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REVIEW PAPER

Laser nano surface texturing for enhancing of physical and chemical properties of dental implants

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ABSTRACT

As a considerable fact, the worldwide application of dental implant operations have significantly increased throughout the past decade, while the future rate of implant failure and revision operations seems to be similarly high as well. The two main factors that lead to implant failure are insufficient osseointegration and bacterial infections. The available surface coatings and surface modification techniques are incapable of providing long-term stability. Additionally, the factors of cell adhesion and survival are mostly influenced by the implant surface features of chemical construction, surface energy, wettability (hydrophilicity/hydrophobicity), coarseness, topography, and surface arrangement. Laser surface texturing (LST) is recognized as the most promising method for the production of biocompatible, antibacterial, and suitable surfaces for advanced bone mending due to offering accurate control over surface topography, morphology, wettability, and chemistry. This approach can provide micro and nano-texture patterns for a broad variety of biomaterials. The present study investigated and introduced the impression of Laser surface texturing (LST) on some physical and chemical characteristics of dental implants in order to aid the conduction of assessments on novel designs of dental implants.

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INTRODUCTION

Dental implants are considered as a common component of prosthetic rehabilitations due to being employed in between 15 to 20 percent of dental prostheses. In United States, 1 to 2 million of implants were implanted in 2010, which is predicted to rise up to 2 to 4 million annually by 2020 [1]. Implant dentistry is now regarded as a therapy option. Despite the general high success and survival rate of dental implants, yet this procedure is challenged with certain issues and peri-implant illnesses that cause substantial difficulties for both patients and clinicians. These complications can be divided into the two groups of mechanical and biological problems[2, 3].

Distant osteogenesis and contact osteogenesis at the surface of implant complete the biomechanical stability. The clinical failure of an implant is mostly associated with the dental fixture, which must be removed due to the incompatibility of osseointegration (early failure) or bone maintenance (late failure). Some of the reasons behind early failures include the weak situation of bone, the health statues of patient, absence of mechanical stability, infections, and other factors, while the inducement of functional overload, peri-implantitis, and subpar prosthetic construction are typically linked to late failures[4, 5].

The majority of dental implant systems is consisted of the implant and abutment, which starts with the placement of endosteal component at the beginning of surgical phase, and is followed by the general attachment of transmucosal connection after implant osseointegration in order to maintain the prosthetic restoration. The failure of peri-implantitis treatment may result from soft

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tissue inflammation, which occurs as the oral bacteria colonizes among the open spaces of these components. Several physiological factors can impact prosthetic restoration and the connection of implant-abutment connection in the course of chewing and biting, since for instance, such forces can cause a pressure as high as 120 N in the axial direction on a single molar implant. There are reports on the value of short force maximum, which reaches up to an average of 847 N in males and 595 N in females. In the course of physiological function, the cyclic loading forces must exceed the maximal strength of an implant-abutment connection to prevent the gradual loosening or failure of connection that occurs by fatigue. The inducement of fatigue failure can be triggered by the absence of force fitting or by the involved form-closure in the design of the connection. The factors of preloads deficiency at abutment screw and the ensued unscrewing or fatigue failure of screw materials are the main causes of loosening in implant-abutment connections[6-8].

Next to mechanical difficulties, the biological issues of implants proved to be as prevalent and serious as well, such as the case of marginal bone loss, in which the survival of both implant and the prosthesis it supports is threatened. The effective parameters on crestal bone loss include peri-implant tissue infection, improper fit at the interface of implant-abutment, and surgical trauma, as well as biomechanical components associated with the utilized occlusal load in the course of masticatory performance and parafunction [9, 10]. A successful osseointegration process is dependent on the two main factors of implant's surface features and the macroscopic design of implant, which is responsible for maintaining the required primary stability for the induction of osseointegration as a biological procedure [11, 12]. In coordination with numerous assessments, surface alteration in implants can considerably increase the progression of osseointegration and extend the percentage of bone-to-implant contact (BIC). Additionally, the factors of cell adhesion and survival are mostly influenced by the implant surface features of chemical construction, surface energy, wettability (hydrophilicity/hydrophobicity), coarseness, topography, and surface arrangement. [13-16].

Surface morphology can significantly influence the optical, mechanical, wettability, chemical, biological, and other aspects of a solid surface. There are limitations to the current surface modification techniques of surface coating and surface chemical adjustment. Due to its weak mechanical structure and possibility of non-uniformity, surface coating can provide a low stability for long periods of usage. On the other hand, the adjustment of surface chemistry can result in the occurrence of chemical reactions. These deficiencies persuaded scientists to laboriously search for the proper adjustment of surface qualities and try to enhance the recent biomaterials. These assessments led to the emergence of an innovative and adaptable approach for designing a broad range of nanostructured products with applicable features for numerous applications in photonics, plasmonics , optoelectronics, biochemical sensing, micro/ nanofluidics, optofluidics, biomedicine, and etc. Laser surface texturing (LST) proved to stand as an auspicious technique for achieving reassuring results in the fabrication of biocompatible, antibacterial, and early bone healing surfaces by providing an explicit control on surface topography, morphology, wettability, and chemistry. Considering its potent ability to create micro and nano-texture patterns for a broad variety of biomaterials. [17-19], this work attempted to assay the impacts of Laser nano surface texturing on physical and chemical features of dental implants.

THE APPLICATION OF LASERS AND LASER SURFACE TEXTURING IN DENTISTRY

The numerous uses of lasers vary from basal scientific and industrial fields to medicinal and manufacturing sectors. The capability of recent conventional laser sources for fabricating enormous amounts of energy in small locations is confined by the diffraction limitation of converging optics and laser frequency. The unique and adaptable instrument of lasers can be utilized for a variety of applications, similar to cutting, welding, soldering, and surface functionalization, which is provided by their efficacious and direct discharge of energy on a manageable space without demanding any material cases. These developments sparked their usage in the medical products of clinical implementations and assessments, leading to the achievement of significant advancements in the majority of medical specialties that particularly involve dentistry [20-22].

Considering the involvement of lasers in nearly every dental specialty for more than 20 years, their usage in dentistry cannot be labeled as a revolutionary technique. The very first dental utilization of this technology was reported in 1960s, which faced a rapid increase throughout recent decades. The implication of dental lasers as a relatively new technology in clinical dentistry helped in addressing some of the issues of traditional dental techniques[23, 24]. These applications include the performance of lasers as a carving tool for rigid dental tissues, a diagnostic instrument for the identification of caries, a disinfecting tool for root canals, and a tool for subgingival calculus. There are also reports on their exertion in endodontics that involve their exploitation in apicectomy, pulp diagnostics, dentinal hypersensitivity, pulp capping and pulpotomy, root canals sterilization, and root canal forging and obturation. Furthermore, the employment of lasers for hard dental tissues resulted in lowering the disquiet and dental concern of patients in regards to dental rotary cutting devices due to the lack of using any injectable local anesthesia [20, 25].

Today, the clinical implementations of laser technology is mostly used for the treatment of hard and soft tissues and dental materials. Moreover, lasers can provide new methods for the refinement of dental substances similar to metals, ceramics, and resins, which demand high energies and careful management. This approach was suitable enough to replace many conventional techniques and simplify the processing of tough and sensitive materials. Additionally, there are reports on the promising results of employing ultrafast lasers in dentistry due to facilitating the conduction of surface processing for challenging cases such as incredibly rigid ceramics, similar to zirconia, with the induction of slight structural alterations[26, 27].

The method of surface texturing involves creating a specific pattern or texture on a work surface. It is a useful technique for surface modification that improves the material's tribological characteristics of materials including load capacity, wear resistance, and coefficient of friction. Researchers have used a variety of texturing techniques to create micro/nanopatterns on working surfaces, which include laser surface texturing (LST), electric discharge texturing, focussed ion beams, electrochemical machining, hot embossing, lithography, and mechanical texturing. The propitious emergence of laser surface texturing (LST) among the other texturing techniques is the result of its supreme effectiveness, controllability, environmental friendliness, and precision. The process of LST involves the melting and vaporization of materials by ablation as the high-energy of laser beams impinges the working surface [28-31].

The irradiation of working surface is conducted by a focused laser beam during the laser ablation process in order to heat up and thus remove the work material from the irradiated area through melting and vaporization. The modification of surface topography is followed by removing the selected materials. As a practical tactic, textures can be created by laser ablation by its rapid, micron level accuracy in the removal of materials [32-34]. There are two types of laser ablation, including pyrolytic and photolytic procedures. In pyrolytic cases, the energy of absorbed laser light by the material is converted into heat and initiates the process of melting and vaporization, whereas photolytic reactions implicate the induction of chemical reactions by photon absorption that is followed by the displacement of material's binding energy[35, 36]. As a forefront technique, laser surface texturing (LST) is capable of creating prevalent and duplicable textures in ranges of micro- and nanoscales, while due to its precise, flexible, and inexpensive features, it is under wide investigations for biomaterials processing. Considering its applicability in regards to metals, composites, polymers, and ceramics, this method can simplify the creation of complex geometry and small features on surfaces. According to related studies, this technique has the ability to improve some physical and chemical characteristics of all types of implants, especially dental implants [18, 37-39].

THE IMPACTS OF LASER SURFACE TEXTURING (LST) ON THE PHYSICAL AND CHEMICAL FEATURES OF DENTAL IMPLANTS

The creation of textures on an implant can be done through the methods of grit blasting, acid etching, anodic oxidation, and chemical vapor deposition, which are difficult to be repeated despite being quick and simple. LST was identified as a potential technique for implant modification due to offering a rapid, clean, and precise modification. The surface topography modification of diverse substances was broadly attempted through the exertion of laser surface texturing in order to tune the obtained optical, tribological, biological, and other surface features. The operating mechanisms of surface textures can affect the behavior of dental

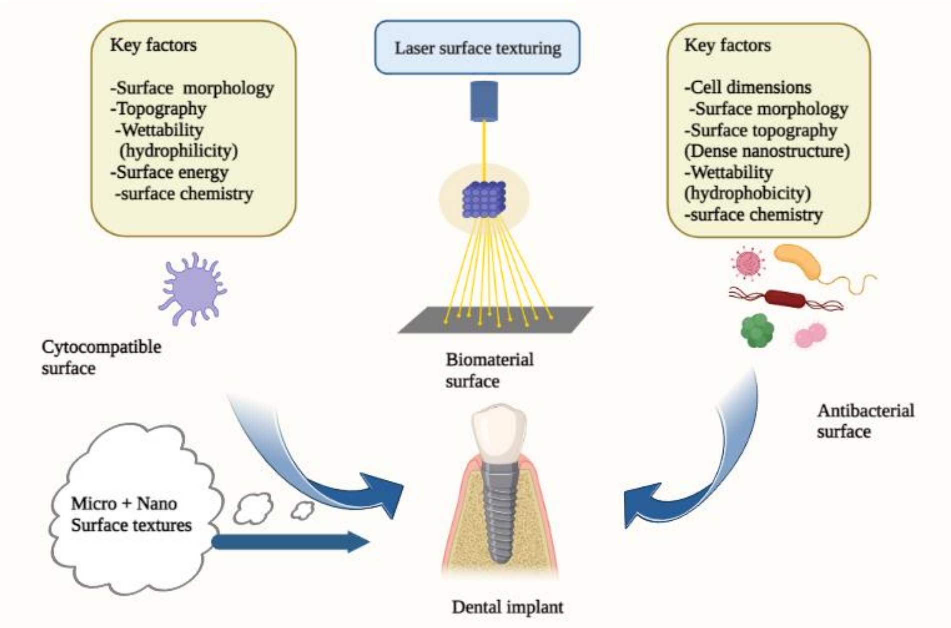

Fig. 1. The impact of laser surface texturing on the physical and chemical characteristics of dental implants

implants. The attributes and texture of implants surfaces is the main factor behind the management of tissues responses. The surface topography, construction, wettability, and chemistry can be accurately managed by laser surface texturing (LST). This suited approach can aid the production of biocompatible, antimicrobial, and convenient surfaces for early bone healing[37, 40, 41].

The crucial parameters of design and topography can severely impact the initial osseointegration procedure of dental implants. The effectiveness of connection method has a direct responsibility in regards to the long-term stability of bone tissue within the neck of dental implant. A rigid surface can enhance the contact area of implants by osteoblasts and consequently accelerate the rate of bone healing. Additionally, the bone resorption and healing time of dental implants can be decreased by improving the factors of interfacial stress distribution and bonding strength [42, 43]. The strong impact of surface topography and roughness on the responses of cells and tissues is undeniable. The function of surface topography is known as a captivating topic throughout the assessments of implant dentistry. In contrast to the smooth surfaces, a larger surface area is available on the surfaces of textured implants to achieve a more efficient integration with the bone by osseointegration. The ingrowth of tissues can be also provided by textured surfaces. The direct interaction of macro, micro, and nanoscale surface topography with cells results in promoting the parameters of cell growth, adhesion, migration, proliferation, and differentiation. Laser surface texturing can affect and improve the qualities of cell adhesion and survival of dental implants, which depend on a number of factors that include chemical construction, surface energy, wettability (hydrophilicity/hydrophobicity), coarseness, topography and surface framework [44-46] (Fig. 1).

Chemical Composition and Wettability

The creation or deliberate introduction of an explicit surface chemistry during the fabrication process is contributed to the exerted rough surface. Nowadays, one of the most important research topics is the biocompatible character of a material with host tissues. Considering the high biocompatibility, corrosion resistance, strength, and osseointegration capability are also quiet essential in the course of selecting a proper implant material. Additionally, the composition and position of an implant, as well as the patient's health, are among the other factors that can affect the biocompatibility of an implant's components[15, 42, 47]. In correlation to hydrophobic surfaces, the results of numerous assays reported the tendency of hydrophilic surfaces to improve the initial stages of cell adhesion, proliferation, differentiation and bone mineralization[48, 49]. The category of materials similar to metal, ceramic, polymeric, and composite biomaterials are suitable for bone and tissue transplantation due to their superior biocompatibility [50-52]. The performance of cells throughout the beginning stage of osseointegration can be impacted by the wettability feature of implant surfaces. The higher suitability of hydrophilic surfaces (with the water contact angle range of 40° to 70°) than hydrophobic surfaces is due to the interacting manner of human body fluids, cells, and tissues with implant surfaces [53-57]. The adhesion of ions and proteins on the surface determines the progression of cell adhesion. Hydrophilic surfaces proved to promote higher levels of protein adsorption than their hydrophobic counterparts, while the extension of hydrophilicity results in intensifying the primary attaching states of osteoblastic cells. Meanwhile, the superior benefits of exerting moderate hydrophilicity (∼40∘ ∼70∘) is a notable fact, which is facilitated through the promotion of balanced protein adsorption and its more advanced primary interaction, motility, proliferation, and cells differentiation [37, 56, 58]. The production of well-defined, regular micropatterns by chemical machining and sandblasting is considered as a challenging task. Despite to the chaotic nature of sandblasting, the method of etching is hampered by the exceptional corrosion resistance and passive oxide layer of titanium alloys, which is commonly generated in addition to the frequent application of dangerous chemicals throughout the operation. Well-defined features are necessary to establish the cause-and-effect correlations between particular traits and also develop more rapid, long-lasting osseointegration. For this aim, the employment of laser surface texturing (LST) can enable the creation of new surfaces. As the laser beam interacts with varying engineering materials, certain thermal and optical effects are achieved and utilized in the course of laser surface modification techniques. Massive amounts of energy are absorbed as the particles are being ejected from the surface of target. Ablation or vaporization are the foundations of removal mechanism, while the effects of fluid dynamics and thermal conduction can be also noticed throughout the majority of operation. Being conditional on the strength of density and temporal working manner of a laser, some particular ablation systems can dominate the other methods, Clearly, a wide range of variables in a process can directly affect the interaction of lasers with the exerted material, which in turn influences the advancing effectiveness and statues. Therefore, it is possible to optimize the topography and chemistry of surfaces for the designated biomedical implementation [37, 59].

It is possible to achieve a solid surface with an ideal wettability for an explicit liquid by combining the factors of surface topography and chemistry[60, 61]. In coordination to the results of numerous researches, surface micro/nanostructuring can provide the means for adjusting the wettability statues of a solid surface. Apparently, a diverse range of wetting plots can be obtained for designing a surface with hierarchical coarseness and smaller nanostructures on top of larger microstructures. Water is able to enter a nanostructure, microstructure, or both. The surfaces that contain deep microstructures and rich nanostructures, with a high dual roughness result in trapping a layer of air among the surface and droplet, which eventually turns the conditions into an extremely superhydrophobic state. A shallower surface microstruc-tures can facilitate the entry of some portions of water droplet, which converts the wetting phase into an intermediate metastable or combined state[62-64]. According to uthor's group, many intense wetting scenarios can be created on alaser-textured surface by managing the dispersive and non-dispersive elements of surface chemistry. Superhydrophobicity, superoleophobicity, superhydrophilicity, and superoleophilicity, as well as the co-existence of superoleophobicity and superhydrophilicity are some examples of extremely high cases of wettabilities[65].

Due to its simple processing setup and operation, laser direct writing is the most frequently employed method for the production of textures on substrates in the cases of extremely wetting surfaces. The manufactured surface frameworks rely on the operating factors of lasers, such as pulse energy and duration, rate of repetition, speed of scanning, wavelength, and working environment, polarization, etc.), as well as substrate material qualities that include thermal conductivity, specific heat, bandgap, etc. The range of pulse widths in lasers start from a few nanoseconds and reaches up to a few femtoseconds along with the wavelengths confine of 355 nm (UV laser) to 1064 nm (IR laser) [66-70]. Nearly every laser texturing techniques implicate the usage of top-down process and naturally results in the production of hierarchical/ dual scale constructions (i.e., both microscale and nanoscale structures) or nanoscale laser-induced periodic surface frameworks (LIPSS). The manufacturing of surface structures involved a variety of pulsed lasers with pulse durations in the ranges of nanosecond (10^{-9}) which can provide microscale structures, as well as picosecond (10^{-12}) and femtosecond (10^{-15}) that aid the production of nanoscale features[71-74].

According to common knowledge, the typical wetting features of surfaces can be altered through the exertion of chemical approaches in the shape of chemisorbed monolayers. The frequency of employing silanes in chemical treatments is due to their suitability in being directly modified with both superhydrophobic and superhydrophilic activities [75-78]. Fluorinated groups that contain a low rate of binding energies can decrease the surface energy of nanostructured surfaces and induce superhydrophobicity. Meanwhile, the appearance of attaching nitrile (-CN), carbonyl (-C(=O)-), and carboxyl (-COOH) groups lead to the occurrence of significant alterations throughout the hydrophilicity of a surface by their high polarity. There are certain groups in these chemical reagents that function as a reactive group and respond to the laser textured Surface to facilitate the attachment of molecules to the textured surface, while some other explicit groups take functional responsibilities for adjusting the surface energy/wettability[79-82].

Surface roughness or surface topography

The impacts of surface roughness on extending the rate of mechanical retention (interdigitation) and facilitating excellent stress distribution can significantly affect bone healing and improve the biomechanical qualities. There are three levels of surface roughness that implicate macro-roughness (Ra scale around 10μm), micro-roughness (Ra scale around 1μm), and nano-roughness (Ra scale<200 nm). Ra refers to the arithmetic average of absolute values in the vertical deviations of a mean plane [15, 40].

Superior bioactivity provides the induction of bone fabrication at the implant-bone contact and consequently shortens the period of osteointegration. The initial stabilization of implants is aided by microtopography, which promotes bone growth and osteoblast differentiation. Moreover, nano-topography enhances the factors of protein Adsorption, cell growth, and rate of osteointegration. The benefit of three dimensional frameworks is the facilitation of osteoblasts with a sufficient amount of nutritions. According to research results on nanostructures with controlled osteoblast proliferation, despite the main accountability of microstructure for osteoblast differentiation, a decrease was observed in cell proliferation as the cell differentiation was increased by microstructure. Therefore, the design of micro-/nanohierarchical framework was under the objective of quickening the rate of cell differentiation and proliferation. Among the available methods for creating various topographies from nanoscale to macroscale, laser surface texturing is the most frequently utilized approach due to its rapid processing rate, high versatility, and ability to perform selective areas adjustment [15, 54, 83-86]. The artificial or natural presence of surface topography, or even surface roughness in the possible range of several micrometers to nanometers[87], may be observed on a real-world surface in the course of manufacturing procedure. Roughening the smooth surfaces of implants can improve their initial fixation and stability, while in comparison to smooth cases, the surfaces that contain a high rate of coarseness can promote a greater interlocking reaction throughout the bone interface zone of implant [15, 54, 88].

In the recent designs of dental implants, the application of surface topography adjustments, as well as biological and non-biological coatings, were considered to impersonate biological surroundings and decrease the possibility of inflammation and infection[89]. The focus of many has been pulled towards small dimension specifications of textures, which imitate multiple tissues and their interfaces similar to micro- and nano-scale topographies; these regions are commonly referred to as cell microenvironment. One of the crucial factors throughout the design of products for biomedical implementations is the management of microenvironment. Previous assays denoted the impacts of cell microenvironment on cellular architecture, cell mechanics, cell proliferation, and cell performance [90]. According to related studies, the extension of human primary cells on Ti substrata can be guided by particular sub-microscale textures. There are also evidences on the existence of localized single mesenchymal stem cells in varying adhesive forms, while their differentiation is apparently controlled by shape anisotropy. A number of groups reported the disparity of cells adhesion and spreading in the scale of microenvironment [91-95]. The significance of applying topography for managing mesenchymal stem cells (MSCs) in bone tissue engineering stands as a possibility. The process of cellular enhancements were remarkably influenced by the attaching and discriminating power of stem cells to particular surfaces. Histological proofs are indicative of the development of new bone at every side of the inert object during osseointegration, forming an unmediated proximity among the bone and applied implant. Along with the factors of inflammation degree and excessive force, the status and quantity of osseointegrated bone all over the implant may affect its stability and consequently its rates of failure. Blood-mediated osseointegration of osteoblasts or MSCs onto the implant surface is dependent on the initial fibrin adhesion in the course of osseointegration and the following mineralization[58, 96-98].

Anti-bacterial capability and biocompatibility

The accumulation and adherence of bacteria to biomaterials is a major challenge in the exertion of long-term implants, since it can result in biomaterial-centered inflection and unsatisfying biocompatibility [99, 100]. The significance of implanted biomaterials in the success of available orthopedic and dental methods is undeniable. Considering the leading stance of microbial infection in the failure of implants, the most important pathogenic process throughout the growth of infection on biomaterials is the production of biofilms that is immediately triggered after bacterial attachment[101]. Some of the elements that might connect bacteria to the implant and result in bacterial infection include the type of bacteria species, exerted materials in implant, environmental parameters, and most significantly the chemical and physical qualities of the applied materials in implant surfaces [99, 102-109]. Therefore, the management of surface properties is a possible strategy for prolonging the lifespan of implants. Two lines of reasoning, including surface chemical adjustments and surface physical topography, were developed in response to this statement. Related researches reported the stance of nanotubes, nanowires, and nanopillars are the main subjects of anti-bacterial nanostructure studies. There are several investigations that confirmed the efficiency of nanotubes in prohibiting bacterial adhesion in Staphylococcus epidermis while supporting cell adhesion. Despite the satisfactory bacteriostatic characteristics of some structures, similar to nanotubes, yet the improvement of their biocompatibility requires the performance of additional treatments such as heat treatment and polymer coating [110-113]. Next to the possible induction of toxicity, the long term application of chemical modification can sometimes result in a poor performance in preventing bacterial adherence; therefore, several researchers attempted to assay the topic of surface physical adjustment [114, 115]. Nevertheless, they mostly focused on either on antibacterial capability or biocompatibility, while the interactions of topography and bacteria and cells on the same framework were insufficiently investigated [110].

An extra layer can be produced on the surface of implants through the loading or diffusion of substances. Surface modification refers to the alteration of an implant's thin layer at atomic, molecular, or geomorphological levels. Apparently, the factor of bacterial adhesion can be explicitly advanced or inhibited by topography, stiffness, surface charge, hydrophilicity, and hydrophobicity of implants surfaces [116-118]. The adjustment of surface morphology can change the surface characteristics of implant products, including surface coarseness and surface nano-micro-hierarchical construction. Certain studies reported the successful reduction of bacterial adhesion through the exertion of specific material surfaces with nanostructured topographic qualities. Among the numerous available methods for creating nanostructures (such as photolithography, femtosecond laser, electron beam radiation, chemical etching, anodization, etc.) , laser surface modification proved to offer the highest degrees of controllability and flexibility. Therefore, laser-induced surface structures, with the potential of fending off bacterial colonization and improving the obtained biocompatibility, were highlighted as an applicable approach for the attainment of implant patterned surfaces for long term applications. Some studies indicated the possible ability of this technique to prevent the entry of S. aureus into the depressions, which would consequently reduce the rate of adhesion. An extending number of researches confirmed the effectiveness of lasers in altering the surface

Table 1: An overview on the application types of laser surface texturing (LST) in improving the physical and chemical features of adental implants

Type of implant	Laser type	Type of surface texturing	Application	Reference
stainless steel	femtosecond laser	micro- and nano-texturing	- controlling cell adhesion and migration	[127]
stainless steel	ultrashort pulsed laser	nano-texturing	- producing antibacterial surfaces	[128]
stainless steel	ultrashort pulsed laser	micro- and nano-texturing	- producing antibacterial surfaces	[129]
AISI 316L stainless steel	nanosecond laser	microstructure	-Super hydrophobic constructions on 316L stainless steel surfaces	[130]
o–Cr–Mo alloy	laser surface texturing (LST)	micro- and nano-texturing	- Improved wettability on tribological features	[131]
titanium	femtosecond laser	nano-ripples and micro-grooves	- Improved biocompatibility -Preventing bacterial colonization and biofilm production	[132]
magnesium–calcium alloys	laser shock peening (LSP)	micro- and nano-texturing	- enhanced the corrosion resistance of alloy by more than 100-fold in simulated body fluid	[133]
Mg-Gd-Ca alloy	fiber laser	Micro-texturing	-corrosion resistance and biocompatibility enhancement	[134]
titanium alloy (Ti–6Al–4V)	ArF laser	nano-texturing	- improvement in bioactivity - significant increase in wear resistance and a marginal change in corrosion resistance	[135]

characteristics of biomaterials in order to enhance their biological and tribological capabilities. The common knowledge of this field signifies the important role of topographic properties of surfaces in the rate of bacterial adhesion. In addition, discoveries denoted the sensitivity of bacteria to the space between nearby pillars, which include Pseudomonas aeruginosa, S. aureus, Escherichia coli (E. coli), and Helicobacter pylori [119-124]. In conformity to observations, next to providing an extension in the bactericidal features of surfaces, the technique of surface modification can also improve the adherence capability of a substrate to human cells. Additionally, there are reports on the achievement of remarkable antibacterial impacts from materials with nanopatterned surfaces against microorganisms that are impervious to antibiotics, such as Methicillin-resistant Staphylococcus aureus (MRSA)[110, 125]. Table 1 presents a summary on some of the most important applications of laser surface texturing (LST) in the physical and chemical properties of dental implants. Furthermore, there is

Table 1: An overview on the application types of laser surface texturing (LST) in improving the physical and chemical features of adental implants , Continued.

Type of implant	Laser type	Type of surface texturing	Application	Referenc e
Ti6Al4V alloy	femtosecond laser	micro- and nano-texturing	-superior antibacterial performance	[136]
stainless steel	high-fluence nanosecond laser	micro- and nano-texturing	- Improving the interaction of osteosarcoma cell with stainless steel surface	[137]
Co–Cr–Mo alloy	laser surface texturing	micro- and nano-texturing	- Improving osteoblast proliferation, morphology and gene expression	[138]
Biodegradable Polymer and Biopolymer/Ceramic Composite	Femtosecond Laser	micro- and nano-texturing	- enhancement of cellular attachment and orientation	[46]
titanium implants	laser surface texturing (LST)	micro- and nano-texturing	-improved primary stability	[37]
copper and brass	nanosecond fiber laser	micro- and nano-texturing	-super hydrophobic metallic surfaces	[139]
Ti-6Al-4V titanium alloy implants	laser microgrooved surfaces	micro texturing	- Improved biocompatibility	[140]
316 LS stainless steel	CO2 laser surface	micro- and nano-texturing	- osteoblast cell adhesion and proliferation	[141]
Ti-15Mo alloy	laser beam irradiation	micro- and nano-texturing	-Physico chemical, morphological, and biological improvement	[142]
titanium implants	laser surface texturing (LST)	micro- and nano-texturing	- Improving both osteoinductive and antimicrobial properties	[89]
Ti6Al4V (TC4) alloy	laser surface texturing (LST)	micro- texturing	- improving the wear resistance	[143]

an intimate relationship between biocompatibility and the reaction of cells that are in correspondence with the surface of employed material, which particularly implicate the factor of adhesion. The physico-chemical features of a implant surface is the determining parameter of tissues feedback. Moreover, the type of implants interaction with their biological surrounding is regulated by surface qualities, which implicate topography (or texture), surface chemistry, surface energy, or wettability [32, 40, 126].

The provided contents and examples in the table confirmed the rapidness, cleanness, and accuracy of LST as a prospective approach for the conduction of implant adjustments, which can aid the design of hydrophilic surfaces on implants through the extension of their wettability[50, 52, 144]. In addition, this ultrafast procedure can extend the surface wettability of an implant and adjust the cytoskeleton format, distribution and area of FAPs, and proliferation in order to guide the performance of human mesenchymal stem cells (hMSCs). Furthermore, there are reports on the exertion of lasers for executing the coating of hydroxyapatite (HAP) on textured implant, which resulted in achieving an stronger resistance towards corrosion and confirmed the suitability of this surface for biomedical implementations. Moreover, researchers created a micro texture on a titanium surface through the help of LST and according to their outcomes, the resultant succeeded in improving the cell adhesion and displayed an excellent performance as a crucial agent in contact guidance[118, 119, 145, 146].

CONCLUSIONS

This paper presents the recent advancements and progresses induced by the impacts of laser nano surface texturing on physical and chemical features of dental implants. LST proved to be a rapid, clean, and accurate approach for the objective of implant modification. Several studies denoted the applicability of LST in improving various physical and chemical characteristics of dental implants, which include chemical composition and wettability, surface roughness or topography, and anti-bacterial capability and biocompatibility. This technique is expected to open new horizons towards the improvement of dental implants performance in order to enhance the quality of peoples lives in the community.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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