The Effect of Piezoelectric Ultrasonic Scaler Tip Wear on Root Surface Roughness at Different Working Parameters: An Atomic Force Microscopic and Profilometric Study

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Abstract

Objective: This study aimed to evaluate the influence of scaler tip wear and different working parameters, *i.e.*, lateral force, power setting and tip angulation, on the roughness of root surfaces following treatment with piezoelectric ultrasonic scaling devices.

Material: Twenty piezoelectric ultrasonic scaler inserts (10 worn/10 new) were selected to examine the erosion ratio (ER) under atomic force microscopy (AFM). A total of 160 root samples were prepared and instrumented by new (n = 80) and worn inserts (n = 80) at different working parameters (tip angulation, power setting, lateral force). Roughness change (Rc) on root surfaces after instrumentation was examined by a contact profilometer.

Results: Statistically significant differences were found between the mean ERs of new and worn tips ($p < 0.0001$). The various combinations of the assessed working parameters showed synergistic effects resulting in a wide range of root surface roughness. The present study found the higher Rc in the group with a 45° angulation, (P10) high power setting and 1.0 N lateral force (subgroup 8) when compared to other groups. Among the groups, the worn scaler tips subgroup 8 showed a higher Rc (5.692 ± 0.81) when compared to new scaler tips subgroup 8 (4.798 ± 0.51; $p < 0.001$).

Conclusion: The findings of the present study highlighted that scaler tip wear strongly influences the root surface roughness when used at higher tip angulation, lateral force and power settings. Hence, ultrasonic scaler tip wear should be periodically evaluated and should be considered as much as the other working parameters.

Key words: Piezoelectric, root surface roughness, working parameters, scaler tip wear

Introduction

Periodontal diseases are primarily caused by bacterial colonization on the root surfaces of teeth. The root surface topography has a noteworthy impact on clinical attachment and biofilm formation after root planing (Rosales-Leal *et al.*, 2015). The perfect instrument for initial periodontal treatment should be able to remove all unessential substances from the root surfaces without iatrogenic effects. Guiding the patient to maintain oral hygiene together with mechanical scaling and root planing is the introductory treatment completed by the clinician to accomplish this goal (Solis Moreno *et al.*, 2012).

Initially, this goal was achieved with hand instruments such as the sickle, chisel, files, hoes and curettes. Later sonic and ultrasonic scalers were used for the same purpose, which was less time consuming and more effective than using hand instruments (Arabaci *et al.*, 2007). Ultrasonic scaling systems are usually utilized as a part of dentistry for the debridement of plaque and calculus from the root and tooth surfaces and have appeared to be as successful as hand instrumentation for enhancing periodontal health (Kamath *et al.*, 2014).

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Ultrasonic scalers are driven by generators that convert electrical energy into ultrasonic waves by means of piezoelectricity or magnetostriction. Several studies have reported comparable clinical outcomes with respect to the utilization of magnetostrictive and piezoelectric ultrasonic scaler devices (Lie and Leknes, 1985; Jotikasthira *et al.*, 1992). However, the piezoelectric ultrasonic scaler was found to be a much more procedure-sensitive gadget. Without proper use, the clinical result of piezoelectric scaling may be compromised, possibly bringing about root surface roughness and inadequate deposit evacuation (Busslinger *et al.*, 2001).

Ultrasonic instruments are equipped for expelling endotoxins from the root surface without cementum or dentin removal or huge root surface alteration (Risko *et al.*, 1996). However, improper application of the ultrasonic scaler tip to the tooth surface or inadvertent over-instrumentation of calculus-free subgingival root zones may bring about surface modifications including gouges, nicks and scratches on the tooth. Piezoelectric ultrasonic scalers should be utilized with high lateral pressure and at high power settings for efficient subgingival scaling in initial periodontal treatment. However, piezoelectric ultrasonic scalers may lose a vital purpose of using them over hand instruments (Busslinger *et al.*, 2001).

The adjustment in the working parameters has an impact on the root surface roughness. Working parameters including tip angulation, the power setting, instrument contact time, tip design, and lateral force are related to the degree of root damage (Zappa *et al.*, 1991; Arabaci *et al.*, 2013).

Two studies have investigated the impact of tip angulation, generator power and lateral pressure on root surface alteration. It has been proposed that scaler tip angulation has a greater influence on root surface defects, followed by lateral pressure and power setting. It has also been proposed that the cumulative increased lateral forces and tip angulations bring about more prominent deformity on the root surface at any power setting (Chapple *et al.*, 1995; Lea *et al.*, 2006).

With clinical utilization, scaler tips may get worn and shorter in length. It has been reported that scaler tip wear diminishes its displacement amplitude and chipping action (Flemmig *et al.*, 1998a, 1998b).

It has been reported that 1 mm of tip wear results in around 25% loss of scaling effectiveness, and 2 mm of tip wear results in roughly 50% loss of scaling efficiency. Hence, scaler tip wear is also considered as an important working parameter that influences scaling efficiency (Busslinger *et al.*, 2001; Lea *et al.*, 2009).

In spite of the fact that the impact of power setting, tip angulation and the lateral pressure have been examined, the impact of tip wear on root surface topography is still unevaluated. Hence, the present investigation was to determine the impact of piezoelectric ultrasonic scaler tip wear on root surface roughness and its association with working parameters, which included 0.5 and 1 N lateral forces; medium (P5) and high (P10) power settings, and 0° and 45° tip angulations.

Materials and methods

Study samples included twenty EMS piezoelectric ultrasonic scaler tips (DS-001A; Electro Medical Systems, Nyon, Switzerland) and 160 extracted maxillary and mandibular single rooted teeth. This study was conducted in the Department of Periodontology in our institution. The study was affirmed by the institutional review board for ethical clearance of our institution. This study was conducted according to the Helsinki declaration of 1975, as revised in 2000.

Ten EMS scaler tips not exposed to any process were examined as new scaler inserts and the other ten inserts were reduced by 1 mm by holding the tip against a stone driven handpiece. A digital vernier calliper (Mitutoyo Digital Vernier Caliper, Japan) was utilized to gauge the 1 mm distance and the marked area was ground away using the top end of a stone that mimics the impact of tip wear resulting from long-term use.

Examination of erosion ratio (ER) of scaler tips

The surface integrity and erosion ratio (ER) of new and worn inserts was inspected and analyzed by using an atomic force microscope (AFM; Bruker; Icon ScanAsyst: Dimension FastScan Bio™, UK). The AFM examination was done at the lateral aspect of tip edges in air at room temperature.

Tooth sample preparation

A total of 160 teeth without root defects were selected and cleaned for 30 seconds in running water to eliminate blood and other debris. Teeth were then preserved with 10% buffered formalin for a maximum of 90 days and again washed in water and then polished with pumice to clear away all debris. Subsequently the samples were partly fixed in resin, leaving the flat root surface exposed. For accurate angulations, a flat root surface was chosen. The flat root surface area was considered approximately 1-2 mm below the cementoenamel junction, usually in the cervical one third of root samples.

Instrumentation of tooth samples

The instrumentation of the root surface was done by utilizing an EMS piezoelectric ultrasonic scaling unit as per the manufacturer's guidelines, in a standard mode with a water rate of 30 ml min^{-1} for 60 seconds for each sample. The samples were divided randomly into two groups. Eighty samples were selected for instrumentation of root surface of teeth using new ultrasonic scaler inserts, and 80 samples were selected for instrumentation of root surface of teeth using worn ultrasonic scaler inserts. The groups were divided further into eight subgroups (1-8). Each subgroup consisted of 10 root samples and was instrumented using a combination of three different working parameters (0° and 45 ° tip angulation; medium (P5) and high (P10) power setting and 0.5 N and 1.0 N lateral force) under standardized conditions using an adjustable sledge device. The subgroups were categorized as illustrated in *Table 1*.

Estimation of root surface roughness

The root surface roughness was characterized as the average of peak and valley separations measured along the centerline of one cut-off length. The estimations were calculated three times on every example prior to and then after ultrasonic instrumentation by a contact profilometer (Mitutoyo SJ-301, Japan). The surface integrity (roughness) was quantified in micrometers before the samples were instrumented. The arithmetical mean of surface integrity was denoted as average roughness (Ra). Profilometry showed maximum and minimum lines drawn at the highest peak and lowest valley. The mean line was determined by equating the areas defined by the profile curve above and below the minimum and maximum lines. The mean difference between pre- and post-instrumentation roughness values on root surfaces was determined as roughness change (Rc) for each sample.

Statistical analysis

The data were processed and analyzed with statistical software (SPSS version 15.0; SPSS, Chicago, IL, USA). The data were expressed as mean ± standard deviation (SD). An independent sample *t*-test was used to analyze the mean ER of new and worn tips. The unpaired *t*-test was used for inter- and intra-group comparison of Rc values. A value of $p < 0.05$ was considered statistically significant. A sample size of 80 had a 95% confidence interval and the power of the study was calculated as 0.90.

Results

AFM results

The ER value (nm) of new and worn scaler tips was analyzed with an AFM and the comparison of ER values is shown in *Figure 1*. The mean ± SD of the ER for new and worn scaler tips was 8.69 ± 1.26 nm and 65.65 ± 18.59 nm, respectively. There was a statistically highly significant difference found between the ER of new and worn scaler tip groups ($p < 0.0001$; CI = 95%).

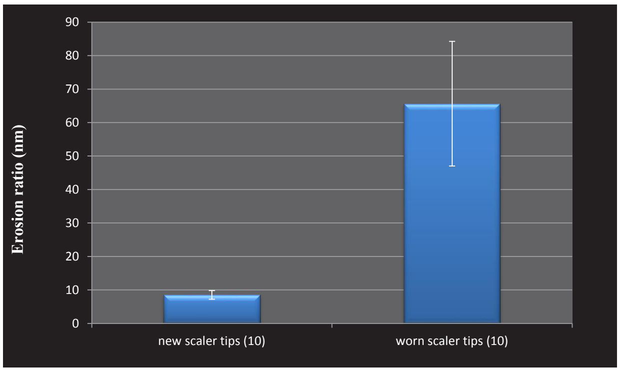

Fig. 1. Comparison of erosion ratio (ER) values (nm) of worn and new scaler tips.
(Student's paired t-test, p < 0.0001; CI = 95%; n = 10)

Table 1: Categorization of new and worn scaler tips subgroups based on working parameters.

Subgroups (n = 10)	New tips (Group I) (n = 80)	Worn tips (Group II) (n = 80)
1	0 °, P 5, 0.5 N (n = 10)	0 °, P 5, 0.5 N (n = 10)
2	0 °, P10, 0.5 N (n = 10)	0 °, P10, 0.5 N (n = 10)
3	45 °, P 5, 0.5 N (n = 10)	45 °, P 5, 0.5 N (n = 10)
4	45 °, P10, 0.5 N (n = 10)	45 °, P10, 0.5 N (n = 10)
5	0 °, P 5, 1.0 N (n = 10)	0 °, P 5, 1.0 N (n = 10)
6	0 °, P10, 1.0 N (n = 10)	0 °, P10, 1.0 N (n = 10)
7	45 °, P 5, 1.0 N (n = 10)	45 °, P 5, 1.0 N (n = 10)
8	45 °, P10, 1.0 N (n = 10)	45 °, P10, 1.0 N (n = 10)

Profilometric analysis

Evaluation of surface roughness (Ra) and roughness change (Rc)

The pre- and post-instrumentation mean surface roughness values of root surfaces (Ra) were obtained for the new scaler tip groups and worn scaler tip groups by using profilometric analysis. Then, the pre- and post-instrumentation mean Ra value differences were calculated for each sample and considered as roughness change (Rc). Both the Ra and Rc values are expressed in μm.

Intra-group comparison of Rc among new scaler tip subgroups

The intra-group comparisons between new and worn scaler tip subgroups (Rc values) are described in *Table 2*. The highest Rc measurement was recorded in subgroup 8 (4.8 ± 0.51 μm), followed by subgroup 7 (4.02 ± 0.35 μm) and subgroup 4 (3.73 ± 0.45 μm). The lowest Rc measurement was recorded in subgroup 1 (0.82 ± 0.27 μm) followed by subgroup 2 (0.92 ± 0.44 μm). The differences in Rc measurements recorded among almost all subgroups was found to be statistically significant ($p < 0.001$; CI = 95%).

Table 2. Intra-group comparisons of Rc values following instrumentation by new and worn scaler tips under different working parameters.

Subgroups (n = 10)	New scaler tips	Worn scaler tips
	p values	
1-2	0.5	0.5
1-3	0.00001*	0.00001*
1-4	0.00001*	0.00001*
1-5	0.08	0.4
1-6	0.006*	0.1
1-7	0.00001*	0.00001*
1-8	0.00001*	0.00001*
2-3	0.00001*	0.00001*
2-4	0.00001*	0.00001*
2-5	0.3	0.8
2-6	0.02*	0.4
2-7	0.00001*	0.00001*
2-8	0.00001*	0.00001*
3-4	0.08	0.06
3-5	0.001*	0.0001*
3-6	0.00001*	0.00001*
3-7	0.003*	0.2
3-8	0.00001*	0.00001*
4-5	0.00001*	0.00001*
4-6	0.00001*	0.00001*
4-7	0.12	0.8
4-8	0.001*	0.001*
5-6	0.2	0.4
5-7	0.00001*	0.00001*
5-8	0.00001*	0.00001*
6-7	0.00001*	0.00001*
6-8	0.00001*	0.00001*
7-8	0.008*	0.002*

*$p < 0.05$

Intra-group comparison of Rc among worn scaler tip subgroups

The intra-group comparisons between worn scaler tip subgroups (Rc values) are also described in *Table 2*. The highest Rc measurement was recorded in subgroup 8 (5.7 ± 0.81 μm), followed by subgroup 4 (4.58 ± 0.5 μm) and subgroup 7 (4.52 ± 0.67 μm). The lowest Rc measurement was recorded in subgroup 1 (0.98 ± 0.49 μm) followed by subgroup 2 (1.17 ± 0.21 μm). The differences in Rc measurements recorded among almost all subgroups was found to be statistically significant ($p < 0.001$; CI = 95%).

Inter-group comparison of Rc among new and worn scaler tip subgroups

The inter-group comparison between new and worn scaler tip subgroups (Rc values) are described in *Table 3*. Higher mean Rc measurements were recorded in all worn scaler tip subgroups than in new scaler tip subgroups. Amongst them, subgroup 8 of the worn scaler tip group showed more Rc than any other groups (5.69 ± 0.8 μm; $p < 0.008$; CI = 95%). There were statistically significant differences found among subgroup 3 ($p < 0.001$; CI = 95%), subgroup 4 ($p < 0.0008$; CI = 95%), subgroup 7 ($p < 0.05$; CI = 95%) and subgroup 8 ($p < 0.008$; CI = 95%).

Discussion

Throughout periodontal therapy, from plaque control to the maintenance phase, management of the deleterious effects of periodontitis on the exposed root surface influences the success of the treatment. Root surface roughness is the decisive element to enhance biofilm formation, which is the primary etiologic factor for periodontal disease initiation and progression (Oda *et al.*, 2004).

Rougher root surfaces are known to increase bacterial colonization and plaque formation, and contribute to retention and attachment of dental calculus (Dragoo *et al.,* 1992). A significant effect of root surface instrumentation roughness upon subgingival bacterial recolonization was demonstrated and it was reported that the most cervical part of the root surface instrumented area was almost completely colonized by bacteria (Leknes *et al.,* 1994).

Rough intraoral surfaces accumulate and retain more plaque and calculus in terms of thickness, area and colony-forming units. Ample plaque also reveals an increased maturity and pathogenicity of its bacterial components, characterized by an increased proportion of motile organisms and spirochetes, or a denser packing of bacteria. The possible mechanism is the increasing threshold level for surface roughness (Ra > 0.2 μm), which facilitates bacterial adhesion. Although surface free energy and surface roughness are two factors influencing plaque growth, the latter predominates (Quirynen *et al.,* 1995).

Table 3. Inter-group comparisons of the Rc values (mean ± SD) depending on instrumentation by new and worn scaler tips under different working parameters.

Subgroups (n = 10)	Rc values (μm) (mean ± SD)		*p* value
	New tips group (n = 80)	Worn tips group (n = 80)	
1	0.818 ± 0.27	0.979 ± 0.49	0.37⁺
2	0.92 ± 0.44	1.175 ± 0.21	0.11⁺
3	3.326 ± 0.55	4.174 ± 0.42	0.001*
4	3.728 ± 0.45	4.584 ± 0.5	0.0008*
5	1.113 ± 0.43	1.14 ± 0.39	0.88⁺
6	1.312 ± 0.26	1.34 ± 0.62	0.89⁺
7	4.022 ± 0.35	4.516 ± 0.67	0.05*
8	4.798 ± 0.51	5.692 ± 0.81	0.008*

*$p \leq 0.05$

Supragingivally, surface irregularities have a direct effect on bacterial adhesion and promote plaque growth indirectly by sheltering the attached microorganisms from oral cleansing. Subgingivally located irregularities seem to shelter submerged microorganisms by impeding the cleaning action of the gingival crevicular fluid (Lie *et al.,* 1978; Siegrist *et al.,* 1991). Hence, instrumentation during periodontal debridement causes damage to the integrity of the root surface, while a rough root surface influences the recolonization of pathogenic bacteria and also significantly affects gingival inflammatory reactions (Leknes *et al.,* 1997).

The initial step of periodontal treatment aims at obtaining a biologically acceptable root surface, which involves the elimination of microbial plaque and calculus with minimal roughness changes on the root surfaces (Kishida *et al*., 2004). Ultrasonic scaling is as effective as hand instrumentation when used to remove plaque and calculus (Oda *et al*., 2004; Petersilka *et al*., 2004).

If an ultrasonic scaler is used without considering its tip wear, it may tend to increase the operating parameters such as lateral force, tip angulation and power setting in order to reduce the scaling time. It has been stated that increasing the tip angulation and power setting results in higher surface roughness. The present study demonstrated that the alteration in the working parameters in ultrasonic scaling such as tip angulation, power setting, lateral force and scaler tip wear have more impact on root surface roughness. This is in agreement with previous studies (Flemmig *et al.,* 1998a; 1998b). Therefore, tip wear can have an indirect effect on root substance removal and its surface roughness (Busslinger *et al*., 2001).

In our study, scaler tip wear was examined with AFM. Erosion ratio (ER) of worn tips was approximately 10 times higher than the new tips and was expressed in nanometers (nm). The ER of worn scaler tips (65.65 ± 18.59 nm) was higher than new scaler tips (8.69 ± 1.26 nm; $p < 0.00001$). These results are in agreement with the outcomes obtained by Arabaci *et al.* (2013).

Intra-group comparisons of new scaler tips showed that 45° tip angulation has higher mean Rc than 0° tip angulation at any working parameters ($p < 0.00001$). These results are in agreement with the findings of Flemmig *et al.* (1998a).

At 1 N lateral force, increasing the generator power from medium (p5) to high (p10) resulted in highr Rc values: 4.02 ± 0.35 μm and 4.8 ± 0.52 μm, respectively ($p < 0.0001$). However, at 0.5 N lateral force, adjusting the power from p5 to p10 caused slightly increased Rc values: 3.326 ± 0.55 μm and 3.728 ± 0.45 μm, respectively ($p < 0.08$). Therefore, the cumulative increase of power setting and lateral force at 45° tip angulation showed more roughness on the root surfaces than scaler unit power setting as an individual parameter. These results are in agreement with Flemmig *et al.* (1998a; 1998b), who stated that power setting is not a better indicator to predict the load of the insert tip and its oscillation.

The lateral force adjustment from 0.5 to 1 N at 45° tip angulation and medium power setting (P5) showed higher Rc values: 3.33 ± 0.55 μm and 4.02 ± 0.35 μm, respectively ($p < 0.003$). At higher power setting (p10), adjustment of lateral force from 0.5 to 1 N showed significantly higher Rc values of 3.728 ± 0.45 μm and 4.798 ± 0.51 μm, respectively ($p < 0.0001$). These findings are in agreement with Lea *et al.* (2003), who reported that increasing the generator power increased efficiency of scaling. The present study has shown that power setting as an individual parameter had less influence on the scaling efficiency. But when considered along with lateral force adjustment and tip angulations, changing the power setting leads to more roughness on the root surface.

Thus, the assessment of different working parameters indicates a synergistic impact, bringing about an extensive variety of root surface roughness differences. In our study, the combination of working parameters, i.e., 45° angulation at P10 and 1.0 N lateral force (subgroup 8) demonstrated a higher mean Rc value (4.8 ± 0.51 μm) compared to other subgroups.

Intragroup comparisons of worn scaler tips showed that the 45° tip angulation had a higher mean Rc than 0° tip angulation at any working parameter ($p < 0.00001$). The present study demonstrated that the power setting from 5 to 10 at constant 1 N lateral force significantly increased the Rc values to 4.52 ± 0.67 µm and 5.7 ± 0.81 µm, respectively ($p < 0.002$), and at 0.5 N lateral force the Rc values slightly increased to 4.12 ± 0.42 µm and 4.58 ± 0.5 µm respectively ($p < 0.06$). These differences were not statistically significant at 0° tip angulation with 0.5 N ($p < 0.2$) and 1 N ($p < 0.4$) lateral force. Higher Rc values were also seen for worn scaler tips (5.692 ± 0.81 µm) at 45° angulation, P10 and 1 N lateral force (subgroup 8) when compared to other subgroups.

The lateral force adjustment from 0.5 to 1 N at 45° tip angulation at P5 showed lesser Rc values, *i.e.,* 4.17 ± 0.42 µm and 4.52 ± 0.67 µm, respectively ($p < 0.18$). At P10 the lateral force adjustment from 0.5 to 1 N at 45° tip angulation resulted in higher Rc value changes of 4.58 ± 0.5 µm and 5.7 ± 0.81 µm, respectively ($p < 0.001$). Therefore, power setting had less influence on roughness changes than the lateral force, which is in agreement with previous studies conducted by Flemmig *et al.* (1998a, 1998b). However, higher generator power and lateral force cumulatively increased the surface roughness of root surface, especially with worn scaler tips groups. These findings are in agreement with the findings of Casarin *et al.* (2006).

Comparisons of new and worn scaler tips groups demonstrated higher Rc values in the worn scaler tip groups compared with the new scaler tip groups at 45° tip angulation, at any working parameter ($p < 0.001$). In the present study, higher mean Rc measurements were recorded in all worn scaler tips groups than new scaler tip groups. Amongst them, 45° angulation, P10 and 1.0 N lateral force (subgroup 8) showed a higher Rc value (5.7 ± 0.81 µm) for worn scaler tips subgroup than a new scaler tip subgroup (4.8 ± 0.51 µm; $p < 0.008$). Therefore, In addition to other working parameters (tip angulation, power setting, lateral force), tip wear also influenced the efficiency of scaling.

The 45° tip angulation along with other working parameters, i.e., power setting and lateral force, showed synergistic effects resulting in a wide range of root surface roughness differences when compared to 0° tip angulation. Worn tips showed higher roughness changes at 45° tip angulation than new tips. Hence this angulation should be avoided during clinical use with high lateral forces.

Despite the fact that the instrumentation was done at higher lateral force and higher power setting, the 0° tip angulation showed no differences between the subgroups. The parallel use of the tip (0°) showed minimal Rc differences between the new and worn tip subgroups. This could be attributed to the smaller sample size (n = 10). In our study the sample treated with 0° tip angulation (subgroups 1, 2 5 and 6) showed smoother surfaces as compared to the samples treated with 45° tip angulation. These results are in agreement with those obtained by Arabaci *et al.* (2013).

This study reveals that the wear ratio of scaler tip has a strong impact on root surface changes when applied with other working parameters. It has also been reported in a previous study that the scaler tip wear reduced the chipping action and the efficiency of scaling, which consequently increased the working time and roughness on the root surface (Lea *et al.*, 2006).

Hence, scaler tip wear should be assessed at regular intervals, and the worn tips should be replaced. Atomic force microscopy has some significant advantages, such as minimal sample preparation and produces high resolution 3-dimensional images. Furthermore, it permits for re-examination of the same samples (Van Hoogmoed *et al.*, 2006; De-Deus *et al.*, 2006).

To the best of our knowledge, this is the first study which investigated the effect of tip wear on root surface roughness along with other working parameters. The outcomes demonstrate that worn tips cause a more deleterious effect on the root surfaces. It is recommended that the tip wear should be given equal importance as other working parameters in order to minimize the surface roughness. A limitation of the present study is the fact that the sample size of the new and the worn scaler tip groups was small. The worn inserts were obtained by keeping the tip against a stone driven handpiece rather than using them in routine clinical practice. Further studies are needed to overcome these shortcomings.

Conclusion

Roughness of the root surface is acknowledged as a critical factor for re-colonization of bacteria and accumulation of debris on root surfaces. The roughness of root surfaces is influenced by various factors such as tip angulation, power setting, lateral force and tip wear. Usage of the ultrasonic scaler without considering the tip wear tends to increase the operating parameters such as lateral pressure, tip angulation and power setting in order to cut down the scaling time. Hence, tip wear has an indirect effect on root surface roughness and root substance removal. Therefore, ultrasonic instruments should always be used with judicious care and only when needed.

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