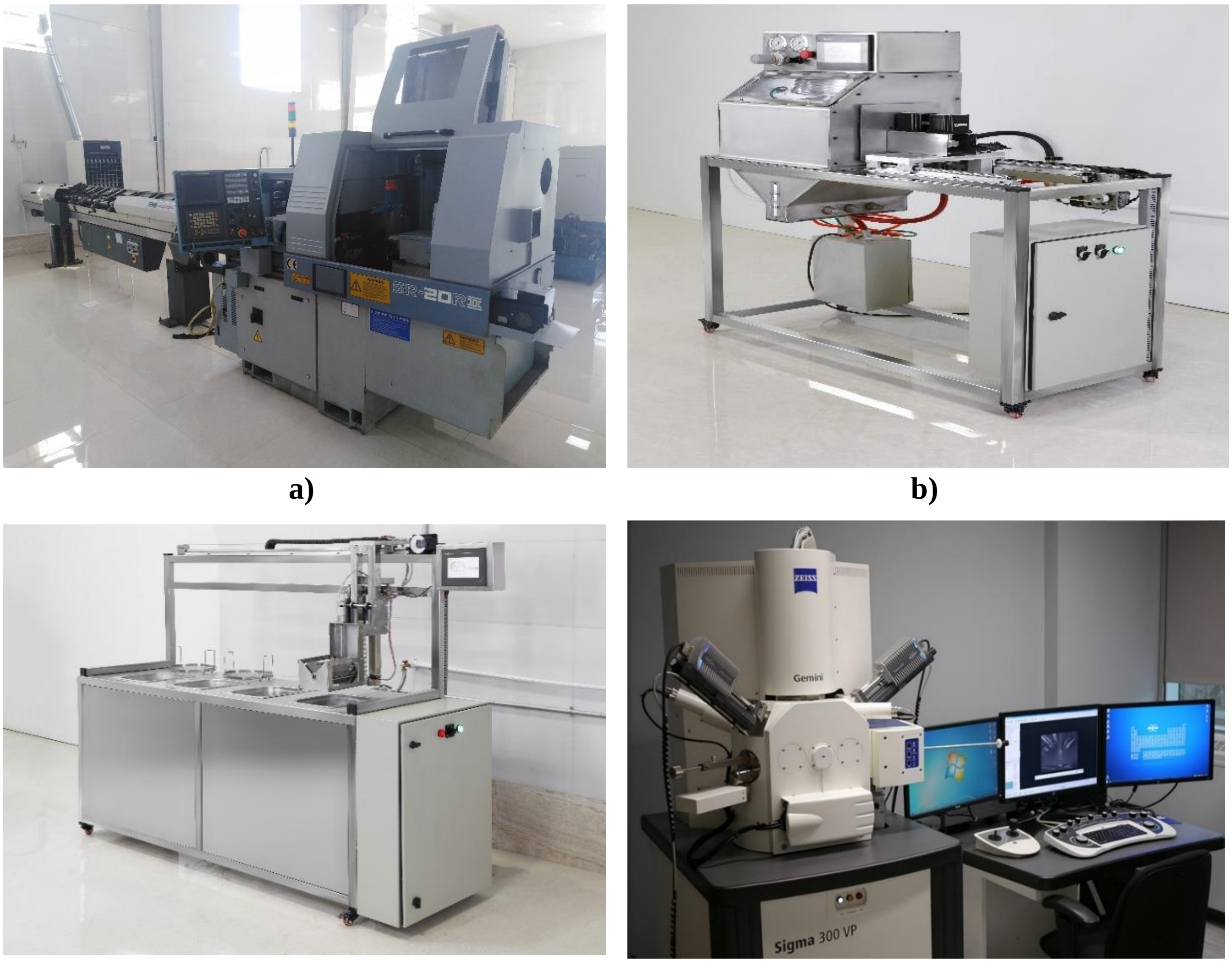
2. Materials and research method

In this study, the surface of the 3A implant is investigated. The 3A implant shown in figure (1) is used with two methods of surface treatment. One of these methods is the SLA surface treatment method, derived from the phrase Sandblasted Long grit Acid etched, and the other is the SLActive surface treatment method, which is from Sandblasted Long grit Acid-etched Active. The difference between these two implant surface treatment methods lies in the last stage of their production process. SLA implants are dried and ready for use after sandblasting and acid etching and washing. While SLActive implants, after the acid etching and washing step, are kept under the protection conditions of N_2 gas and 0.9% solution of NaCl (saline solution), which is isotonic (meaning that it neither causes the cells to swell nor shrink).

a) b)

Fig.1. Implant fixture 3A a) before and b) after sandblasting operation and acid etching

First, titanium alloy (fifth grade) rebars are machined with a CNC machine (figure (2-a)). Then sandblasting operation will be performed. It should be noted that in performing the sandblasting step, the particles of different materials, such as aluminum oxide or titanium oxide or soluble substances such as hydroxyapatite, sulfate, or phosphate compounds are applied to the fixture’s surface with Pressure, causing the implant surface to become porous. The size and depth of the cavities on the implant surface are proportional to the sandblast particle's diameter and stiffness, and spraying intensity. In this study, 150-micron particles of aluminum oxide were used and sprayed with 5 bar air pressure by two nozzles automatically on the implant's surface, which rotates axially at a speed of 50 rpm. The resulting surface also has 12 holes per square millimeter with an average depth of 4 microns, which is completely in line with the standard of implants with medium and not rough levels. Figure (2-b) shows the different views of a fully automatic and controllable sandblasting machine used for sandblasting operations in the present study. One of the essential things in using aluminum oxide for sandblasting is cleaning the implant surface from particles and particles of aluminum oxide left on the implant fixture's surface. This cleaning is done using a strict protocol and rinsing with an automatic rinsing machine and using cold and hot rinsing by creating expansion and contraction on the surface area. An image of the automatic washing machine is shown in figure (2-c). In order to study the surface of the implant more accurately on a micro and nanoscale and to analyze the hydrophilicity, bioavailability, and osseointegration properties of the 3A implant fixture surface with the gingival bone, advanced imaging methods have been used. In this regard, a scanning electron microscope (SEM) that can be magnified from 10 to 500,000 times be used to study topography, roughness, porosity, biocompatibility, and the degree of implant surface bonding with bone. The image of this device is shown in figure (2-d).



a) b) c) d)

Fig.2. the process of doing the work used in this research: a) Machining of implants with CNC machine. b) The fully automatic and controllable sandblasting. c) The automatic acid etching and washing machine d) Scanning electron microscope (SEM) equipment used in the present study.

3. Results

After observing the results of SEM, the surface properties of the 3A implant were examined. The results showed that the 3A implant surface, prepared using the SLA surface treatment method, was hydrophobic and not hydrophilic. While the images obtained from SEM for the titanium 3A implant fixture, which was prepared by the SLActive surface treatment method, show the existence of a suitable hydrophilic property on the surface of the implant fixture. Figure (3) shows the SEM images of the SLA (hydrophobic) surface treatment method for the titanium 3A implant fixture. As shown in Figure (3), the surface porosity and roughness of the non-hydrophilic SLA implant are low, and even its surface is hilly, which doesn’t allow hydrophilicity for the titanium surface of the implant fixture when placed inside the gingival bone. Due to the SLA method's lack of hydrophilicity, the implant fixture surface can not be well adapted to the surrounding gingival bone during implantation, bone attachment, and bone grafting. Figure (4) shows the SLActive surface treatment method's SEM images for the titanium 3A implant fixture. As can be seen, when the surface of the 3A implant is prepared by the SLActive method, the surface roughness and porosity are significantly increased, resulting in biocompatibility and osseointegration. In other words, the 3A implant fixture surface, with its better hydrophilicity, establishes a better bond with the gingival bone and, ultimately, a faster biocompatibility property in the first weeks after surface treatment.

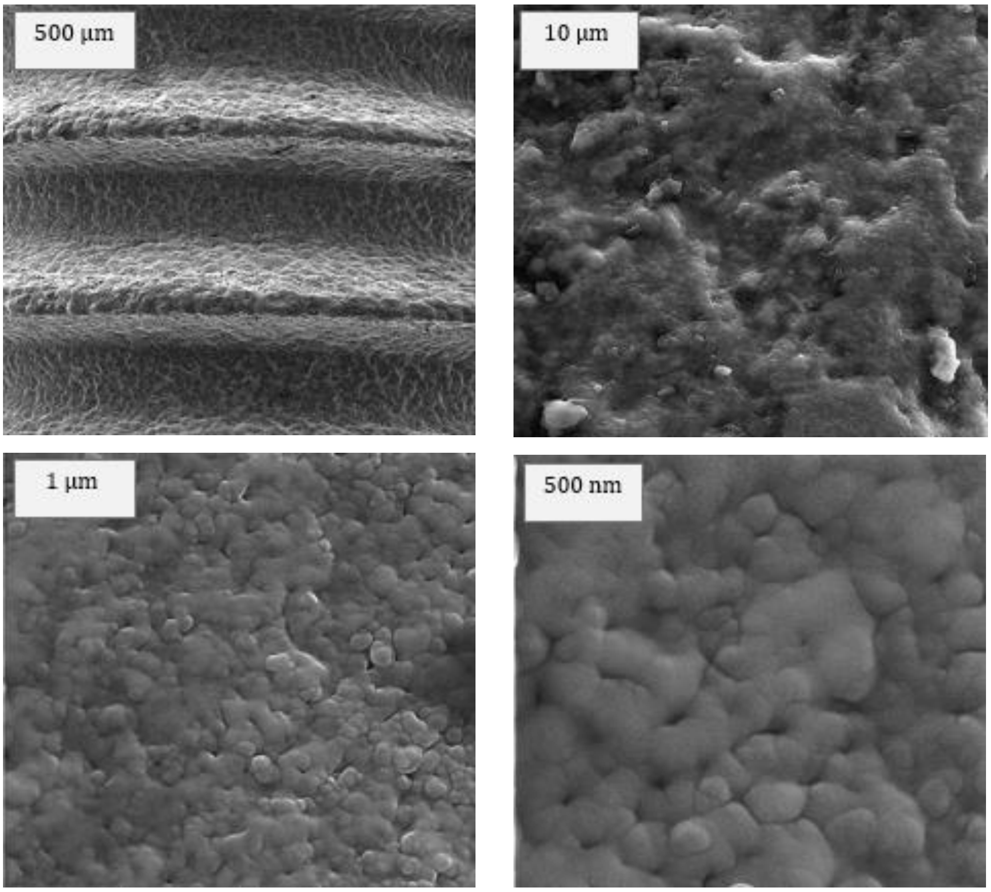


Fig.3. SEM images related to SLA surface treatment method for 3A titanium implant fixture

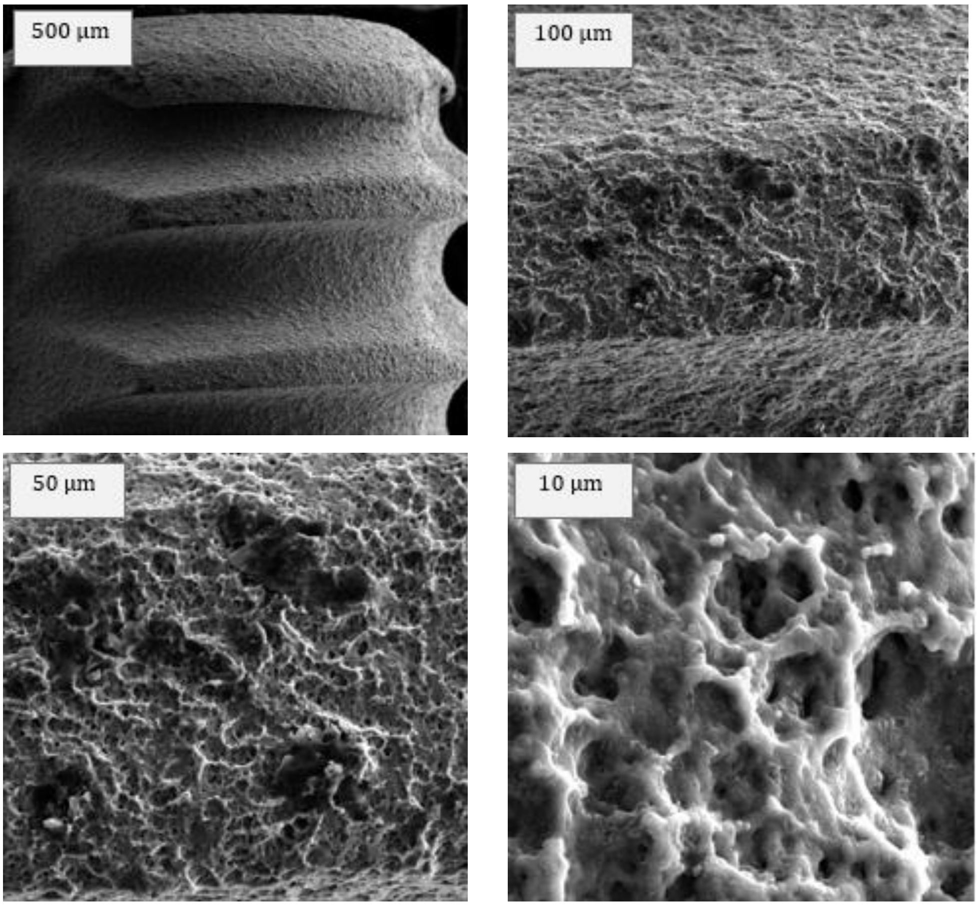


Fig.4. SEM images related to SLActive surface treatment method for 3A titanium implant fixture

The examination of the surface's topographic and chemical properties shows that materials with water-absorbing surfaces provide high-energy surfaces that can play a significant role in molecules, cells, and tissues' biological activities. The biological response largely depends on the surface free energy and its ability to absorb water, which is very important in the power of the implant's surface to access biological aqueous liquids during the early stages of the healing process. Surface energy and hydrophilicity in the initial phase of osseointegration alter the rate of protein absorption. In other words, all the proteins on the surface will change with the way water is absorbed, depending on the surface's characteristics. Hydrophilic and hydrophobic surfaces absorb different proteins. In fact, fewer proteins tend to adhere to hydrophobic surfaces, and their amount of stiffness and strength of adhesion is less compared to hydrophilic surfaces. On hydrophilic surfaces, proteins attach from their hydrophilic region to the surface with all water-protective layers. However, on most hydrophobic surfaces, proteins appear to adhere more to the surface without a water protective layer from the hydrophobic portions. The comparison results of SLA and SLActive methods, which are used in Dorin kasht mana Company for implant 3A, are shown in Figure (5). These results are comparable to those of similar studies such as Soylu et al [17]. In 2020, Soylu et al. Compared the SLA and SLActive methods. The results according to Figure (5) showed that the SLActive surface preparation method accelerates the bone graft between the implant surface and the endogenous bone for two to four weeks and forms a better bone graft. The results of this study on 3A implants show the same thing. With the difference that it shows better results in the weeks after surface treatment for both SLA and SLActive methods. So that osseointegration and treatment time for both methods improved by about one week compared to Soylu results.

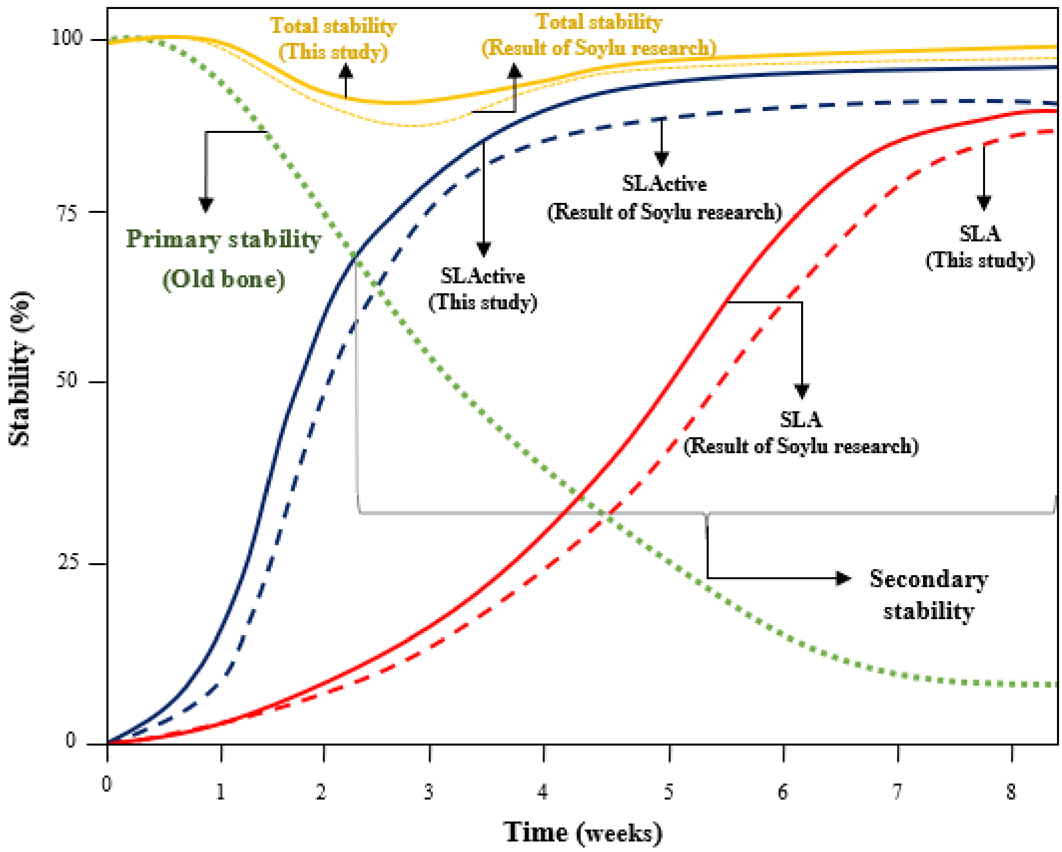


Fig.5. Comparison of the results of similar experiments such as Soylu with the results obtained from this study for both SLActive and SLActive surface treatment methods.

4. Discussion

In dental implants treatment, the formation of strong bone is crucial. Osseointegration is accelerated in the SLActive surface treatment method, and Bone Implant Contact (BIC) is performed better by increasing mineralization. Ultimately, this will increase and accelerate the titanium dental implant fixture's biocompatibility with the bone in the gums. In other words, by increasing the hydrophilicity of the fixture surface and increasing the osseointegration and biocompatibility of the 3A implant titanium surface with the gingival bone, the SLActive surface passes the initial recovery stages quickly and enters a stable phase. This reduces the risk of failure in the early stages of recovery after surface treatment with 3A implants and increases the dental implant's durability and compatibility. The reduction of recovery period from 6 to 8 weeks to 3 to 4 weeks in the SLActive method indicates this method's success due to the increase in hydrophilicity, and ultimately, the rise in biocompatibility and osseointegration of the titanium fixture surface of 3A dental implants. The results also show that with the increase of hydrophilicity in the implant surface treatment method, the improvement of surface treatment in the first 2 to 4 weeks after implant placement has grown and gained more speed. In fact, the hydrophilic surface of SLActive compared to the hydrophobic surface of SLA enhances bone formation and growth and increases the Bone Implant Contact and biocompatibility properties. The SLActive surface treatment method's high success rate has led to a success rate of 96.8%.

5. Conclusions

The porosity and roughness of the surface in non-hydrophilic implants is low and even the surface is hilly, which in no way allows hydrophilicity for the titanium surface of the implant fixture when placed inside the gingival bone. Due to its lack of hydrophilicity, the implant fixture surface cannot be well adapted by being inserted into the gums connection and bone grafting. The so-called undesirable hydrophobicity reduces the possibility of interaction with the aquatic bio system. However, hydrophobicity due to roughness is known at the microstructural surface. Finally, it was found that the adsorption rate of the implant’s titanium surface to the gingival bone decreased from about eight weeks to about Four weeks, when the implant surface was hydrophilic compared to the time it lacked this property. This result indicates an acceleration in the process of adaptation of the 3A implant’s titanium surface when it has biocompatibility.

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