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Changes in implant abutment topography following surface instrumentation

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ABSTRACT

Introduction: This experimental laboratory study aimed to evaluate the surface roughness (Ra and Rz) and the shape of surface topography (Rsk) following two different types of surface instrumentation. *Method*: Twenty-one MegaGen® implant abutments were divided into three different groups. In group 1, the abutments were left un-instrumented as a control, in group 2, rubber cups with pumice were used or treated and in group 3, the instrumentation was done using Er, Cr: YSGG laser with a wavelength of 2780nm, 1.5W power setting with the pulse repetition rate of 30Hz and applied using a radical firing perio tip for two minutes. Quantitative and qualitative evaluations were done using a profilometer. *Results*: Results showed no significant differences in Ra value among the tested groups whereas the significant differences in Rz value were observed among all treated groups ($p<0.05$) as the p-value equal to 0.02 and 0.01 in pumice-laser and control-laser groups respectively. The shape of 3D surface topography (Rsk) was found to be the same in the laser-treated and control groups, with the presence of more valley, lesser peak and the possibility of deep scratches Er, Cr: YSGG laser produced rougher abutment surface and able to maintain manufacturer lines, in comparison with the control group. *Conclusions*: In contrast, rubber cups and pumice could produce smoother surface outcomes.

Keywords: Dental implant, surface roughness, profilometer, Er, Cr: YSGG laser

1. INTRODUCTION

Currently, piles of dental implant systems have been introduced into the market with the annual global sales have reached 12 to 18 million implants, representing more than 100 commercial brands (Klinge et al., 2018). Despite higher success rates having been reported and reaching up to 95 percent in 10 years of survival rates Buser et al., (2012), Jemt, (2016), the implants may suffer from biological complications which are termed peri-implant disease. According to the consensus report of the 6th European Workshop of Periodontology, peri-implant mucositis is defined as an inflammatory reaction in the mucosa surrounding a functional implant, while peri-implantitis can be defined as inflammation that affects the soft tissue around the osseointegrated implant in function and thus results in loss of supporting bone structure (Lindhe and Meyle, 2008). The disease is commenced by the dysbiotic imbalance of the oral microflora. In a healthy patient, the peri-implant organism consists mainly of gram-positive cocci and non-motile bacilli species.

On the contrary, high numbers of cocci, motile bacilli, and spirochetes species are reported in peri-implant mucositis, while the dominant population by the red complex species (*Porphyromonas gingivalis, Tannerella forsythia,* and *Treponema denticola*) are noticed in peri-implantitis (Carcuac and Berglundh, 2014). Studies have concluded that the disease can develop similarity in terms of immune- and histopathology characteristics with the disease influencing the natural teeth. The long-term success and survival of implants predominantly depend upon long-term maintenance as well as excellent oral care. According to Mombelli, (2018), maintenance therapy may have a good impact and be more cost-effective than primary prevention in cases following post-extensive periodontal treatment and implant therapy. It is believed that a constant periodic maintenance regimen along with effective plaque control is a crucial element in achieving healthy tissue around the implant structure. To stop future damage, it is crucial to manage both local and risk systemic factors such as plaque control, diabetes, smoking, and peri-implant inflammation (Rosing et al., 2019).

Various type of armamentarium has been suggested for implant cleaning, ranging from manual hand scaler to ultrasonic-powered driven scaler device. Ideally, the instrument should be effective, cause less damage to the surface, and be durable. Deterioration on the implant surface may enhance plaque development and threaten the biocompatibility of the implant system (Lang et al., 2016). Further changes in chemical composition, surface free energy, and surface coating further influence microorganism colonization toward the implant surface (Nascimento et al., 2014). In the earliest study, plastic curette was largely recommended for instrumentation during the maintenance phase, as it caused the least damage compared with the metallic curette (Fox et al., 1990).

However, they were more fragile and their bulky design made it difficult to reach all the surfaces to be cleaned. In addition to that, limited flexibility may further prevent instrument adaptation and decrease cleaning efficiency (Louropoulou et al., 2014). Plastic curettes also may produce vertical microgrooves on the component of the prosthetic part and are found to be ineffective for the removal of mature calculus (McCollum et al., 1992). "Light amplification by stimulated emission of radiation" also known as laser, has been widely introduced in every field of dentistry, including implant therapy as it is found beneficial to both clinician and patient. In periodontology, the application varies from calculus removal, soft tissue excision, incision, decontamination, ablation, bio-stimulation, bacteria irradiation, and osseous surgery. Erbium-doped yttrium aluminium garnet (Er: YAG) and Erbium-doped chromium yttrium scandium gallium garnet (Er, Cr: YSGG) lasers have a higher range of wavelength and are suitable in osseous surgery.

While diode and Neodymium-doped yttrium aluminium garnet (Nd: YAG) lasers are more highly absorbed by haemoglobin and commonly used when coagulation is mandatory. Therefore, this in vitro study aimed to assess the effect of hygiene instruments on the titanium implant abutment surface, namely the untreated (control), treated with Er, Cr: YSGG laser and, rubber cup with pumice powder. The knowledge about these hygiene instruments used for implant care could be useful in selecting the most appropriate and least damaging method for cleaning the implant abutment and preventing the colonization of bacteria.

2. METHODOLOGY

Study design

This experimental laboratory study was analyzed by profilometry scanning.

Study duration and period

The study period started on November 9, 2021, and ended on March 9, 2022.

Titanium-implant abutment samples

Twenty-one Megagen® titanium-implant abutments were randomly divided equally into three groups: Untreated/control group, rubber cup with pumice, and Er, Cr: YSGG laser (Waterlase ExpressTM, Biolase Technology, San Clemente, CA). In this study, the transmucosal part with a dimension of 2x3mm surface area was selected for instrumentations and, the apical portion attached to the impression component, Megagen® analogue, with a diameter of 4.5mm, and length of 12.0mm. The analogue was embedded into a 2x2x2cm box of shaped dental stone and labelled (Figure 1).

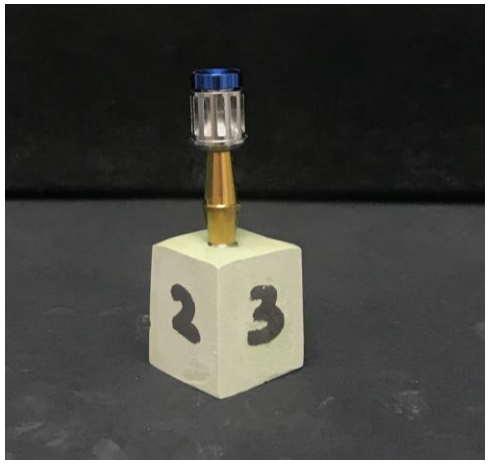

Figure 1 The apical portion of Megagen® abutment was attached to the analogue embedded into 2x2x2cm of dental stone

Group 1: Control (n= 7)

Samples were directly unpacked from the sterile packages and irrigated with normal saline and fixed with 25% glutaraldehyde. The abutments were left un-instrumented as a control.

Group 2: Rubber cup with pumice (n= 7)

Samples were treated with a rubber cup polishing kit with the pumice, wetted with normal saline, and polished perpendicular onto the abutment surface while moving in a gentle motion. The rubber cup was rotated with a contra-angle slow-speed hand piece at an approximate speed of 2,000rpm for 2 minutes' duration on all surfaces (Figure 2).

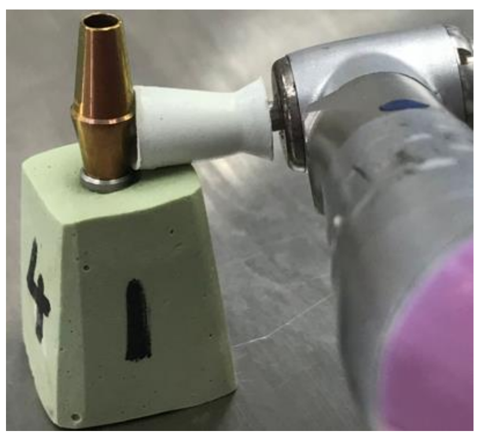

Figure 2 Rubber cup with pumice was instrumented perpendicular to the abutment surface

Group 3: Erbium-doped chromium yttrium scandium gallium garnet laser (n= 7)

The selected samples were instrumented using Er, Cr: YSGG laser, a wavelength of 2780nm and applied using a radical firing perio tip (RFTP5-14mm, Biolase). The laser parameter was set at a power output of 1.5 watts. Upon application, the laser tip was aligned parallel toward the implant surface, at a focal distance of 0.5mm, for 120 seconds for each sample. In addition to that, the laser pulse was set at 30Hz with air and water irrigation at 50% of the maximum (Strever et al., 2017) (Figure 3).

All treated abutments were irrigated using normal saline and fixed with 25% glutaraldehyde overnight. The samples were dried, wrapped in sterile 2x2cm dry gauze, and stored in individual compartments before mounting and scanning procedures.

Quantitative and qualitative assessments using profilometer

All samples of abutment were scanned using a laser profilometry scanner (3D optical surface texture analyzer; model: Infinite Focus® Real 3D Alicona). The specimen was placed onto the motorized stage and illuminated with modulated white light. In this experiment, the parameters measured were average surface roughness (Ra; μm) and the mean roughness profile depth (Rz; μm). In addition to that, the Rsk value was compared between the groups. The captured image was viewed and the surface roughness was measured using an Infinite-Focus Microscope (IFM) via a computer system.

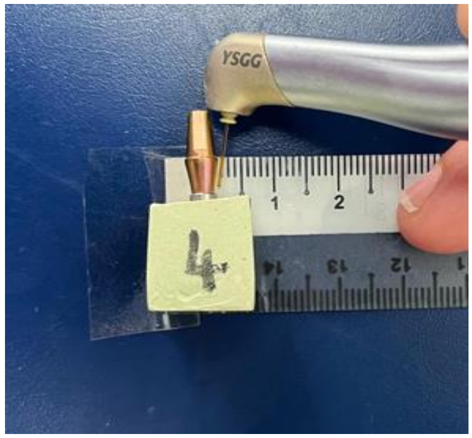

Figure 3 The laser tip was positioned parallel to the abutment surface in a non-touching mode

Statistical analysis

The data was analyzed using Statistical Package for Social Sciences (SPSS) version 27. The data was entered, checked for any data entry errors, explored, and cleaned. Frequencies and means for each item score were tabulated and any missing records were verified. Assumptions were made before running statistical tests. The significant level was set at $p<0.05$ and a confidence interval of 95%.

3. RESULTS

Average surface roughness (Ra)

Results revealed the mean value for Ra of control, rubber cup with pumice and Er, Cr: YSGG laser groups were 0.199μm, 0.210μm and 0.221μm, respectively (Table 1). There was a slight increase in Ra value following surface instrumentation using both rubber cups with pumice and Er, Cr: YSGG laser. From the data analysis, the Ra value was not significant, as the p-value was calculated as 0.065 ($p>0.05$). Therefore, there is no difference in Ra value among the treated groups (Table 2).

Table 1 Mean and median value for Ra in between groups

Group	Sample	Mean	Median
Control	28	0.199	0.194
Rubber cup with pumice	28	0.210	0.206
Er, Cr: YSGG laser	28	0.221	0.219

Table 2 Statistical analysis of Ra value using ANOVA test

	Sum squares	df	Mean square	F	Sig
Between groups	.006	2	.003	2.826	.065
Within groups	.091	81	.001	-	-
Total	.098	83			

Mean roughness profile depth (Rz)

The mean values for Rz of control, rubber with pumice and Er; Cr: YSGG laser were found as 1.05μm, 1.070μm and 1.201μm, respectively (Table 3). It showed an increased pattern of Rz value following instrumentation compared with the control group. During the data analysis, the data distribution was abnormal and after some consideration, outlier data was removed before analysis. Following that, ANOVA was used to examine the data and to detect any significant differences between them (Table 4). Furthermore, the Bonferroni post hoc test revealed a significant difference in Rz value between Er, CR: YSGG laser with rubber cup with pumice groups; and Er, CR: YSGG laser with the control group, as the p-value lesser than 0.05 (p-value equal to 0.02 and 0.01, respectively) (Table 5).

Table 3 Mean and median value for Rz in between groups

Group	Sample	Mean	Median
Control	28	1.057	1.071
Rubber cup with pumice	28	1.070	1.035
Er, Cr: YSGG laser	28	1.205	1.203

Table 4 Statistical analysis of Rz value using ANOVA test

	Sum squares	df	Mean square	F	Sig
Between groups	.357	2	.178	5.650	.005
Within groups	2.462	78	.032	-	-
Total	2.819	80			

Table 5 Post hoc analysis of Rz value using Tukey HSD and Bonferroni

	(I) treatment	(J) treatment	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
Tukey HSD	Control	Pumice	-.01354	.04792	.957	-.1280	.1010
		Laser	-.14853*	.04882	.009	-.2652	-.0319
	Pumice	Control	.01354	.04972	.957	-.1010	.1280
		Laser	-.13499*	.04839	.018	-.2506	-.0194
	Laser	Control	.14853*	.04882	.009	.0319	.2652
		Pumice	.13499*	.04839	.018	.0194	.2506
Bonferroni	Control	Pumice	-.01354	.04792	1.000	-.1308	.1037
		Laser	-.14853*	.04882	.010	-.2680	-.0291
	Pumice	Control	.01354	.04792	1.000	-.1037	.1308
		Laser	-.13499*	.04839	.020	-.2534	-.0166
	Laser	Control	.14853*	.04882	.010	.0291	.2680
		Pumice	.13499*	.04839	.020	.0166	.2534

Surface skewness (Rsk)

In this study, descriptive analysis was done using a parameter labelled as Rsk, to evaluate the shape of surface topography height distribution. Analysis revealed negative mean values in both the control and laser groups (-0.097 and -0.157) (Table 6). This indicated the presence of more valleys, fewer peaks and the possibility of deep scratches (Figure 4).

Table 6 Mean value for Rsk between the tested groups. The negative and positive values were noted between groups

Group	Mean
Control	-0.097
Rubber cup with pumice	0.108
Er, Cr: YSGG laser	-0.157

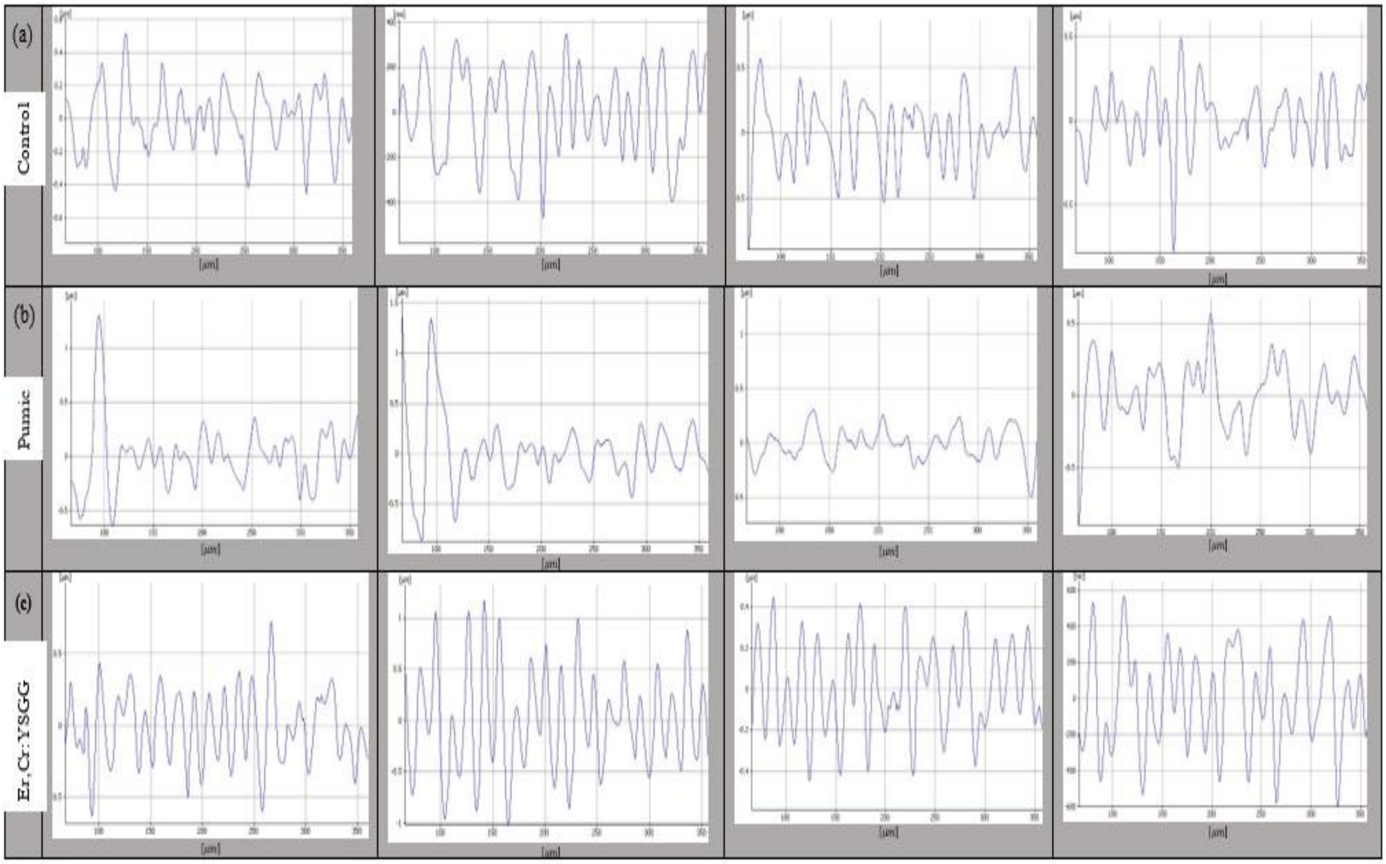

Figure 4 Graph analysis between groups to determine the surface texture differences based on valley and peak distribution for sample no 1 of (a) control, (b) pumice and (c) Er, Cr: YSGG laser

4. DISCUSSION

Experimental finding

Implant instrumentation is vital to ensure the longevity of the prosthesis by preventing the development of diseases such as peri-implantitis. The instrument should effectively clean the implant surface without causing any surface alteration, maintaining biocompatibility. Research in this field has evaluated the surface changes against various types of instrumentation, either metal or non-metal, and diverse results have been obtained. Recently, the laser has been introduced as one of the options available with promising outcomes. This experiment aimed to study the topography changes on the implant surface abutment following instrumentation using a pumice and Er, Cr: YSGG laser. The presence of a micro-gap area between the fixture-abutment interface and superstructure is the potential area for bacteria deposition, hence the development of peri-implantitis. It is believed that bacterial leakage at the implant-abutment interface can negatively influence long-term implant survival.

According to Quirynen et al., (1990), changes in surface roughness on the abutment surface play a predominant role in microbial adhesion. In this study, qualitative and quantitative evaluations were done using a profilometer. Procedures that increase surface roughness might be expected to produce a detrimental effect concerning plaque and calculus deposition, while a smooth surface might have the opposite effect. In this current study, there were changes in the average roughness profile of Ra value in the tested groups compared with the non-instrumented group. However, the changes were found to be non-significant. On the contrary, the result revealed a significant change in the Rz parameter.

Profilometer as a descriptor in surface roughness

The quantitative evaluation of the instrumented surfaces was performed using a profilometer. A 3D profilometer was found to be appropriate for measuring the surface roughness as it describes the surface organization (Canabarro et al., 2009). The average roughness profile, Ra, is the arithmetic mean of the absolute values of real profile deviations related to the mean profile. While the average maximum height profile (Rz) is defined as the arithmetic mean of the positive predominant crest and the analogue absolute value of the negative crests. Ra value is a good general description of the height variation, but it was found to be insensitive in measuring short wavelengths (Thomas, 1981).

Different parameters have been recommended for the 3D characterisation of surface roughness. According to Thomas, (1981), assessment with Ra and skewness (Rsk) was adequate in data analysis with Gaussian height distribution. Rsk can be used to describe the shape and height of distribution. Other studies supported this analysis, and it is believed that Rsk data could be used in surface roughness studies (Canabarro et al., 2009). However, there needed to be more studies comparing Rsk value after implant surface instrumentation. In detail, a profile with a high peak and valley filled is considered to have positive skewness. Also, this parameter is easier to measure and insensitive toward deep scratches and other irrelevant surface events.

Surface roughness (Ra, Rz) between control and treated groups of titanium implant abutment surface under profilometer

Analysis revealed no significant difference in Ra value among the groups as the p-value was equal to 0.065 ($p>0.05$). This was in agreement with the previous study, which stated a similar outcome of surface roughness measured following or in comparison with the control group. Most studies reported no significant differences in surface micro-roughness analysis of the implant abutment before and after Er, Cr: YSGG laser treatment (Strever et al., 2017). This was supported by another study by Chegeni et al., (2020), who believed Er, Cr: YSGG laser did not produce a pronounced surface alteration as long it was applied with correct angulation, suitable laser tip, and correct parameter setting. Based on the study, Er, Cr: YSGG laser with side-firing, conical shape tips at 50mJ (1.5W/30Hz) for 60 seconds and a percentage of 50% air and 40% water did not produce surface damage. Delgado-Ruiz and Romanos, (2018) recommended a pulse mode, short periods of laser irradiation, and a correct air-water ratio during surface decontamination.

In this current study, there was a significant difference in a Rz unit between the tested groups ($p = 0.005$). A post hoc test was done using Bonferroni and Tukey HSD. According to Bonferroni's analysis, the significant differences were 0.01 and 0.02 in both laser-control and laser-pumice groups. To date, few studies have compared the Rz value following implant-treated surface. A study by Moeintaghavi et al., (2021) found a significant mean surface alteration between the threads following CO2 and Er, Cr: YSGG laser instrumentation. The experiment involved instrumentation on explanted implants previously diagnosed as peri-implantitis. Qualitative and quantitative findings demonstrated a significant surface alteration among Er: YAG and Er, Cr: YSGG lasers' samples. Micro-explosion secondary to the lasering action and inadequate water irrigation may be responsible for the damaging effect on the surrounding implant surface.

Thus, the author concluded that both approaches should be cautiously used to prevent surface deterioration. This was supported by a study by Koopaie et al., (2020), as Er, Cr: YSGG laser treatment may affect surface roughness, surface topography, wettability property, the chemical composition of the surface, and bacterial count. Even so, no adverse alteration was reported within the control parameter. In this experiment, to standardise the experiment and for optimum laser irradiation, the clinical setting parameter was based on previous work done by (Strever et al., 2017). The power setting was safe as there were no changes in temperature rise, surface micro-roughness, and water contact angle measurement. Maintaining the material's biocompatibility and osseointegration with the surrounding bone is crucial.

The evaluation of Risk of the abutment surface

Risk value is used to assess the asymmetry of surface deviation around the mean plane. The value is zero for the Gaussian surface, which is presented with a symmetrical shape for surface height distribution. While, for the asymmetric distribution of surface height, the skewness can be either positive or negative, as the negative value presented with a longer tail at the lower side of the mean plane, i.e., more valleys than peaks. In this study, the mean value surface treated with Er, Cr: YSGG laser was found to have a negative value (-0.157) corresponding with the control group (-0.097), suggesting the high frequency of features below the mean plane (valleys) and a decrease in the surface peaks. The opposite could be observed from the pumice sample, as the mean value was shown to have a positive result (0.108).

5. CONCLUSION

This study evaluated the effects of proposed oral hygiene instrumentation on commercially titanium alloy implant abutments. Qualitative assessment discovered no significant difference in average surface roughness (Ra) value, while a significant difference was recorded in mean roughness profile depth (Rz) value. There was a similarity in surface skewness (Rsk) between the control and Er, Cr: YSGG lasers' groups, indicating the possibilities of deep scratches and pits between the groups. Er, Cr: YSGG laser produced a rougher abutment surface and maintained manufacturer lines compared to the control group. On the other hand, rubber cups with pumice can present smoother surface results compared to Er; Cr: YSGG lasers.

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Author Contributions

Zanarita Aspanut: Original draft preparation

Hareem Ghaffar, Haslina Taib: Review and editing

Akram Hassan: Supervision, review and editing

Mohamad Arif Awang Nawi: Analysis of data, and final approval.

Ethics Approval

There was no ethics approval in this study.

Informed Consent

Not applicable

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Conflict of interest

The authors declare that there is no conflict of interests.

Data and materials availability

All data sets collected during this study are available upon reasonable request from the corresponding author.

REFERENCES AND NOTES

1. Buser D, Janner SFM, Wittneben JG, Brägger U, Ramseier CA, Salvi GE. 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: A retrospective study in 303 partially edentulous patients. Clin Implant Dent Relat Res 2012; 14(6):839-51. doi: 10.1111/j.1708-8208.2012.00456.x
2. Canabarro A, Figueiredo F, Paciornik S, De-Deus G. Two- and three-dimensional profilometer assessments to determine titanium roughness. Scanning 2009; 31(4):174-9. doi: 10.1002/sca.20156
3. Carcuac O, Berglundh T. Composition of human peri-implantitis and periodontitis lesions. J Dent Res 2014; 93(11):1083-8. doi: 10.1177/0022034514551754
4. Chegeni E, Espanã-Tost A, Figueiredo R, Valmaseda-Castellón E, Arnabat-Domínguez J. Effect of an Er, Cr: YSGG laser on the surface of implants: A descriptive comparative study of 3 different tips and pulse energies. Dent J (Basel) 2020; 8(4):109. doi: 10.3390/dj8040109
5. Delgado-Ruiz R, Romanos G. Potential causes of titanium particle and ion release in implant dentistry: A systematic review. Int J Mol Sci 2018; 19(11):3585. doi: 10.3390/ijms19113585
6. Fox SC, Moriarty JD, Kusy RP. The effects of scaling a titanium implant surface with metal and plastic instruments: An in vitro study. J Periodontol 1990; 61(8):485-90. doi: 10.1902/jop.1990.61.8.485
7. Jemt T. Single-Implant Survival: More than 30 years of clinical experience. Int J Prosthodont 2016; 29(6):551-558. doi: 10.11607/ijp.4892
8. Klinge B, Klinge A, Bertl K, Stavropoulos A. Peri-implant diseases. Eur J Oral Sci 2018; 126 Suppl 1:88-94. doi: 10.1111/eos.12529
9. Koopaie M, Kia-Darbandsari A, Hakimiha N, Kolahdooz S. Er, Cr: YSGG laser surface treatment of gamma titanium aluminide: scanning electron microscopy-energy-dispersive x-ray spectrometer analysis, wettability and Eikenella corrodens and Aggregatibacter actinomycetemcomitans bacteria count- In vitro study. Proc Inst Mech Eng H 2020; 234(8):769-783. doi: 10.1177/0954411920924517
10. Lang MS, Cerutis DS, Miyamoto T, Nunn ME. Cell attachment following instrumentation with titanium and plastic instruments, diode laser, and titanium brush on titanium, titanium-zirconium, and zirconia surfaces. Int J Oral Maxillofac Implants 2016; 31(4):799-806. doi: 10.11607/jomi.4440
11. Lindhe J, Meyle J. Peri-implant diseases: Consensus report of the sixth European workshop on Periodontology. J Clin

Periodontol 2008; 35(8 Suppl):282-5. doi: 10.1111/j.1600-051X.2008.01283.x

12. Louropoulou A, Slot DE, van-der-Weijden F. The effects of mechanical instruments on contaminated titanium dental implant surfaces: A systematic review. Clin Oral Implants Res 2014; 25(10):1149-60. doi: 10.1111/clr.12224
13. McCollum J, O'Neal RB, Brennan WA, van-Dyke TE, Horner JA. The effect of titanium implant abutment surface irregularities on plaque accumulation in vivo. J Periodontol 1992; 63(10):802-5. doi: 10.1902/jop.1992.63.10.802
14. Moeintaghavi A, Bagheri H, Pour MY, Shafiei S, Moslemi H, Abbasi K, Nobar BR, Mehdizadeh A, Ahrari F, Alam M. Effects of diode, CO2, Er: YAG, and Er, Cr: YSGG on titanium implant surfaces by scanning electron microscopy. Adv Mater Sci Eng 2021; 1-8. doi: 10.1155/2021/3551097
15. Mombelli A. Microbial colonization of the periodontal pocket and its significance for periodontal therapy. Periodontol 2000 2018; 76(1):85-96. doi: 10.1111/prd.12147
16. Nascimento C, Pita MS, Fernandes FHNC, Pedrazzi V, de Albuquerque Junior RF, Ribeiro, RF. Bacterial adhesion on the titanium and zirconia abutment surfaces. Clin Oral Implants Res 2014; 25(3):337-343. doi: 10.1111/clr.12093
17. Quirynen M, Marechal M, Busscher HJ, Weerkamp AH, Darius PL, van-Steenberghe D. The influence of surface free energy and surface roughness on early plaque formation: An in vivo study in man. J Clin Periodontol 1990; 17(3):138-44. doi: 10.1111/j.1600-051x.1990.tb01077.x
18. Rosing CK, Fiorini T, Franciso ANS, Muniz WMG, Oppermann RV, Susin C. The impact of maintenance on peri-implant health evidence for peri-implant maintenance. Braz Oral Res 2019; 33(suppl 1):e074. doi: 10.1590/1807-3107 bor-2019.vol33.0074
19. Strever JM, Lee J, Ealick W, Peacock M, Shelby D, Susin C, Mettenberg D, El-Awady A, Rueggeberg F, Cutler CW. Erbium, Chromium:Yttrium-Scandium-Gallium-Garnet laser effectively ablates single-species biofilms on titanium disks without detectable surface damage. J Periodontol 2017; 88(5):484-492. doi: 10.1902/jop.2016.160529
20. Thomas TR. Characterization of surface roughness. Precis Eng 1981; 3:97-104. doi: 10.1016/0141-6359 (81)90043-X