Surface Modifications of Orthodontic Temporary Anchorage Devices – A Narrative Review

Dr. Menta Sai Kalyan, M.D.S, Research Scholar, Department of Orthodontics and Dentofacial Orthopaedics, AB Shetty Memorial Institute of Dental Sciences, Nitte (Deemed to be) University, Mangalore, Karnataka, India.

Dr. Megha Ramani Revaneti, B.D.S, Post graduate resident, Department of Orthodontics and Dentofacial Orthopaedics, AB Shetty Memorial Institute of Dental Sciences, Nitte (Deemed to be) University, Mangalore, Karnataka, India.

Dr. Aditya Kalra, B.D.S, Post graduate resident, Department of Orthodontics and Dentofacial Orthopaedics, AB Shetty Memorial Institute of Dental Sciences, Nitte (Deemed to be) University, Mangalore, Karnataka, India.

Dr. Marakini Subrahmanya Ravi, PhD, Head of the Department, Department of Orthodontics and Dentofacial Orthopaedics, AB Shetty Memorial Institute of Dental Sciences, Nitte (Deemed to be) University, Mangalore, Karnataka, India.

Corresponding Author: Dr. Marakini Subrahmanya Ravi, Head of the department, Department of Orthodontics and Dentofacial Orthopaedics, A.B. Shetty Memorial Institute of Dental Sciences, Nitte (deemed to be) University, Mangalore, Karnataka, India. ORCID No - https://orcid.org/0000-0002-5544-8799, E-mail – drmsravi@gmail.com

---

Abstract: TADs are widely used as the source of absolute anchorage in contemporary orthodontics. Since years, TADs are used for anchorage management efficiently. Stability of these mini-implants on bone were studied and it helped the researchers to modify the implant surfaces to overcome the failures over a period of time. Various techniques were introduced which includes Anodic Oxidation, Plasma ion implantation, SLA, Micro-grooving, Resorbable Blasting Media, UV photofunctionalization and various nanoscale modifications. All these techniques improved the surface characteristics of TADs and they had better bone-surface contact compared to machined ones. Initial stability, Tissue healing, and osseointegration were greatly improved with the surface modifications. The surface modifications enhanced the biologic potential of TAD surface. Modified surface properties made TADs more stable in the bone and serves the purpose of achieving absolute anchorage without fail. Roughening the surfaces enabled more mechanical interlocking of the TADs on bone. UV treatment improved the osteoconductive capacity of titanium TADs. Micro-grooving helped to have a positive tissue response and better healing capacity. Anodic Oxidation was found to be associated with increased removal torque ensuring better stability in bone. Plasma Ion implantation made the surface without any defects and improved the mechanical properties of TADs. SLA treated TADs exhibited overall better characteristics than machined ones. Surface modifications enhanced the stability and potential of TADs, which helps an orthodontist to use them as a source of absolute anchorage throughout active orthodontic treatment.

Keywords: Osseointegration, Orthodontics, Titanium.

Introduction: Anchorage preservation is always a major issue faced by orthodontists, which actually decide the final treatment outcome. Skeletal anchorage systems made a revolutionary change in the field of orthodontics. Mini-plates and mini-implants help in anchorage preservation and various orthodontic tooth movements like intrusion, distalizationas well. Orthodontic mini-implants or TADs (Temporary anchorage devices) became popular and a valuable addition for the use as an absolute anchorage choice.[1]

A temporary anchorage device (TAD) is a device which is used for anchorage preservation either by acting as a direct unit or as a supportive unit for teeth, which can be inserted transosteally, subperiosteally, or endosteally and can be removed after active orthodontic treatment. The first use of a metal screw for carrying out tooth movement was published by Gainsforth and Higley in 1945 after doing their study in a dog ramus. They used vitallium screw for their work, which was not meeting the requirement completely.[2]Over a period of time, they became a good choice for orthodontists as an aid in anchorage preservation because of their cost, efficiency, easy loading, unloading and less cooperation requirement from patients.[1,2]

The success of these is multifactorial. It is dependent on mechanical factors, microbial factors, biological factors and placement technique. Mechanical factors include diameter of the screw, surface characteristics, microgrooves, length of mini-implants, and the effective load applied on implants. Improved surface characteristics like sandblasting and micro-grooving significantly reduced implant failure rates.[3] A study by butcher et al showed that a force value greater than 900 c N mm resulted in failure.[4] Palatal area was found to be associated with increased failure rate.[3,5]Self-drilling mini-implants used for up righting tooth were found to have more failure than self-tapping mini-screws in a study done by Chen et al.[6]Microbial factors also play a role in deciding the success of mini-implants.[7] Various mechanical alterations helped to overcome the failure to some extent.

Stability of mini-screws were always a question and there were many attempts to modify the surface characteristics to improve the success rate. Tissue irritation and pain during insertion were also a matter of concern. Over a period of time, various placement techniques were introduced to overcome these concerns. Failure rates were motivating researchers to introduce various surface modifications to enhance stability of TADs.[8] Thus, the current narrative review summarizes the various techniques applied for modifying the surface of orthodontic TADs available in the literature.

Classification of TADs: Classification of TADs is given in Table no 1.[9]

Parts of a mini-implant: A screw has three parts: a head, core, and a helix. Head is basically for application of force by providing provision for various attachments as well as to apply twisting torque. Core supports the screw and is attached to head covered by helical thread. Shank is the part extending from head to thread. Pitch is the area between two threads. (Figure 1)[9]

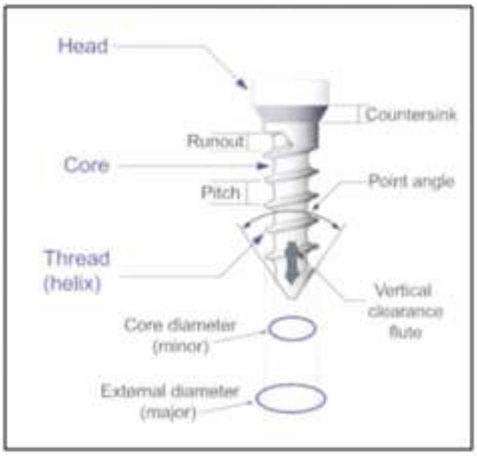

Figure 1: Parts of a Mini- implant

Surface Modifications of TADs: The implant surface which is inserted in the bone decides the stability of the implant as the surface comes in contact with the bone cells and biological fluids. Now, let's discuss about various types of surface modifications given in Table 1.[10]

Anodic Oxidation: It is an additive method in modifying the surface characteristics of an implant. It is a process by which an oxide film is created on the metallic surface. It is an electrochemical process which will produce a Titanium oxide (TiO_2) layer on the surface which is 10 to 25 µm in thickness. Surface roughness were greatly increased with the surface anodic oxidation. (Figure 2)

Figure 2: A) Machined surface. B) After Anodic Oxidation

Osteoblasts are better attached to rough surfaces which creates better bone formation around the screw surface, thereby ensuring greater stability. Quantity of calcium and phosphorous on the surface were higher in anodized implants. The presence of different porosities aids in potential drug incorporation and release around these implant surfaces. Choi S H et al conducted a study on the structural stability of anodized mini-screws and he could find that the surface characteristics are improved when compared with machined surfaces, even if little alteration of surface characteristics by self-drilling procedure is present.[10,11]

Omar et al did a Quantitative polymerase chain reaction test and immunohistochemistry study to find the gene expression and cellular activity around anodized implants and he could find Rapid triggering of gene expression and Transient nature of inflammation associated with these implant surfaces.[12] A study by Sanket Karmarker and his colleagues on effect of these surface anodization revealed increased interfacial shear strength and shear strength or removal torque compared to machined ones.[13]

Plasma Ion Implantation: Corrosion and wear resistance of titanium screws were improved with plasma ion implantation. It is a technique which involves coating the implant surface with titanium nitride or zirconium nitride. Improved characteristics were found associated with this technique. Kim et al found in his study that the surface smoothness was improved after ion implantation and reduced corrosion density.[14] In Contrast, Cho et al found similar properties when comparing coated with non-coated machined implants.[15]

Nanoscale Modifications: Nanoscale modifications are newer techniques which involves formation of nano-tubular arrays by anodization of surface under specific voltages in various electrochemical solutions. Anodization was done with TiO_2nano-tubular arrays and it was followed by cyclic pre-calcification and heat treatment. This procedure is called as APH treatment. APH treated mini-screws were found to have higher RT (Removal Torque) and BSC (Bone screw Contact) values after 3 weeks and 6 weeks of healing in a study conducted by Oh et al.[16] Early mineralization with dense bone ensured excellent bonding of screws in bone. Jang et al also found similar results in rats. He performed his study after creating Nano-tubular arrays of TiO_2 using two step anodization process. Higher Bone-volume ratio and Bone surface contact were found associated with modified implant surfaces when compared with machined ones.[17]

Even though the scope is limited, all these studies by various authors show that Nanoscale modifications on the implant surfaces show increased surface potential and they can enhance the stability in bone.[10]

Sandblasting, Large grit, Acid Etching (SLA): Sandblasting is one of the earliest techniques in order to increase surface characteristics. It is a technique by which Alumina (Al_2O_3) particles are blasted onto the implant surface, followed by acidic solution treatment. The size of alumina particles varies from 250-500 µm and solutions like hydrochloric acid, Nitric acid, and sulfuric acid are commonly used for the acidic solution treatment. This technique makes the implant surface rough enough to enhance the stability in bone. The technique of using large grit alumina particles for sandblasting, followed by acidic solution treatment and is known as SLA method[8]

Figure 3: Implant Surface with large grits, sandblasting and acid etching

Surface roughness is of varying types: Macro, Micro and Nano sized. Macro includes the surface topographical changes in the range of millimeters to tens of microns. It gives a surface roughness more than 10 µm. Studies were always showing that early fixation and long

-term stability were improved with rough surface, as it has better mechanical interlocking in bone. The major risk involved with these were peri-implantitis and increased ionic leakage. Micro level surface roughness includes surface changes in range of 1 – 10 µm. These were found to have lesser complications post insertion and found to be better in their stability as well. Hemispherical pits of 1.5 µm depth and 4 µm in diameter on implant surface seem to be the ideal surface. The rough implant surfaces are preferred in conditions where we require early fixation and good bone screw contact, like in cases of poor host bone quality.(Figure 3)[10]

Titanium plasma spraying is a technique used to create rough implant surfaces. Titanium powder loaded in Plasma torch is sprayed onto implant surface, which condense and fuse to create 30 µm thick film on implant surface. This treatment usually improves the surface area of the implant and showed improved tensile strength.[18]Studies comparing the mechanical properties of SLA and TPS implant surfaces didn't show much differences.[19]

SLA surface treated implants always expressed better mechanical properties compared to machined ones. In vivo studies were performed and presented better results. A study which involved use of SLA treated implants with nitride treated implant followed by SLA treatment for increasing surface wettability. The nitride treated surface was found to have improved properties such as reduced healing time and better osseointegration.[20] In an in-vitro study, Proff et al compared three groups of implants by incubating them in fibroblast cell culture: SLA treated, airflow treated, and machined implants. They conduced Alamar blue assay and Fluorescence microscopy studies and found reduced metabolic cell activity after 24 hours in airflow treated group. Rate of cell proliferation and fibroblast survival were found to be same associated with all three groups.[21]Naham et al conducted a gene proliferating analysis and he could find genes regulating extracellular matrix were upregulated in early stages of healing and those genes associated with bone mineralization, ossification on later satges.[22]

Kim et al studied the chemical integration mechanism between titanium screw and human bone. They performed STEM and electron energy loss spectroscopy and found interlocking hydroxyapatite crystals with implant surface with presence of an oxide later between bone and implant surface. It revealed presence of carbon in polysaccharides, titanium in oxidized state and calcium, phosphorus in aggregated form as tricalcium phosphate. It also explained about the possibility of presence of traces of $CaTiO_3$ as well.[23] Layer profiling using atom probe tomography in a study revealed presence of calcium and phosphorus in bone and titanium oxide in interface at higher concentrations ensuring good osseointegration.[24]

SLA modifications on implant surface showed advantages over conventional machined implants. Various studies have revealed greater biological potential of these modifications and they were proved to have better osseointegration and bone screw contact as well. Orthodontists always look for those mini-implants which will be stable throughout the treatment period as they are loaded with various accessories like springs and elastics with multiple force levels. These modifications improve the quality of treatment as a whole.

Micro-grooving: This is one of the easiest ways of surface modification. It involved making microgrooves on implant surface, which improved the cutting capacity and biomechanical properties. (Figure 4)[10]

Figure 4: Micro- grooving on implant surface

Microgrooves (50 µm pitch, 10 µm depth) were used by Kim et al in a study to compare with conventional screws and found higher bone screw value on pressure side of the modified screws. Gingival connective tissue fibers were found to be oriented perpendicular in surface of micro-grooved implants compared to machined implant surfaces. Both groups had shown similar bone modelling on pressure side and these were suggestive of improved biomechanical properties of the implants. They were presented with good bone healing and improved soft tissue adaptation.[10,25]

Resorbable Blasting Media: Surface treatment with Hydroxyapatite and calcium phosphate is another technique for improving the surface characteristics and stability. Biomimetic coating was introduced by Kokubo et al in 1990. The implant surfaces were immersed in stimulated body fluid for getting a hydroxyapatite coating for 1-2 weeks. This was a difficult procedure because of the time required. This was overcome by the two- phase technique developed by Klass De Root in 2001. His technique involved immersing implants in a five-fold SBF for 24 hours at 37º for preparation of BioCaP as a seeding layer which was then followed by immersing them in calcium phosphate solution at 37º for 48 hours. Incorporating proteins in these were further improving the quality of these implants. The Crystalline Biomimetic calcium phosphate coating on mini-implant surface to accelerate osseointegration and to extend drug release duration was investigated by Li et al and he could find that the coated implants were of superior quality in comparison with the amorphous ones. He concluded that biomimetic coatings improve the quality of mini-implants used in orthodontics.[26]

A study by Ganshukh et al found increased surface are for those RBM treated implant surfaces compared to the machined surfaces in his study. Surface coating with these RBM improves the cellular response of bone towards the implant and they were found to be good in initial stability and they were also found to be have enhanced osseointegration property. They didn't affect the cutting capacity of the implants too.[26,27]

Ultraviolet (UV) Photofunctionalization: Superhydrophilicity of titanium surface after UV Photo-functionalization was found in 1997. The biomechanical anchorage of these implants was tested by researchers and found to be promising to have better quality and results. The following effects were found associated after UV treatment of implant surface: Increased osteoblast migration, Increased adsorption of proteins, increased attachment of osteoblasts, improved osteoblast spread, increased proliferation of osteoblasts, increased rate of osteoblast differentiation. Improved cellular response and mechanical properties were found associated with these modified implant surfaces. All the properties are inter-related as well. The effects are due to superhydrophilicity and reduced atomic carbon content on implant surface, induced by UV treatment.

Pre-treatment with UV light improved the osteoconductive property of the implant surfaces. The bone healing and osseointegration without soft tissue involvement were found associated with them. After 4 weeks the bone-implant was found to be 100 percent which was relatively lower for untreated implants. Protein adsorption and cellular proliferation were found relatively improved in the treated samples.[28]

Peri-Implantitis was a common problem faced post their insertion. UV treatment had reduced these problems and was found to be a better choice. There were reduced bacterial attachment and biofilm formation on UV treated surfaces.[29] Cytoskeletal structure is responsible for good cell retention and adhesion, which were found excelled with the UV treated surfaces.[30]

The schematic description of the underlying mechanism under UV treatment is explained in the figure given below (Figure 5)[30]

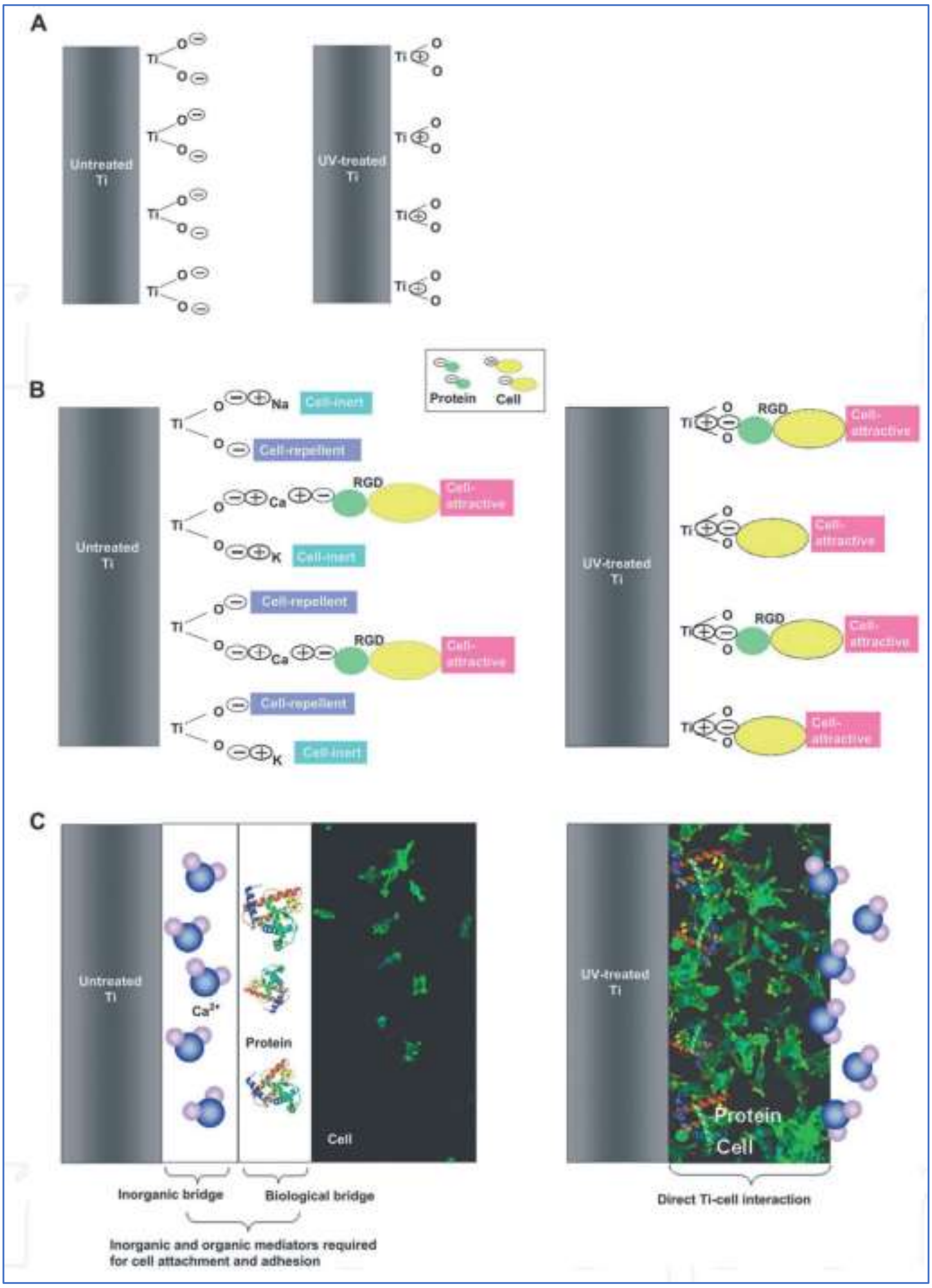

Figure 5: A: The normal surface of implants is electronegative and UV treated are electropositive. B) Electrostatic interaction of both surfaces is shown. Untreated surface shows monovalent cations bonded to charged TiO_2 surfaces. These surfaces attract proteins and cells only with the help of cations. UV treated surface is of RGD sequencing which doesn't require the support of cations to attract cells and proteins. C). UV treated surfaces

show a distinct layer of protein and cells are formed and in untreated surfaces they stay as different layers as they require cations for the attachment.

Surface engineering by Electro-spraying: It is another technique which results in formation of titanium dioxide on titanium surfaces. Titanium dioxide nanofibers were created on implant surface using electrospinning. Simple effective way to create nano particles on implant surface is by electrospraying/ electrospinning with titanium salts. This is done using Ti (IV) n- butoxide salt. Electrospraying technique enhanced the bone mineralization rate and rate of matrix mineralization on the implant surfaces.[31]

Surface coatings on Mini- Implants: Various physical modifications were discussed and there are many implant coating techniques also available which improves the clinical efficacy. Coating bioactive material on implant surface was found to be associated with improved clinical performance. They were improving bioactivity, anti-bacterial properties along with good osseointegration. Various surface coatings include HA (stable biological form of calcium phosphate), nano-hydroxyapatite, magnesium, Graphene, growth factors, extracellular matrix proteins. Magnesium coatings were found to be increasing the osteoblast proliferation rates. Graphene coating improved structural stability and resistance to mechano-chemical degradation.

Growth factor coatings are of two types: Vascular endothelial growth factor (VEGF) and bone morphogenic factors (BMP). VEGF was enhancing the bone proliferation rate and increased alkaline phosphatase activity along with activation of genes. BMPs were increasing the bone mesenchymal stem cell proliferation. Extracellular matrix protein coatings improved the rate of osseointegration at an early stage after insertion.[32]

Biomechanical anchorage of mini-implant treated with SLA were studied by Calderon et al and found improved anchorage when surfaces are modified.[33]Dual threaded implant surfaces are another modification currently followed. They were found to have better similar initial stability with cylindrical mini-screws. The insertion torque was found higher when compared with cylindrical screws.[34]Four different types of implant surfaces were compared: machined, acid etched, grit blasted with alumina, Grit blasted and acid etched. This study was performed by Yadav et al and he found there was an increased surface roughness for the group which is sandblasted with alumina when compared to other groups.[35]

Table 1: Classification of TADs

S.No	Classification	
1	According to Head type	a. Head with a hole in the neck. b. Head with button like design. c. Head with bracket like design d. Head with a hook.
2	According to surface structure	a. Threaded or Non-threaded b. Porous or Non-Porous
3	According to composition	a. Stainless Steel b. Cobalt- Chromium-Molybdenum c. Titanium d. Ceramic Implants e. Miscellaneous such as Vitreous Carbon and Composites
4	Based on Configuration	a. Root Form Implants. b. Press Fit c. Self-drilling Pre-tapping d. Blade / Plate Form Implants. e. Pre-Fabricated.
5	Dr. J. B. Cope's Classified them as	a. Biocompatible TADs b. Biological TADs
6	Based on clinical applications and design	a. Subperiosteal Palatal Onplants b. Temporary Palatal Endosseous implants c. Bone plates. d. Bone screws.

Table 2: Types of Surface Modifications

S.No	Types of Surface Modifications	
1	Additive methods	a. Anodic oxidation b. Plasma ion implantation

		c. Nano scale modification
2	Subtractive method	a. Sandblasting, Large grit, Acid Etching(SLA) b. Micro-grooving c. Resorbable Blasting Media (RBM)
3	Non-Additive, Non-Subtractive methods	Ultraviolet (UV) Photofunctionalization

Conclusion: Anchorage is always the greatest concern for an orthodontist during active orthodontic treatment. We rely on TADs for absolute anchorage since years. Surface modifications improve the quality of orthodontic mini-screws and they improve mechanical and biological properties of the implant surfaces. Improved surface characteristics ensure stability of the screw in bone. Nanoscale modifications of TADs are still more to be researched for further more advances in the field of orthodontics.

References

1. Singh K, Kumar D, Jaiswal RK, Bansal A. Temporary anchorage devices–Mini-implants. *Natl J Maxillofac Surg*. 2010;1(1):30.
2. Shetty SK. Tads in Orthodontics. *Sch J Dent Sci*. 2021;7:234-238.
3. Daokar SS, Agarwal G. Orthodontic Implant Failure: A Systematic review. *Int J Oral Implantol Clin Res*. 2016;7(1):1-6.
4. Büchter A, Wiechmann D, Gaertner C, et al. Load- related bone modelling at the interface of orthodontic micro- implants. *Clin Oral Implants Res*. 2006;17(6):714-722.
5. Moon C-H, Park H-K, Nam J-S, Im J-S, Baek S-H. Relationship between vertical skeletal pattern and success rate of orthodontic mini-implants. *Am J Orthod Dentofac Orthop*. 2010;138(1):51-57.
6. Chen Y, Chang H, Lin H, Lai EH, Hung H, Yao CJ. Stability of miniplates and miniscrews used for orthodontic anchorage: experience with 492 temporary anchorage devices. *Clin Oral Implants Res*. 2008;19(11):1188-1196.
7. Uysal T, Yagci A, Esel D, Ramoglu SI, Kilinc A. Investigation of bacteremia following insertion of orthodontic mini-implants. *World J Orthod*. 2010;11(4).
8. Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. *Dent Mater*. 2007;23(7):844-854.
9. Baghel S, Garg A, Sahu S, Verma N, Choudhary AS, Raghuwanshi S. Temporary

Anchorage Devices–An Update. *IOSRJDMS*. 2019;18(3):37-46.

10. Rampurawala A, Patil A. Surface Modification of Titanium Orthodontic Implants. In: *Current Concepts in Dental Implantology-From Science to Clinical Research*. IntechOpen; 2021.
11. Choi S-H, Cha J-Y, Joo U-H, Hwang C-J. Surface changes of anodic oxidized orthodontic titanium miniscrew. *Angle Orthod*. 2012;82(3):522-528.
12. Omar O, Svensson S, Zoric N, et al. In vivo gene expression in response to anodically oxidized versus machined titanium implants. *J Biomed Mater Res Part A An Off J Soc Biomater Japanese Soc Biomater Aust Soc Biomater Korean Soc Biomater*. 2010;92(4):1552-1566.
13. Karmarker S, Yu W, Kyung H-M. Effect of surface anodization on stability of orthodontic microimplant. *Korean J Orthod*. 2012;42(1):4-10.
14. Kim SJ, Moon YP, Park GH, et al. Surface characteristics and electrochemical behaviors of TiN and ZrN coated orthodontic mini-screw. *J Korean Inst Surf Eng*. 2008;41(5):232-239.
15. Cho Y-C, Cha J-Y, Hwang C-J, Park Y-C, Jung H-S, Yu H-S. Biologic stability of plasma ion-implanted miniscrews. *Korean J Orthod*. 2013;43(3):120-126.
16. Oh E-J, Nguyen T-DT, Lee S-Y, Jeon Y-M, Bae T-S, Kim J-G. Enhanced compatibility and initial stability of Ti6Al4V alloy orthodontic miniscrews subjected to anodization, cyclic precalcification, and heat treatment. *Korean J Orthod*. 2014;44(5):246-253.
17. Jang I, Shim S-C, Choi D-S, et al. Effect of TiO 2 nanotubes arrays on osseointegration of orthodontic miniscrew. *Biomed Microdevices*. 2015;17:1-7.
18. Buser D, Schenk RK, Steinemann S, Fiorellini JP, Fox CH, Stich H. Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs. *J Biomed Mater Res*. 1991;25(7):889-902.
19. Roccuzzo M, Bunino M, Prioglio F, Bianchi SD. Early loading of sandblasted and acid- etched (SLA) implants: a prospective split- mouth comparative study: One- year results. *Clin Oral Implants Res*. 2001;12(6):572-578.
20. Schätzle M, Männchen R, Balbach U, Hämmerle CHF, Toutenburg H, Jung RE. Stability change of chemically modified sandblasted/acid- etched titanium palatal implants. A randomized- controlled clinical trial. *Clin Oral Implants Res*. 2009;20(5):489-495.
21. Proff P, Kauschke E, Rumpel E, et al. The survival and proliferation of fibroblasts on orthodontic miniscrews with different surface treatment: an in vitro study. *Folia*

Morphol (Warsz). 2006;65(1):78-80.

22. Nahm K-Y, Heo JS, Lee J-H, et al. Gene profiling of bone around orthodontic mini-implants by RNA-sequencing analysis. *Biomed Res Int*. 2015;2015.
23. Kim J-S, Kang S-M, Seo K-W, et al. Nanoscale bonding between human bone and titanium surfaces: osseohybridization. *Biomed Res Int*. 2015;2015.
24. Kim J-S, Ahn J-P, Kim Y-H, Seo KW, Zadeh H, Kim S-H. Atomic layout of an orthodontic titanium mini-implant in human tissue: Insights into the possible mechanisms during osseointegration. *Angle Orthod*. 2019;89(2):292-298.
25. Kim T-W, Baek S-H, Kim J-W, Chang Y-I. Effects of microgrooves on the success rate and soft tissue adaptation of orthodontic miniscrews. *Angle Orthod*. 2008;78(6):1057-1064.
26. Li M, Wu G, Wang M, Hunziker EB, Liu Y. Crystalline Biomimetic Calcium Phosphate Coating on Mini-Pin Implants to Accelerate Osseointegration and Extend Drug Release Duration for an Orthodontic Application. *Nanomaterials*. 2022;12(14):2439.
27. Gansukh O, Jeong J-W, Kim J-W, Lee J-H, Kim T-W. Mechanical and histological effects of resorbable blasting media surface treatment on the initial stability of orthodontic mini-implants. *Biomed Res Int*. 2016;2016.
28. Aita H, Hori N, Takeuchi M, et al. The effect of ultraviolet functionalization of titanium on integration with bone. *Biomaterials*. 2009;30(6):1015-1025.
29. Yamada Y, Yamada M, Ueda T, Sakurai K. Reduction of biofilm formation on titanium surface with ultraviolet-C pre-irradiation. *J Biomater Appl*. 2014;29(2):161-171.
30. Iwasa F, Hori N, Ueno T, Minamikawa H, Yamada M, Ogawa T. Enhancement of osteoblast adhesion to UV-photofunctionalized titanium via an electrostatic mechanism. *Biomaterials*. 2010;31(10):2717-2727.
31. Javadi A, Solouk A, Nazarpak MH, Bagheri F. Surface engineering of titanium-based implants using electrospraying and dip coating methods. *Mater Sci Eng C*. 2019;99:620-630.
32. Dong H, Liu H, Zhou N, et al. Surface modified techniques and emerging functional coating of dental implants. *Coatings*. 2020;10(11):1012.
33. Calderón JH, Valencia RM, Casasa AA, Sánchez MA, Espinosa R, Ceja I. Biomechanical anchorage evaluation of mini-implants treated with sandblasting and acid etching in orthodontics. *Implant Dent*. 2011;20(4):273-279.
34. Lee Y, Choi S-H, Yu H-S, Erenebat T, Liu J, Cha J-Y. Stability and success rate of dual-thread miniscrews: a retrospective study using the buccal alveolar region as the

insertion site. *Angle Orthod*. 2021;91(4):509-514.

35. Yadav S, Upadhyay M, Roberts WE. Biomechanical and histomorphometric properties of four different mini-implant surfaces. *Eur J Orthod*. 2015;37(6):627-635.