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Review Article

Titanium fixture implants treated by laser in dentistry: Review article

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ABSTRACT

Surface modifications of titanium implants are necessary for predictable implant success, especially in circumstances where the bone is of low density or when rapid implant loading protocols are needed. Currently, overwhelming data regarding different surface modification techniques have been documented; among these, lasers stand out as a clean and effective modality. This article aims to review the studies related to laser-treated titanium implant surface and laser metal sintered titanium implant surface.

1. Introduction

Implant therapy has become a basic healthcare need particularly in countries like Korea or Sweden where the national healthcare insurance coverage includes dental implants for the edentulous patients [1]. The majority of dental implants are made from titanium. Titanium is often regarded as an ideal material for dental implants due to its ability to osseointegrate with bone. Although Branemark's discovery of the direct union of bone to titanium in 1952 was purely serendipitous, he made strides thereafter that led its way to the widespread use of titanium as an implant material [2]. In 1981, Albrekstton et al. recommended six parameters for ensuring successful osseointegration: surgical technique, the status of bone, loading conditions, implant material, implant design, and implant surface [3]. Nowadays, the indications for titanium implants have been stretched to include compromised bone and early or immediate loading protocols [4]. Therefore, advances in titanium surface topography have become integral in the manufacturing process of commercial dental implants.

Various methods for surface modification include:

1) sandblasting,
2) acid etching,
3) anodization,
4) biomaterial coating,
5) laser-treating or
6) a combination of these.

The main reason for altering the implant surface by these methods is for creating an optimal surface roughness of titanium which according to Albrektsson and Wennerberg is a roughness average (Ra) that falls somewhere between 1–2 µm [5]. The ubiquitous Sandblasting Large-grit Acid etching (SLA) surface has a 10 year survival rate of 98.8–99.7% [6]. However, surface texturing methods like (SLA) could produce a hydrophobic surface, while the grit-blasting process could leave behind contaminants [7]. These contaminants could induce unsatisfactory cellular or molecular responses resulting in early marginal bone loss [8]. In this train of thought, lasered surfaces stand out as a contaminant-free alternative which is clean and biocompatible [9]. This article aims to review the studies related to laser-treated titanium implant surface(LTIS) and laser metal sintered(LMS) titanium implant surface.

This review covers the following topics:

1) In-vivo studies that compare LTIS with machined surfaces
2) In-vivo studies that compare LTIS with other surface modification methods
3) laser metal sintering
4) in-vitro studies
5) soft tissue response to lasered titanium surfaces.

An electronic search was conducted on PubMed and Google Scholar using the following keywords: implant, laser, surface treatment, surface, titanium. All articles related to dental implants were included,

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Table 1
These abbreviations were used.

FULL NAME WORD	ABBREVIATION
roughness average	Ra
sandblasting large-grit acid	SLA
laser-treated titanium implant surface	LTIS
laser metal sintered	LMS
removal torque value	RTQ
energy dispersive spectroscopy	EDS
Implant Stability Quotient	ISQ
Bone-to-implant-contact	BIC
Electron probe microanalyzer	EPMA
hydroxyapatite	HA
computer aided design	CAD
Alumina blasted/acid etched	AB/AE
bone area fraction occupied	BAFO
bone mesenchymal stem cells	hBMSCs
krypton fluoride	KrF
3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide	MTT
Human gingival fibroblast	HGF
focal adhesion kinase	FAK
pocket depth	PD
versus	VS

there was no exclusion criteria due to the limited number of studies in laser treated dental titanium implants. (Table 1)

2. Discussion

2.1. In vivo studies: LTIS VS machine surfaces

Branemark's original implants were machined and had a relatively smooth surface. These implants were free of impurities and had a proven track record but required 3–6 months for healing before loading [10]. Allegrini et al. conducted an in-vivo study on rats which compared machined titanium surfaces with LTIS at 15 days and 30 days post insertion into the right and left femur. Accelerated bone deposition at the implant and bone interface were present for LTIS in contrast to machined surfaces after 15 days. The same study reported Ra values for machined surfaces and LTIS to be 0.67 μm and 2.01 μm respectively, clearly establishing the roughness of LTIS in the optimal zone [11]. Allegrini's in-vivo studies indicate faster healing capacity in LTIS which favors rapid loading protocols, thus, reducing waiting time for final restorations on implants. The removal torque value (RTQ) is another important indicator of strong osseointegration.

Cho and Jung implanted 7 machined surface implants and 7 LTIS in rabbit tibiae, 8 weeks after implantation the average removal torque for LTIS was 62.57 ± 10.44 Ncm and 23.58 ± 3.71 Ncm for machined surfaces [12]. In the same vein, albeit with larger sample size, Faeda et al. inserted implants into rabbit tibiae, they summarized that LTIS has the potential for increasing RTQ, achieving optimal Ra value, and producing a rich oxide layer on the implant surface [13].

Trisi et al. achieved similar results in a sheep model where the implants were placed in the iliac crest to mimic low-density bone, here the RTQ were almost three-fold in the LTIS specimens when compared to machined surfaces [14], thus confirming the viability of LTIS in bone with low quality.

Palmquist et al. published consecutive studies that experimented with LTIS. The first study used Titanium Alloy implants (TI6AL4V) in rabbits, using 10 machined surface implants as the control against 10 LTIS implants. Although the implants were only partially treated by laser (valleys of the four upper threads), results obtained after 8 weeks showed a 270% increase in RTQ for LTIS compared to machined surface implants. Furthermore, histological sections of torqued-out LTIS revealed fractures in the mineralized bone instead of the bone-implant interface area, and this was attributed to the direct bone-bonding to the nano-porosities created by laser melting [15]. Subsequently, Palmquist et al. researched with laser-treated commercially pure Titanium and compared them with machined surfaces after 6 months, the results were consistent with the previous studies, hence supporting long term osseointegration with strong bonds between LTIS and bone that unite on a nano-level [16].

On the other hand, Hallgren et al. experienced mixed results in their research, their initial pilot study displayed no significant benefit of LTIS over machined surfaces in terms of RTQ, however, their second study which used an optic-mount rail with an in-situ stereomicroscope to monitor the laser treating process produced implants with significantly higher RTQ [17].

2.2. In vivo studies: LTIS VS other surface modification methods (Table 2) [10–14,16–19]

The majority of LTIS studies show promising results when compared to machined surfaces which are considered an unaltered surface. However, because surface modification methods like SLA, modified SLA and anodization are frequently used, it is then necessary to compare LTIS with them. Kang NS et al. documented a significant increase in the RTQ from rabbit tibiae in LTIS compared to implants that had an SLA surface. The study also recorded a larger pore size (20–40 mm) in LTIS in contrast to SLA (0.2-0.5 mm). Moreover, the energy dispersive spectroscopy (EDS) showed a layer that had 26.17% oxygen on LTIS whereas the SLA surface was deprived of it [18].

The Implant Stability Quotient is a measurement for primary stability which is a key factor for success in immediate implant cases [19]. Lee et al. then analyzed the RTQ and resonance frequency by using ISQ of LTIS, LTIS soaked in NaCl and primary cultured cells, they found no significant difference between three treatment methods in terms of RTQ and ISQ measurements [20]. Although, another study conducted by Park et al. also failed to display a significant increase in RTQ for LTIS over modified SLA implants [21], these studies could serve as a

Table 2
RTQ from in vivo animal studies.

Authors	year	species	*n = number implants*	Observed time	Machined (NCm)	SLA/modified SLA (NCm)	Anodized (NCm)	LTIS /LMS (NCm)
Cho and Jung [10]	2003	rabbit	14	8 weeks	23.58	–	–	62.57
Faeda et al. [11]	2009	rabbit	24	4, 8, 12 weeks	23.8, 24.0, 33.9	–	–	33.0, 39.9, 54.6
Palmquist et al. [13]	2010	rabbit	20	8 weeks	12.6	–	–	44.1
Palmquist et al. [14]	2011	rabbit	42	6 months	20	–	–	56
Kang et al. [19]	2011	rabbit	24	8 weeks	–	–	32.83	48.59
Witek et al** [25]	2012	dog	76	1,3,6 weeks	–	40,120,130	–	70,140,200
Stubinger et al. [26]	2013	sheep	54	2, 8 weeks	34.7, 19.9	67.8, 73.1	–	78.5, 189.2
Kang et al. [16]	2014	rabbit	24	6 weeks	–	52.7	–	79.4
Lee et al. [17]	2016	rabbit	42	3weeks / 4weeks	–	41.56/ 42.27	–	39.25* / 39.49
Trisi et al. [12]	2016	sheep	4	8 weeks	30	–	–	86
Park et al. [18]	2018	rabbit	40	7, 10 days	–	12.2, 16.2	–	12.3,16.5

* Laser treated samples that were activated with NaCl.
** Values were estimated from bar chart, actual values were not published in this manuscript.

justification for an alternative surface treatment method that guarantees clinical outcomes, especially for rapid loading cases, which are on par with modified SLA. Anodized implants are largely represented on the implant market as TiUnite;

Kang SH et el implanted 5 commercially available Nobel Biocare implants (TiUnite surface) and 5 LTIS, the RTQ results were 32.83 ± 6.15 Ncm and 48.59 ± 8.07 Ncm, respectively, this significant increase, 148%, according to the author could have been due to the larger pore size in LTIS [22].

Combining or mixing different surface texturizing techniques is the logical step towards creating the ideal surface for predictable outcomes in dental implant therapy. Accordingly, acid etching LTIS was an idea explored by Rong et al., the authors found similar Bone-to-implant-contact (BIC) values at 2 weeks and 4 weeks in acid-etched LTIS and SLA implants, but the Electron probe microanalyzer (EPMA) revealed Aluminium particles on SLA surfaces, whereas the LTIS were free of contaminants [23]. Faeda and colleagues coated LTIS with hydroxyapatite(HA) via the biomimetic method, they noted that implants treated this way had superior RTQ compared to machined surfaces and LTIS without HA.

Although the roughness of the LTIS + HA surface was similar to LTIS, the chemical presence of HA was thought to be the reason for the significant increase in RTQ [24]. Karin et al. conducted a similar study on 30 male rabbit tibiae; they concluded that LTIS is capable of decreasing healing time, encouraging osseointegration in the initial phase post-surgery, while HA served as an adjuvant to promote healing [25].

2.3. Laser metal sintering

The advent of laser metal sintering (LMS) introduced a method for attaining a laser exposed titanium surface directly from titanium powder, thus bypassing having to machine titanium prior to subjecting it to laser. Consequently, 3D custom shapes of titanium could be manufactured economically by a direct laser beam that fuses a thin layer of a localized region of titanium powder by melting it in accordance to its 3D computer aided design (CAD) [26].

LMS implants were reported to have a 99.5% success rate in human patients after a 1 year follow up, a two-stage technique was used with a healing period of 2–3 months in the mandible and 3–4 months in the maxilla [27]. Although only 1 implant failed out of 201 implants [27], this study does not indicate the potential of LMS implants for rapid loading protocols and success in bone with poor quality.

LMS implants were then compared with Alumina blasted/acid etched (AB/AE) implants, Witek et al. found higher RTQ in dog jaws with LMS implants in contrast to those inserted with AB/AE surface, these higher values were distinctly obvious in the first week following implantation [28]. The authors found the histomorphometric results: the BIC and bone area fraction occupied (BAFO) to reflect the biomechanical measurements only at 1 week after insertion of implants [28]. Similarly, Stubinger and colleagues placed three different titanium implants (Machined, SLA, LMS) in the pelvis of sheep, RTQs were significantly higher in LMS implants in comparison to the other implants after 8 weeks, however BIC values were considered similar in all implants [29].

2.4. In vitro studies

On a cellular level osteoblast cell adhesion to titanium could be evaluated via the use of primary culture cell lines or tumor cell lines [30]. Romanos et al. used two different laser beams, Group 1 CO_2 laser, Group 2 Er,Cr:YSGG laser to irradiate titanium discs that were either machined, coated with HA, sandblasted or Titanium plasma sprayed; Group 3 as control, were the modified and machined implants that were not irradiated by laser. Although osteoblast (from human osteosarcoma cell line SaOS-2) colonized the titanium discs in every group, the authors only described the laser irradiated groups as having good cell maturation (presence of filipodia) [30].

Wang and colleagues evaluated the surface characterization and osteogenic potential in machined, SLA and LMS titanium implants [9]. Surface characterization was analyzed under a scanning electron microscope and X-ray photon spectroscopy, the study found significantly higher Ra value in LMS samples (6.02 ± 0.35) μm relative to machined (0.27 ± 0.03) μm and SLA surfaces (2.92 ± 0.04) μm.

Consistent with Rong et al., Aluminium traces were present on SLA samples, indicating the presence of impurities from the sandblasting with Al2O3 which is part of the proprietary process of Institute Straumann AG. Another substantial finding, was that human bone mesenchymal stem cells (hBMSCs) were attached to the LMS titanium 1.29–1.31 times more than SLA titanium [9].

These results have been consistently documented in in-vitro studies on LTIS, Chu SF et al. had similar results in terms of surface purity, osteoblast adhesion (MG-63 osteosarcoma cell line) and hydrophilicity favoring LTIS over polished surfaces and SLA surfaces, although the SLA samples were rougher they displayed the least cell proliferation through 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay at every observation time point (24 h,72 h,120 h). Additionally, the Alkaline phosphatase(ALP) and PGE2 levels which are key osteogenic markers, were significantly higher in LTIS [31].

Contrarily, Gyorgyey et al. found no statistical difference between sandblasted acid etched titanium, Nd:YAG Laser treated titanium and krypton fluoride (KrF) excimer laser treated titanium when analyzed with MTT assay and Alamar Blue dye, they found good osteoblast(MG-63) adhesion in all three samples [32]. A unique detail in Gyorgyey et al.'s study is the fact that the lasered titanium samples were sandblasted and acid etched prior to laser ablation, they also found that laser-treating caused a significant decrease in roughness despite displaying a similar amount of MG-63 adhesion.

2.5. Soft tissue response to lasered titanium surfaces

The interface between titanium and connective tissue fibroblast cannot be overlooked because it creates the appropriate barrier for preventing noxious bacterial invasion and epithelial ingrowth [33]. Numerous studies have documented poorer fibroblast adherence to sandblasted titanium in contrast to smooth machined surfaces [33,34].

However, laser treated titanium implant collars have displayed good connective tissue attachment in humans, Nevins et al. harvested the implants en bloc together with surrounding hard and soft tissues 6 months after implant insertion, the histology and SEM results showed direct adhesion of connective tissue to the lasered collars in between the apical termination of junctional epithelium and alveolar bone crest [35]. Nonetheless, it is impossible to generalize Nevin et al.'s results due to the small sample size (n = 4) and the fact that the harvested implants were those that did not contribute to the restoration of the dental arch [35], essentially these implants were unloaded and non-functional samples.

In line with the human study, recent in vitro experiments have found laser microchannels at 5 μm expressing higher amounts of adhesion protein and larger fibroblasts cells in contrast to smooth machined surfaces [36]. Lasered titanium surfaces also promote higher human gingival fibroblast (hGF) and focal adhesion kinase (FAK) levels compared to polished and sandblasted surfaces [37]. Laser treating titanium with extra pulses produced deeper porosities on the titanium surface, these deep holes were surrounded by beads which appeared to be the preferred site for fibroblast adhesion, Heinrich et al inferred that Lasered implants could prevent the downward growth of plaque [38].

Moreover, Rath et al. observed significantly less probing pocket depth(PD) (1.5 mm at 6months, 1.667 mm at 12 months) in patients who received laser treated titanium implants in comparison to machined implants(2.083 mm, 2.167 mm) [39]. These results advocate lasers for texturizing titanium implants particularly around the collar to form a mucosal seal which is important for maintaining successful osseointegration.

Laser-treated titanium implant surface and laser metal sintered titanium offer promising results in terms of osseointegration and soft tissue attachment between junctional epithelium and crestal bone. The 3D surface geometries with holey structures produced by laser treating titanium promote osteoblast adhesion and fibroblast growth. Despite being less rough than SLA surfaces, lasered surfaces appear to attract a similar amount of osteoblast cells, this could be attributed to the lack of contamination or the optimal roughness range of lasered surfaces. The placement of bone grafts into fresh extraction sockets immediately after SLA titanium implant insertion was reported to improve the primary stability of the implants [19]. Similar experiments with lasered implants should be conducted to prove any hypothetical advantage that lasered implants could offer over other surface modification modalities, particularly when there are gaps between the implants and the buccal or lingual bone.

Additionally, multiple in-vivo studies done to assess the RTQ of implants seem to demonstrate higher values in lasered samples, even when compared with anodized and SLA surfaces. The majority of animal studies in this review used rabbits for assessing post-implant RTQ, the main reason for this could be because rabbits are more cost effective compared to other animals such as dogs or sheep, rabbits are also easy to handle and have the ideal size for implant insertion [40].

One of the countries that have included implant therapy into their national health insurance policy is Korea. According to the National Health Insurance Review and Assessment Service from the Republic of Korea, the highest level of evidence (Level 1) should be given to systematic literature reviews targeting randomized controlled trials with or without meta-analysis [1]. Clearly, further research ideally through multicenter randomized clinical trials should be conducted to prove the efficacy of lasered titanium surfaces as dental implants, long-term success (more than 5 years) in human subjects should be documented longitudinally. Recently, immediate implant loading has garnered more acceptability due to the quicker treatment time, instantaneous esthetics, early function and the ability to prevent the mesial migration of posterior teeth into the edentulous space in single tooth implant sites [6]. Future studies pertaining to immediate loading with LTIS and LMS implants should be conducted.

3. Conclusions

Although existing literature cannot justify with certainty the success of using LTIS and LMS titanium implants for low-density bone and immediate loading protocols, conflicting studies suggesting any deleterious effects of LTIS, were to the best of this author's knowledge scarce. The outcome of analysis shows that lasers could produce titanium implants with surfaces that are biocompatible, contaminant free, high in oxide content, and displays high removal torque after osseointegration.

Therefore, LTIS and LMS should at least be regarded as a viable alternative to other more popular surface modifying techniques that dominate the implant market such as SLA and Anodization.

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Ethics approval

This is the review article so there is no requirement for the IRB No. from the committee for ethic approval.

Declaration of Competing Interest

We also had no conflict of interest with any organization.

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