Journal of Chemical Health Risks

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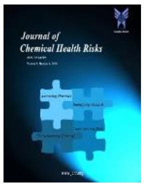
JCHR (2024) 14(2), 1927-1941 | ISSN:2251-6727



Advancements in Surface Treatment Techniques for Dental Implants: Enhancing Osseointegration and Clinical Outcomes

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(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS

Dental implants, Surface treatment, Osseointegration, Bioactive coatings

ABSTRACT:
Surface treatment of dental implants plays a pivotal role in optimizing implant performance and osseointegration. This comprehensive review examines the current state of surface treatment techniques, including traditional methods and emerging technologies. It explores the principles, effects, and clinical outcomes of various surface treatments, such as acid etching, sandblasting, plasma spraying, anodization, bioactive coatings, surface functionalization, and antibacterial treatments. Additionally, the review discusses in vitro assessment methods, in vivo animal studies, and clinical trials used to evaluate the effectiveness of these surface modifications. The findings emphasize the efficacy of surface treatments in enhancing osseointegration and patient outcomes. Furthermore, the review identifies challenges, such as the need for improved long-term stability and durability of surface-treated implants, and highlights the potential of emerging technologies to address these limitations. Patient-specific modifications for individuals with compromised bone quality or systemic diseases are also discussed. In conclusion, this review outlines the implications of these key findings for clinical practice and future research directions, paving the way for enhanced implant performance and improved patient outcomes in dental implantology.

Introduction

Dental implants have revolutionised the practise of restorative dentistry by offering a practical replacement for lost teeth. When compared to conventional prosthetic options, they offer better aesthetics, usefulness, and long-term stability. To replace the tooth root of a missing tooth, a dental implant is a biocompatible titanium device that is surgically inserted into the jawbone. Long-term implant success depends on successful osseointegration, the direct structural and functional connection between the implant surface and surrounding bone.

It is impossible to stress the importance of surface treatment for dental implants. An implant's surface properties are crucial in promoting osseointegration and assuring predictable clinical results. Surface alterations are intended to increase bone growth and implant stability by maximising the biological response at the bone-implant contact. [1]

However, achieving successful osseointegration is crucial for long-term implant survival. Osseointegration refers to the direct structural and functional connection between the implant surface and surrounding bone, which provides the necessary stability for implantsupported restorations. Surface properties, such as topography, chemistry, and wettability, significantly influence the cellular and molecular events occurring at the implant-bone interface.

Importance of Surface Treatment for Dental Implants

In order to optimise the biological response and boost the clinical performance of dental implants, surface treatment techniques have developed over time. Surface modifications' main goal is to develop a biocompatible interface that encourages early bone growth and integration. It has been demonstrated that surface roughness, created by methods like acid etching and sandblasting, increases the implant's surface area for better osseointegration and improves mechanical interlocking. Additionally, cutting-edge surface modification methods including anodization, hydroxyapatite coatings, laser surface modification, and nanotopography offer special benefits in encouraging cellular attachment, protein adsorption, and ensuing bone formation.[2] These methods enable specific alterations to the implant surface, affecting osteogenic signalling pathways, gene expression, and cellular behaviour.

It is essential to evaluate and contrast different surface treatment methods in order to determine the best strategies for enhancing implant integration and long-term success rates. Results from in vitro research, animal models, and clinical studies offer important insights into the biocompatibility, stability, and functionality of various implant surfaces.[3]

Objectives of the Review Paper

This present review has three distinct goals. In the beginning, it seeks to clarify the history and relevance of dental implants as a restorative choice for people who have missing teeth. Second, it highlights how important surface treatment is in determining how well dental implants osseointegrate and last over time. Finally, it aims to assess and contrast various surface treatment methods, including conventional and cutting-edge methods, in terms of their impacts on implant integration and clinical results. Based on the methods employed to change the surface qualities, implant surfaces are categorised. The surface alterations are designed to improve cellular adhesion, protein adsorption, and subsequent bone production in order to maximise osseointegration. One popular classification scheme divides implant surfaces into three broad types namely machined surfaces, roughened surfaces and modified surfaces [4].

Traditional Surface Treatment Techniques

Acid Etching: Principles and Effects on Implant Surface

Acid etching is one of the methods frequently used to treat the surface of dental implants. It entails applying an acid solution, such as sulfuric acid (H_2SO_4) or hydrochloric acid (HCl), to the implant surface for a predetermined amount of time. The purpose of acid etching is to increase surface roughness and produce regulated micro-scale imperfections, which improves the mechanical interaction between the implant and the surrounding bone.

Fresh titanium, which is more reactive and biocompatible, is exposed after the oxide layer has been selectively removed from the implant surface by the acid etching process. This encourages enhanced protein absorption, cellular adhesion, and subsequent bone production. As a result, the surface is roughened, increasing the surface area available for osseointegration and assisting in the creation of a robust bone-implant contact. [5]

Sandblasting: Technique, Materials, and Outcomes

Sandblasting, sometimes referred to as abrasive blasting, is another tried-and-true method for treating the surface of dental implants. During this procedure, aluminium oxide (Al_2O_3) or titanium dioxide (TiO_2) are projected into the implant surface using compressed air or a blasting device. Surface imperfections and surface roughness are increased as a result of the impact of these abrasive particles.

Sandblasting increases surface roughness, fostering better osseointegration and bone-implant interaction. In addition, it boosts surface wettability and energy, which makes protein adsorption and cellular adhesion easier. In order to achieve the ideal surface roughness and preserve the integrity of the implant surface throughout the sandblasting process, it is essential to use the right abrasive materials, particle size, and pressure.[6,7]

Plasma Spraying: Process, Coating Materials, and Advantages/Disadvantages

Thermal spraying methods like plasma spraying are frequently used to apply coatings to dental implant surfaces. During this procedure, powdered coating materials are melted and propelled onto the implant surface by a high-temperature plasma jet created by a plasma torch. Titanium and its alloys, hydroxyapatite (HA), and calcium phosphate-based compounds are common coating materials.

Plasma spraying offers versatility in customising implant surfaces to meet particular clinical requirements since it allows for exact control of coating thickness, porosity, and composition. Due to their outstanding biocompatibility, advantageous mechanical characteristics, and capacity to promote osseointegration, titanium plasma-sprayed (TPS) surfaces, which are produced by plasma spraying pure titanium particles, are extensively used.[8,9]

Titanium Plasma-Sprayed (TPS) Surfaces: Properties and Clinical Performance

Dental implants frequently employ surfaces made of titanium plasma sprayed (TPS). These surfaces have a microstructure that has been roughened and is made up of titanium particles that are fused to the implant surface in uneven shapes. The distinct morphology of TPS surfaces encourages mechanical interaction with the bone, improving osseointegration and enhancing early stability.[10,11]

Large surface areas offered by TPS surfaces enable greater protein adsorption and cellular adhesion. Additionally encouraging bone development, the rough surface shape allows for the entrapment of biological fluids, growth nutrients, and osteogenic cells. Clinical studies have shown that TPS surfaces have positive long-term effects, such as high success rates, enhanced implant durability, and decreased chance of implant failure.[12]

Traditional surface treatment methods, such as acid etching, sandblasting, and plasma spraying, have the benefits of being affordable, simple to use, and therapeutically successful. But it's crucial to take into account any potential drawbacks, such as the potential for surface damage, difficulties in obtaining a constant surface topography, and the danger of contamination throughout the surface treatment procedure.

Advanced Surface Modification Techniques for Dental Implants

By providing creative approaches to optimise implant surfaces for improved osseointegration and long-term clinical success, advanced surface modification techniques have completely changed the field of dental implantology. The four advanced surface modification methods anodization, hydroxyapatite (HA) coatings, laser surface modification, and nanotopography are all thoroughly reviewed in this article. Each methodology is examined, along with its guiding principles, modes of use, advantages, and drawbacks. The goal is to give dental implantologists insightful knowledge of these cutting-edge methods and their possible effects on implant function.

Anodization: Principles, Types, and Outcomes

An electrochemical procedure called anodization entails carefully forming an oxide layer on the surface of titanium implants. In order to improve osseointegration, this method makes use of the titanium's natural oxide layer and alters its thickness and makeup. Different electrolyte solutions and electrical settings can be used for anodization, which alters the surface properties.

It is feasible to design an oxide layer with a specific surface roughness, shape, and bioactivity by modifying the anodization parameters. Increased surface roughness, higher wettability, and improved protein adsorption are all characteristics of anodized surfaces that encourage cellular adhesion and eventual bone formation.[13] Anodization can also be used in conjunction with other methods of surface modification to further improve the implant surface for better osseointegration.

Hydroxyapatite (HA) Coatings: Methods of Application and Benefits

Because hydroxyapatite (HA) coatings are analogous to the mineral that makes up natural bone, they are frequently employed as bioactive coatings on dental implants. Several procedures, such as plasma spraying, electrophoretic deposition, and biomimetic coating processes, can be used to provide HA coatings on implant surfaces. The potential of HA coatings to offer a bioactive surface that encourages quick osseointegration is its principal advantage. Early bone apposition onto the implant surface is made possible by the HA coating, which also speeds up healing and improves implant stability. Additionally, HA coatings can operate as a growth factor reservoir and encourage osteogenic cell differentiation, promoting bone regeneration at the implant-bone contact.[14]

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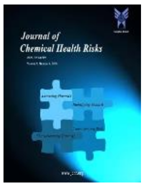

Laser Surface Modification: Techniques, Advantages, and Limitations

Laser surface modification includes modifying the surface characteristics of dental implants using laser radiation. You can use many laser systems, including Nd:YAG, Er:YAG, and CO2 lasers, with different energy levels and pulse durations. Techniques for using lasers to modify surfaces include laser sintering, laser ablation, and laser-induced microstructures.[15] With laser surface modification, you can precisely regulate the surface topography, generate very little heat, and add features at the micro- and nanoscale. Increased roughness, better wettability, and greater cellular responses are all characteristics of the changed surfaces that aid in osseointegration. However, there are drawbacks to laser surface modification, including the risk of heat damage to the implant surface, the demand for competent operators, and the necessity for suitable safety precautions.

Nanotopography and Nanocoatings: Fabrication Methods and Effects on Cell Response

Fabricating surface features at the nanoscale, which typically ranges from a few to hundreds of nanometers, is known as nanotopography. Contrarily, nanocoatings are thin layers or films that are applied to implant surfaces using processes like chemical vapour deposition or electrospinning. Cellular behaviour and osseointegration can be greatly influenced by nanotopography and nanocoatings.[16] Nanostructured surfaces can improve cell adhesion, proliferation, and differentiation because they closely resemble the extracellular matrix in nature. Additionally, they alter bone-related signalling pathways and gene expression. Additional advantages of nanocoatings include controlled drug release, antimicrobial qualities, and enhanced biocompatibility.

Studies looking at how nanotopography and nanocoatings affect dental implants have shown increased osseointegration, quicker bone growth, and more stable implants. There are still issues with fabrication techniques, the durability of coatings, and the standardisation of nanoscale characteristics. Dental implant surfaces can be improved using cutting-edge surface modification techniques such anodization, hydroxyapatite coatings, laser surface modification, and nanotopography.[17,18] These methods offer ways to increase surface roughness, bioactivity, and cellular responsiveness, ultimately leading to better osseointegration and lasting clinical results. Dental implantologists can use these cutting-edge methods to modify implant surfaces for particular patient requirements and enhance the science of implantology.

Surface Chemical Modifications for Dental Implants

A promising strategy for improving the biological response and clinical function of dental implants is surface chemical alterations. The surface features of dental implants can be modified to enhance osseointegration, lessen infection, and foster long-term success by adding certain biomolecules, bioactive coatings, growth factors, and antibacterial treatments. This thorough analysis concentrates on four methods of surface chemical modification: surface functionalization, bioactive coatings, growth factor surface immobilisation, and antibacterial surface treatments. The goal is to give dental implantologists insightful knowledge of these methods and their possible influence on clinical outcomes and implant integration.

Surface Functionalization: Introduction of Biomolecules

In order to improve the implant's biological capabilities, the surface of the device is functionalized with biomolecules. It is possible to chemically or physically immobilise a variety of biomolecules, such as peptides, proteins, and extracellular matrix components, onto the implant surface. The regulated immobilisation of biomolecules is made possible by functionalization processes like self-assembled monolayers, plasma polymerization, and layer-by-layer deposition, which encourage particular cellular responses and enhance tissue integration. These macromolecules can affect cell adhesion, proliferation, differentiation, and formation of extracellular matrix, which promotes faster healing and improved osseointegration.[19,20]

Bioactive Coatings: Calcium Phosphate-based Materials and Applications

Dental implants' osseointegration could be improved by using bioactive coatings, especially those made of calcium phosphate compounds. These coatings, such tricalcium phosphate (TCP) and hydroxyapatite (HA), imitate the mineral makeup of actual bone and make it easier for a direct link to form with the surrounding tissue. Calcium phosphate-based coatings can be applied to implant surfaces using a variety of techniques, such as plasma spraying, sol-gel, and

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JCHR (2024) 14(2), 1927-1941 | ISSN:2251-6727

electrochemical deposition. The osteoconductive qualities, stimulation of osteoblast activity, and promotion of bone apposition onto the implant surface are all provided by the bioactive coatings. Additionally, they serve as a storage space for calcium and phosphate ions, aiding the remineralization of harmed bone tissue and hastening the healing process.[21] Different implant systems use different methods of surface treatment which are summarised in Table 1.

S.NO.	IMPLANT SYSTEM	SURFACE MODIFICATION
1.	Straumann	SLA (Sandblasted, Large-grit, Acid-etched)
2.	Noble Biocare	TiUnite is a proprietary surface treatment developed by Nobel Biocare. It is a combination of both a moderately rough, titanium oxide surface and a microroughened texture.
3.	Zimmer Biomet	Tapered Screw-Vent system typically involves a combination of roughening techniques, including sandblasting and acid etching.
4.	MIS Implants	TiUltra is a surface treatment technology developed by MIS Implants. The TiUltra surface is created through a combination of processes, including acid etching and oxidation.
5.	BioHorizons	The Tapered Internal surface treatment by BioHorizons is designed to enhance osseointegration and implant stability. This surface treatment involves a combination of techniques, including surface blasting and acid etching.
6.	Osstem	"TSLA" (TwinShot Laser Ablation)
7.	Adin	Combination of sandblasting and acid etching processes

Table 1- Different implant systems use different methods of surface treatment

Surface Immobilization of Growth Factors: Methods and Potential for Enhanced Osseointegration

A promising strategy for fostering improved osseointegration and bone regeneration around dental implants is surface immobilisation of growth factors. Growth factors, like platelet-derived growth factors (PDGFs) and bone morphogenetic proteins (BMPs), are essential for cell division, proliferation, and the production of extracellular matrix.

Growth factors can be immobilised on implant surfaces using a variety of methods, such as physical adsorption, covalent binding, and affinity-based immobilisation.[22] Growth factors that have been immobilised engage with cellular receptors to start signalling cascades that improve cellular responses and quicken bone development. This strategy has a great deal of potential to enhance the clinical results of dental implant therapy, especially in situations when the quality of the bone or underlying illnesses are affected.

Antibacterial Surface Treatments: Strategies to Reduce Infection and Peri-implantitis The long-term success of dental implants is seriously hampered by bacterial infections and peri-implantitis. In order to lower the risk of infection and implant failure, antibacterial surface treatments aim to reduce bacterial colonisation and biofilm formation on implant surfaces.

Numerous methods have been researched for their antibacterial qualities, including the insertion of antibacterial chemicals, surface modification with nanomaterials, and photodynamic therapy. These remedies can stop bacteria from adhering, stop them from growing, and help get rid of any bacterial biofilms that already present. These procedures promote the health of the peri-implant tissue by integrating antibacterial characteristics into the implant surface, adding an additional line of defence against infection.[23]

Dental implants' performance and long-term success could be considerably improved by surface chemical changes like surface functionalization, bioactive coatings, surface immobilisation of growth factors, and

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antibacterial surface treatments. With the help of these methods, implant surfaces can be modified to enhance osseointegration, encourage bone regeneration, lower infection risks, and enhance peri-implant tissue health. Dental implantologists can use surface chemical alterations to their advantage to overcome clinical obstacles and develop implantology.

In Vitro Assessment Methods: Surface Characterization and Biocompatibility Testing

Understanding how surface treatments for dental implants affect implant function, osseointegration, and long-term clinical results is essential. The evaluation of surface treatments using in vitro testing techniques, in vivo animal research, and clinical trials is the main topic of this in-depth analysis. To emphasise the dynamic character of research in this area, future ideas for assessment methods are also highlighted. A thorough awareness of the evaluation methods used to gauge the performance of surface treatments and their possible effects on implant success might be helpful for dental implantologists.

Dental implants with surface treatments can be identified and their biological response can be assessed using in vitro procedures. Surface topography, roughness, and morphology can all be learned by surface characterisation methods like scanning electron microscopy, atomic force microscopy, and profilometry. These methods make it possible to analyse surface characteristics quantitatively, which is important for understanding how cells adhere, multiply, and differentiate.

To evaluate the biological reaction of cells and tissues to surface-treated implants, biocompatibility testing is crucial. Cellular responses to implant surfaces can be assessed using a variety of in vitro techniques, including gene expression studies, proliferation assays, and cell viability assays. Studies on protein adsorption and analyses of cellular adhesion and morphology also shed light on how cells interact with the altered implant surfaces.[24]

Clinical Studies and Outcomes: Long-Term Success Rates and Patient Satisfaction

Clinical trials are essential for assessing the effectiveness of surface-treated dental implants in people. Evaluations are made on long-term success rates, implant survival rates, and side effects such implant failure and peri-implantitis. Clinical research also assesses patient-reported outcomes, such as satisfaction, dental health, and appearance.

Large sample sizes and well-defined study methodologies in prospective clinical studies offer solid proof of the efficacy of surface treatments. Bone loss around the implant can be measured using radiographic evaluation methods such periapical and panoramic radiography. To determine the implant's long-term stability and the existence of peri-implant inflammation, clinical characteristics such as probing depth, bleeding on probing, and soft tissue health are also assessed.[25]

In order to gauge patient satisfaction, quality of life, and readiness to refer patients for dental implant treatment, patient-reported outcomes are evaluated by questionnaires and arbitrary assessments. These results offer important information on the general effectiveness and effects of surface-treated implants on patients' daily life.

Future Perspectives for Evaluation Techniques

The combination of cutting-edge technology, including as 3D imaging, molecular biology methods, and computational modelling, is one of the future prospects in the evaluation of surface treatments for dental implants. Cone-beam computed tomography (CBCT) and micro-CT are two three-dimensional imaging modalities that allow for thorough evaluation of the bone-implant interface and peri-implant bone quality.

The molecular mechanisms driving osseointegration and tissue response can be better understood using molecular biology approaches like gene expression analysis and proteomics. These methods assist uncover potential indicators of implant success and give a fuller understanding of the cellular and molecular processes taking place at the implant-bone contact.

Additionally, based on surface features, implant performance can be predicted and optimised using computer modelling and simulation approaches. In order to plan and optimise surface treatments, finite element analysis and computer-aided design allow for the study of stress distribution, bone remodelling, and biomechanical stability.[26]

A variety of methodologies are used to evaluate surface treatments for dental implants, including in vitro analyses, in vivo animal studies, and clinical research. These evaluation techniques offer vital information about how surface treatments affect implant

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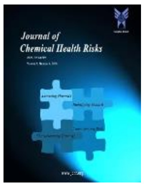

functionality, osseointegration, and long-term clinical results. Our knowledge of the biological reaction to surface-treated implants will be further improved by the incorporation of cutting-edge technology and future perspectives in evaluation procedures, which will support the creation of superior implant designs and surface modifications.

Limitations of Current Surface Treatment Techniques

Despite the effectiveness of surface treatment methods, a number of issues need to be resolved. One restriction is the potential for implant surface degradation throughout the therapeutic process, which may compromise the implant's structural integrity and biocompatibility. The difficulty of achieving consistent and repeatable surface topography, which might affect the osseointegration process, is another problem. Additionally, the long-term stability of various surface treatments is still debatable, and the molecular mechanisms behind their effects are still poorly understood. For surface-treated implants to remain effective over time, it is essential to look into their durability and long-term performance.

Emerging Technologies and Potential Advancements

Innovative surface treatment methods can be advanced through the use of emerging technologies. The inclusion of bioactive materials into implants and precise control over implant surface architecture are two examples of such technologies. Additive manufacturing, often known as 3D printing, is one such technique. Customised surface qualities in 3D-printed implants hold the promise of better osseointegration and patient-specific care.[27]

Another interesting field that could improve surface modification methods is nanotechnology. With regulated nanoscale features, nanomaterials and nano coatings have shown enhanced physiological responses, antimicrobial activities, and drug transport abilities. Furthermore, improvements in surface modification methods such plasma electrolytic oxidation and electrochemical processes offer chances to create unique surface treatments with improved attributes.

Regulatory Considerations and Standardization Efforts

The application of surface treatment procedures is greatly influenced by regulatory considerations. For the use of particular surface treatments, it is crucial to follow legal requirements and get the required approvals. To prove the safety and effectiveness of surface-treated implants, thorough preclinical and clinical evaluation, including biocompatibility testing, animal studies, and clinical trials, is needed.

In order to guarantee consistent and trustworthy results while using various surface treatment processes, standardisation initiatives are also essential. The standardisation of characterization techniques, evaluation procedures, and reporting standards can improve study comparability and support the use of evidence in decision-making. To provide uniform protocols and standards for surface treatment techniques, researchers, doctors, and regulatory authorities must work together.[28]

Dental implants' surface treatment is hampered by a number of issues, including the limitations of present methods, the need for new developments and technologies, patient-specific adjustments, and regulatory issues. Improving implant performance, patient outcomes, and the long-term success of dental implant therapy will result from addressing these issues and considering potential future paths. Dental implantologists can advance the discipline and improve surface treatment methods by integrating cutting-edge technologies, customising surface modifications for particular patient populations, and putting in place regulatory and standardisation measures.

Implications for Clinical Practice

The results of this review have significant ramifications for clinical dental implantology practice. Techniques for surface treatment are essential for increasing osseointegration, maximising implant performance, and raising long-term success rates. Sandblasting and acid etching are two common surface treatment methods that are still effective for increasing surface roughness and biocompatibility.

Anodization, bioactive coatings, surface functionalization, and antibacterial treatments are just a few of the cutting-edge surface treatment methods that have recently emerged. These techniques offer exciting new options to improve implant surfaces and tackle particular clinical issues. Improved biocompatibility, quicker osseointegration, and customised alterations to meet the demands of individual patients are all provided by anodized surfaces, bioactive coatings, and surface

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JCHR (2024) 14(2), 1927-1941 | ISSN:2251-6727

functionalization processes.[29] Antibacterial surface treatments offer practical ways to lower the risk of implant failure and peri-implant infections.

Furthermore, the personalization and optimisation of surface treatment methods have a lot of potential when future technologies like nanotechnology and additive manufacturing are combined. With controlled topography and the integration of bioactive materials, additive printing makes it possible to design patient-specific implant surfaces. The ability to modify and cover materials at the nanoscale improves cellular responsiveness, antibacterial characteristics, and drug transport capabilities. Studies previously done from last 10 years were studied and evaluated and are enlisted in table2.

S.NO.	AUTHOR	TOPIC	YEAR OF STUDY	TYPE OF INTERVENTION	ASSESSMENT METHODS	OUTCOME
1	Krajewski et al	A Study of the Methodology for Treatment of Titanium Substrates to be Coated with Hydroxyapatite	2013	homogeneous hydroxyapatite coatings	Scanning Electron Microscopy/ Energy Dispersive Spectroscopy and low-angle X-ray Diffraction	RFMS process successfully produced dense and uniform coatings without detachments on DTi and PTi substrates
2	G Szabó, L Kovács, K Vargha	Possibilities for improvement of the surface properties of dental implants (2). The use of ceramic oxides in surface coating for titanium and tantalum implants	1995	ceramic oxide layer with a coherent crystalline structure was produced on the surface of titanium implants	physical, chemical electronmicroscopic, etc. tests for their qualitative characterization	tests demonstrated the good properties of the implants
3	B C Ling , B R Gillings	Cleansing and surface modifying agents on implants: fixation and related aspects of aesthetics.	1995	treatment of air-aluminum oxide blasted implants using a mixture of 30% HNO3-5% HF acids	SEM	produced a surface which meets the consideration of aesthetics for implants placed in the anterior maxillary region.
4	Siti nadia rahimi et al	Surface Modificati	2022	A variety of surface modifications have been	Clinical evaluation	Implant surface modifications have

		on of Dental Implants		developed and are currently being used to enhance clinical performance, including turned (machined), hydroxyapatite-coated surface, titanium plasma-sprayed, grit-blasted, acid-etched, anodization, laser-microtextured as well as combinations thereof		also resulted in the change of surgical protocol from a two-stage to a one-stage surgery, with the possibility of early or immediate loading. These improvements have significantly reduced the discomfort and inconvenient endured by patients undergoing implant therapy
5	S Szmukler-Moncler , T Testori, J P Bernard	Etched implants: a comparative surface analysis of four implant systems.	2004	sandblasting was performed prior to etching, surface topography was a combination of macro- and microroughness	scanning electron microscope (SEM)	treating titanium surfaces with acid does notcreate a standard topography. The latter varies according toseveral parameters, such as prior treatment, acid mixturecomposition, temperature, and time of acid treatmen
6	aditya alagatu et al	Detailed study on basic methodology of dental implant and surface modification techniques	2022	Acid etching	SEM	this article use different implant materials and different surface modification techniques
7	Sankhadeep banejee et al	scanning electron microscopic study on the HA-coating of implant following insertion into the cadaver goat jaw bone	2016	hydroxypatite coating	Scanning of electronmicroscopy	enhances osseointegration when implanted in osseous sites
8	Jian ye han	The Surface	2009	coating dental implants with	SEM	TiO2, the HA/TiO2 composite coatings

		Modifications of Dental Implants that are made of a Near-β Type Titanium Alloy		hydroxyapatite/TiO2 composite material		adhered tightly to the dental implants and no longer existed cracks
9	Naresh et al	Hydroxyapatite and nanocomposite implant coatings in dental implants	2020	Hydroxyapatite	SEM	HA-based nanocomposite may have a significant impact on bone growth and osteointegration, thereby restoring functions of teeth
10	Herbert Deppe et al	Surface morphology analysis of dental implants following insertion into bone using scanning electron microscopy: a pilot study.	2015	sandblasted and acid etched surface of dental implants	SEM	subtractive modifications of implant surfaces are less important than the reestablishment of the destroyed TiO2 layer
11	Ayousha Iqbal et al	Recent advancements in surface modifications of dental implants.	2021	hydrophilic surfaces.	SEM	modify the implant surface topography as well as surface chemistry in order to achieve a micro-porous structure with nano-scale architecture, with increased bio-activity; hydrophilicity and anti-bacterial properties.
12	Ralf smeets et al	Effect Of Various Implant Surface Treatments On Osseointegration - A Literature	2016	sandblasting, acid-etching, and hydrophilic surface textures	SEM	Major advancements have been made in developing novel surfaces of dental implants. These innovations set the stage for rehabilitating

						patients with high success and predictable survival rates even in challenging conditions.
13	Radhika b parekh et al	Surface Modifications for Endosseous Dental Implants	2012	Roughening	SEM	The purpose of altering the surface topography of an implant is to improve its stability
14	Vinaya bhat et al	Surface topography of dental implants	2014	Roughening the surfaces	SEM	roughness/smoothness of the implant surface which becomes more favourable to achieve osseointegration. This modified surface exhibits varied biological responses when the implant is placed in the oral cavity.
15	M. ayogi et al	Implants for bones, joints and teeth roots and method of manufacture	1976	thermal spraying, of hydroxyapatite or a mixture of hydroxyapatite and ceramic materials	SEM	The implant has excellent strength properties, in particular high impact strength, and furthermore good affinity for tissues of living beings.
16	D.C Smith et al	Dental implant materials. I. Some effects of preparative procedures on surface topography	1991	autoclaved (steam sterilization), radiation-sterilized, nitric acid-etched, or plasma-cleaned	scanning electron microscopy and by contact angle measurements.	the results of wettability studies indicated marked changes in surface energy corresponding to the different preparation methods, and differences in surface morphology were also observed. These differences could have significant consequences on in vivo implant behaviour as mediated by tissue-implant interactions.
17	N. Sargolzaei et	THE EFFECT	2008	Sandblasted, Large grit, Acid-etched	Bleeding on probing,	Based on these findings, it is better

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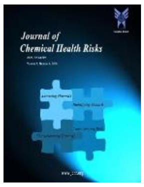

	al	OF TWO TYPES OF IMPLANT SURFACE COATING ON BONE AND SURROUNDING TISSUES OF PROSTHESIS WITH IMPLANT SUPPORTING			pocket depth and bone loss were evaluated one year after insertion. The data were collected and analyzed using Mann Whitney U test	to make use of implants with SLA surface coating.
18	A. Ballo et al	Dental Implant Surfaces Implant Dentistry - A Rapidly Evolving Practic : Physicochemical Properties, Biological Performance, and Trends	2001	second generation of clinically used implants underwent mechanical blasting coupled or not, with acid etch, bioactive coatings, anodized and, more recently, laser modified surfaces	long-term clinical studies and experimental histological and biomechanical evaluation in animal models	implant surface modifications is to promote osseointegration, with faster and stronger bone formation.
19	D. wismeijer	Consensus Statements and Recommended Clinical Procedures Regarding Restorative Materials and Techniques for Implant Dentistry.	2014	Mechanical methods	SEM	Surface treatment for dental implants is recommended clinical procedures for implant dentistry.
20	Dr Mukti Chadda , Dr Raghunath Patil	Implant and 3'S (Surface topography , Surface treatment, Sterilization)	2014	.1 Mechanical, 2Chemical, 3Electrochemical 4Electro polishing 5 Vacuume6 Thermal 7Laser methods	SEM	In thermal treatments, surface roughness and amount of oxide layer formation are temperature and time dependent. Laser surface treatment, on the

						other hand, can used to produce desired surface roughness without any contamination of the implant surfaces

TABLE 2- Previous studies enlisted.

<u>Future Research Directions</u>

Although surface treatment methods for dental implants have advanced significantly, there are still issues to resolve and potential future paths to consider. The limitations of present surface treatment methods, newly developing technology, possible breakthroughs, surface alterations for certain patient populations, regulatory issues, and standardisation initiatives are the main topics of this in-depth assessment. For dental implantologists to enhance implant performance, patient outcomes, and the overall effectiveness of dental implant therapy, it is essential to understand these difficulties and future directions.[30]

The analysis identifies numerous areas for future research to improve surface treatment methods for dental implants. Understanding the performance of surface-treated implants over lengthy periods of time requires research on their long-term stability and durability. Additionally, obtaining a better understanding of the cellular and molecular processes underpinning osseointegration and tissue response will make it possible to create surface changes that are more efficient.

Exploring surface alterations for certain patient populations, such as those with weakened bone quality or systemic disorders, calls for more investigation. Customised adjustments that include growth factors, antibacterial characteristics, and bioactive components can address the particular difficulties these patients confront and enhance therapeutic results.

In the area of surface treatment procedures, regulatory concerns and standardisation initiatives are particularly crucial. For the safe and efficient use of surface-treated implants, regulatory compliance and getting the required permissions are essential. The improvement of study comparability, facilitation of evidence-based decision-making, and promotion of improvements in surface treatment procedures are all facilitated by standardisation of evaluation methods, characterization techniques, and reporting criteria.

<u>Conclusion</u>

The overview of surface treatment methods for dental implants concludes by highlighting the effectiveness and potential of both conventional and cutting-edge approaches. The results highlight the significance of surface alterations in promoting osseointegration, enhancing clinical outcomes, and resolving particular clinical issues. It is essential to integrate new technology, adapt for patient-specific needs, and take regulatory and standardisation initiatives into account. By utilising these important discoveries and their consequences, dental implantologists can advance clinical practice and influence the course of future research, which will eventually improve patient outcomes and ensure the long-term success of dental implant therapy.

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