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Influence of tip wear of piezoelectric ultrasonic scalers on root surface roughness at different working parameters. A profilometric and atomic force microscopy study

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Abstract: Roughness on tooth surfaces is reported to facilitate the reestablishment of microbial dental plaque. Hence, the main goal of dental scaling is to remove bacterial plaque and obtain smoother tooth surfaces. This study was aimed to assess the influence of tip wear of ultrasonic scaler inserts on root surface roughness at different working parameters. Twenty piezoelectric ultrasonic scaler inserts (10 worn/10 new) were selected to examine the erosion ratio (ER) on the scaler tips and to assess the influence of tip wear on root surface roughness. Erosion on the tip surfaces was evaluated under atomic force microscopy (AFM). Root samples were prepared and instrumented by new (Group I) and worn (Group II) inserts at different working parameters. Roughness change (Rc) on root surfaces after instrumentation was examined under profilometer and compared between and within the groups. Statistically significant differences were found between the mean ERs of new and worn tips ($P < 0.01$). The results of this study showed that tip angulation and instrument power strongly influenced the Rc values on instrumented samples ($P < 0.05$). It was also revealed that tip wear influenced the Rc values on root surfaces especially at 45° tip angulation ($P < 0.05$). Therefore, tip wear should also be considered as much as the other parameters to minimize the surface roughness during ultrasonic treatment.

Key words: atomic force microscopy; surface roughness; tip wear; ultrasonic scaler

Introduction

Ultrasonic scalers are widely used instruments for removal of deposits from the tooth surfaces in periodontal treatment procedure (1, 2). It is primarily achieved by the mechanical chipping action of the scaler tips (3–5). The scaling performance and vibration characteristics of ultrasonic scaler systems are related to instrument type and shape of the tips (6, 7). In addition to these factors, scaler tip wear also influences the oscillation of the inserts (8). During clinical usage, scaler tips wear and reduced in length. It has been reported that 1 mm of tip wear results in approximately 25% loss of efficiency and 2 mm of wear results in approximately 50% loss of efficiency, and at this point tip should be replaced (9). Lea *et al.* (10) investigated the ultrasonic tip wear under scanning laser vibrometer, and they stated that tip wear resulted in reducing of vibration displacement amplitude of the inserts. It has also been reported that reducing of the chipping action depending on tip wear reduces the scaling performance and efficiency of the ultrasonic devices and requires more scaling time (10, 11).

Periodontal diseases are primarily caused by bacterial colonization on dental surfaces. The periodic mechanical removal of sub- and supragingival deposits is of central importance to systematic periodontal treatment (12). Roughness of the root surfaces was found to significantly influence the microbial plaque establishment and fibroblast attachment on root surfaces (13, 14). It has also been reported that bacterial plaque adheres easily to the rough root surfaces after ultrasonic treatment (15). Therefore, it is recommended to achieve a smooth surface structure after scaling and root planning procedures (16, 17). Previous studies (15, 18, 19) compared the root surface roughness induced with instrument type, shape of the scaler tip and working parameters such as tip angulation, lateral force and instrument power setting, but there is a lack of information about the influence of tip wear on root surface roughness. Currently, there is no effective method measures the wearing ratio on ultrasonic scaler tip surfaces. Atomic force microscopy (AFM) is used to characterize the erosion and material loss of hard surfaces, and capable of giving images with atomic resolution with minimal sample preparation (20–23). Atomic force microscopy was used in this study to compare the erosion ratio (ER) on the tip surfaces of worn and new piezoelectric ultrasonic scaler inserts. On the other hand, this study was aimed to evaluate the influence of tip wear of piezoelectric ultrasonic scaler tips on root surface roughness at different working parameters including instrument power setting and scaler tip angulation.

Materials and methods

Obtaining of worn and new scaler inserts

Twenty same-type piezoelectric ultrasonic scaler inserts, DS-001 scaler tips (Instrument A; Electro Medical Systems, Nyon, Switzerland), were selected for this study. According to the study protocol, ten of the scaler inserts were selected to be exposed a randomized wearing process, and considered as worn scaler inserts. To obtain worn insert group, ten of the inserts were used randomly in a periodontology clinic by five doctoral students (Ataturk University, Faculty of Dentistry) in scaling procedures for 1 year. Each scaler insert was used approximately four times in a day, and 1400 times in a year. On the other hand, the doctoral students were advised to use the inserts only at medium power during the dental scaling procedures. However, the remaining ten scaler inserts were not exposed any process, and considered as new scaler inserts.

Examination of ER and surface imaging on new and worn scaler tips

At the end of the wearing process (after 1 year), the surface integrity and ER on the tips of worn and new inserts were examined and compared by an AFM (Pico SPM; Molecular Imaging Inc., Tempe, AZ, USA) (24). 450-μm-long silicon nitride cantilevers with a 0.58 N m^{-1} spring constant and 13 kHz resonant frequency for AFM were used. All images were taken in air at the room temperature. The AFM examination was performed at the lateral side and at the tip third of the inserts (at tip zones), which are exposed to most erosion.

Preparation and instrumentation of the tooth samples

Eighty extracted human central incisors, free of root defects, were obtained from the extracted tooth store of our faculty and prepared for instrumentation. The instrumentation procedure of this study was performed using an EMS mini piezon piezoelectric ultrasonic scaling unit (EMS CORP., Dallas, TX, USA). The ultrasonic unit was operated according to the manufacturer's instructions under water irrigation for cooling of the scaler tip. The samples were divided randomly into two groups (Group I and II), and each group included 40 specimens. The root surfaces of the teeth in Group I and II were selected to be instrumented using new and worn ultrasonic scaler inserts, respectively. Each group was divided into four subgroups ($n = 10$) for ultrasonic instrumentation. The root samples in the subgroups were instrumented by worn and new inserts under standardized conditions on a fixed mechanism as described previously by Flemmig *et al.* (25) at different working parameter combinations including 0° tip angulation at medium power setting (P5), 0° tip angulation at high power setting (P10), 45° tip angulation at P5 and 45° tip angulation at P10.

Quantification of surface roughness on instrumented root surfaces

The root surface roughness was defined as the average of peak and valley distances measured along the centreline of one cut-off length. The measurements were performed three times on each sample before and after ultrasonic instrumentation by a profilometer (Mitutoyo SJ-301; Mitutoyo Corporation, Kanagawa, Japan). The mean difference between pre- and post-instrumentation roughness values on root surfaces was determined as roughness change (Rc) for each sample.

Statistical analysis

Statistical analysis was performed using PASW® Statistics 18 software for Windows (IBM Corporation, Armonk, NY, USA). The mean ER on the new and worn tips was compared by independent samples t-test ($P = 0.01$). Intra- and inter-group comparisons of the Rc values on instrumented root surfaces were analysed by one-way analysis of variance (ANOVA) and *post hoc* Tukey HSD test ($P = 0.05$).

Results

AFM results

Figure 1 shows the AFM images of the surface topography of new and worn scaler tips. The height profiles (trace of vertical

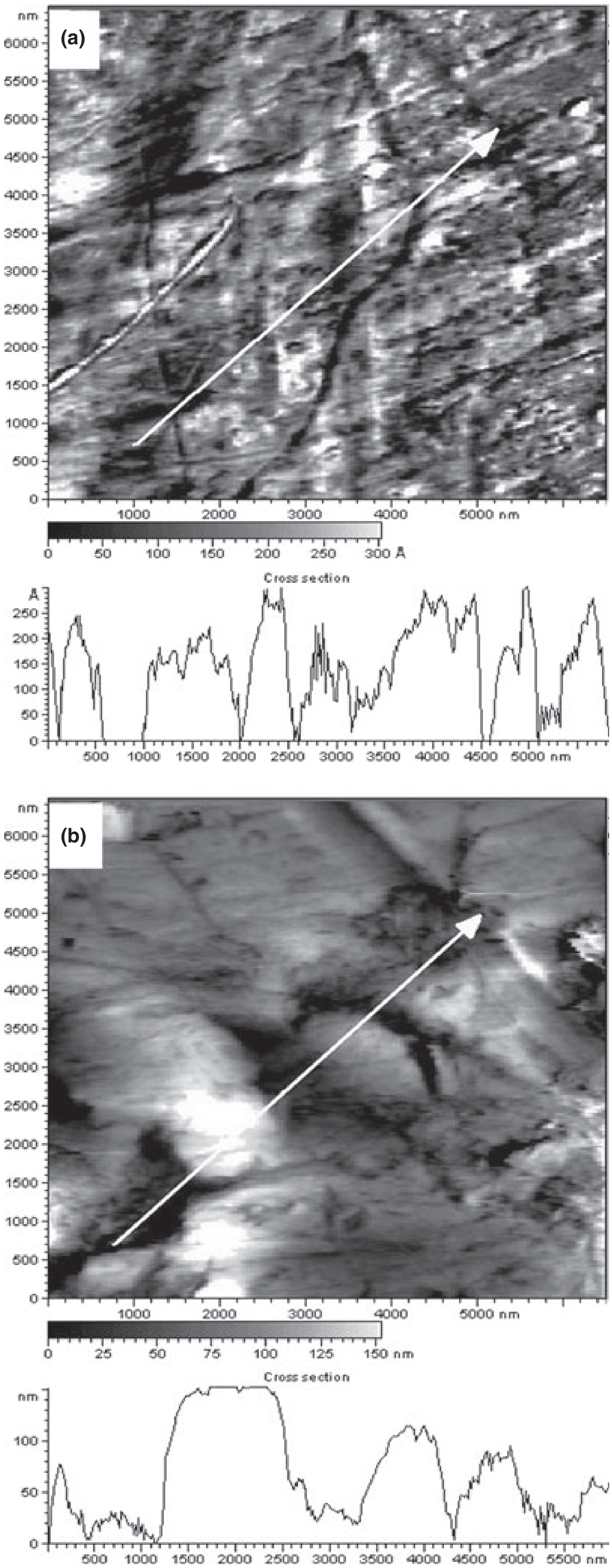

Fig. 1. Atomic force microscopy images of the surface topography of new and worn scaler tips. (a) The surface topography of new tip; (b) the surface topography of worn tip.

z position of the tip) on tip surfaces were indicated by an arrow in the lower panel of figures. Atomic force microscopy measurements showed that the mean ER on the tips of new and worn inserts was 14.65 ± 2.49 nm and 143.59 ± 13.16 nm, respectively. The differences between the ER values were found statistically significant ($P < 0.01$; Table 1).

Profilometric results

Intra-group profilometric comparisons (Table 2) showed that the mean Rc values on instrumented root surfaces were statistically higher at 45° tip angulation compared with 0° tip angulation at any power settings for both groups ($P < 0.05$). It was also found that increasing of generator power from 5 to 10

Table 1. **Comparison between the mean erosion ratio (ER) values of worn and new scaler tips**

	Mean ER (nm)		
	New insert	Worn insert	*P* value
Tip 1	11.25	140.85	
Tip 2	13.84	137.21	
Tip 3	14.08	161.51	
Tip 4	16.64	154.23	
Tip 5	17.51	128.41	
Tip 6	18.21	127.46	
Tip 7	12.56	161.02	
Tip 8	11.21	142.25	
Tip 9	15.19	129.81	
Tip 10	16.03	153.12	
Mean ± SD	14.65 ± 2.49	143.59 ± 13.16*	<0.01

*The mean difference is significant at the 0.01 level.

Table 2. **Intra-group comparisons of the Rc (Mean ± SD) values between the subgroups according to the working parameters**

		P value
Group I		
New tip, 0°, P5 (0.77 ± 0.11)	New tip, 0°, P10 (0.89 ± 0.13)	0.114
New tip, 0°, P5 (0.77 ± 0.11)	New tip, 45°, P5 (1.32 ± 0.15)*	<0.05
New tip, 0°, P5 (0.77 ± 0.11)	New tip, 45°, P10 (1.96 ± 0.17)*	<0.05
New tip, 45°, P5 (1.32 ± 0.15)	New tip, 45°, P10 (1.96 ± 0.17)*	<0.05
Group II		
Worn tip, 0°, P5 (0.69 ± 0.09)	Worn tip, 0°, P10 (0.72 ± 0.11)	0.153
Worn tip, 0°, P5 (0.69 ± 0.09)	Worn tip, 45°, P5 (2.18 ± 0.19)*	<0.05
Worn tip, 0°, P5 (0.69 ± 0.09)	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05
Worn tip, 45°, P5 (2.18 ± 0.19)	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05

P5, medium power generator; P10, high power generator.
Analysis of variance and a *post hoc* Tukey HSD test were used.
*The mean difference is significant at the 0.05 level. The *P* values lower than 0.05 are statistically significant.

significantly increased the Rc values at 45° tip angulation ($P < 0.05$), but the differences were not statistically significant at 0° tip angulation. Inter-group comparisons (Table 3) showed that the Rc values on instrumented samples at 45° tip angulation were statistically higher in Group II compared with Group I at any power settings ($P < 0.05$). However, there were no statistically significant differences between the groups at 0° tip angulation.

Discussion

The purpose of mechanical periodontal therapy is reducing of bacterial plaque and calculus, and obtaining a smoother root surface for fibroblast attachment (15). Root surface roughness after mechanical treatment facilitates the re-accumulation of bacterial dental plaque and calculus formation on tooth surfaces (18). Hence, the scalers used in periodontal treatment must be efficient on achieving smoother root surfaces. Ultrasonic scalers are currently the most common and effective instruments used for periodontal treatment. The scaling performance of an ultrasonic device is primarily related with its chipping action, which is differed according to the instrument type, tip shape and tip wear. These factors also influence the vibration characteristics of the ultrasonic scaler tips and surface roughness of instrumented surfaces.

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

Group I	Group II	*P* value (group I versus II)
New tip, 0°, P5 (0.77 ± 0.11)	Worn tip, 0°, P5 (0.69 ± 0.09)	NS
New tip, 0°, P5 (0.77 ± 0.11)	Worn tip, 0°, P10 (0.72 ± 0.11)	NS
New tip, 0°, P5 (0.77 ± 0.11)	Worn tip, 45°, P5 (2.18 ± 0.19)*	<0.05
New tip, 0°, P5 (0.77 ± 0.11)	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05
New tip, 0°, P10 (0.89 ± 0.13)	Worn tip, 0°, P5 (0.69 ± 0.09)	NS
New tip, 0°, P10 (0.89 ± 0.13)	Worn tip, 0°, P10 (0.72 ± 0.11)	NS
New tip, 0°, P10 (0.89 ± 0.13)	Worn tip, 45°, P5 (2.18 ± 0.19)*	<0.05
New tip, 0°, P10 (0.89 ± 0.13)	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05
New tip, 45°, P5 (1.32 ± 0.15)	Worn tip, 45°, P5 (2.18 ± 0.19)*	<0.05
New tip, 45°, P5 (1.32 ± 0.15)	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05
New tip, 45°, P10 (1.96 ± 0.17)	Worn tip, 45°, P5 (2.18 ± 0.19)*	<0.05
	Worn tip, 45°, P10 (2.74 ± 0.22)*	<0.05

Analysis of variance and a *post hoc* Tukey HSD test were used.
*The mean difference is significant at the 0.05 level. The *P* values lower than 0.05 are statistically significant.

Tip wear of ultrasonic scaler inserts was previously reported to reduce the vibration displacement amplitude and chipping action of the tips, and hence reduce the scaler tip efficiency (9–11). Today, many of the clinicians use the ultrasonic scaler tips without regarding tip wear, and they mostly tend to increase the working parameters such as tip angulation and generator power setting to reduce the scaling time. It was stated that increasing of tip angulation and generator power setting resulted in higher surface roughness (25–28). Although the effect of instrument type, tip shape and the working parameters has recently been investigated, the influence of tip wear on root surface roughness is still unevaluated.

As far as we are aware, in the current literature, no effective method that checks the wearing on the scaler tip surfaces was mentioned. However, it was reported that AFM, scanning tunnelling microscope, scanning electron microscope, transmission electron microscope and optical interferometric microscope could be used to evaluate the surface roughness and erosion ratio on several materials (29, 30). Atomic force microscopy is capable of giving images with atomic resolution and allows for a direct quantitative characterization of the surfaces (20, 31, 32). It has some important advantages such as minimal sample preparation, high resolution and visualization of a 3-dimensional image of the surfaces (21). Furthermore, it allows for re-examination of the same specimen (33). On the other hand, the effect of tip wear on vibration displacement amplitude and scaler tip performance were examined under scanning laser vibrometer by Lea *et al.* (10). Scanning laser vibrometer was also mentioned by Felver *et al.* (34) to be a useful method for measuring of tip vibration. However, measuring of the tip length is thought as the easiest method to evaluate the scaler tip performance (9). In an another study, Pereira *et al.* (5) developed an innovative cavitometer for quantitative performance assessment of dental ultrasonic scalers.

In this study, wearing ratio of the ultrasonic scaler tips was examined under AFM. ER values on the worn and new ultrasonic scaler tips were compared, and the results showed that the worn tips were eroded approximately 10 times more than the new tips (Fig. 1, Table 1). To evaluate the influence of tip wear on surface roughness, root samples were prepared and instrumented by same-type new and worn scaler inserts using generator power settings 5 and 10 and at tip angulations of 0° and 45°. Intra-group comparisons (Table 2) showed that the mean Rc values were statistically higher at 45° tip angulation compared with 0° tip angulation at medium and high power settings ($P < 0.05$). It was also found that setting up the generator power from 5 to 10 significantly increased the Rc values when using at 45° tip angulation in both groups ($P < 0.05$).

The main goal of this study was to compare the Rc values on instrumented root samples by new and worn scaler inserts. The results showed that the Rc values at 45° tip angulation were statistically higher in Group II compared with Group I at any power settings ($P < 0.05$). The findings of this study compressed that scaler tip wear strongly influenced the root surface roughness when used at higher tip angulation and power settings. It may be related with the loss of flexibility of the scaler tip metal depending on wear. Therefore, tip wear of the ultrasonic scaler inserts should periodically be evaluated by the methods mentioned above, and the tips worn out should be replaced. This study revealed that AFM measurements can be useful for evaluating the tip wear of ultrasonic scalers, albeit further investigations are needed. On the other hand, this study does not give information about the effects of tip angulation and instrument power on scaler tip wear. New *in vitro* studies are required to evaluate the effects of these working parameters on tip wear and ER values on scaler tip surfaces. However, this is to our knowledge the first study in this area, and we believe that it may form basis for further researches investigating the wearing process and performance of the ultrasonic scaler inserts.

Clinical relevance

Scientific rationale for the study

Root surface roughness is accepted as an important predisposing factor for re-establishment of microbial deposits on tooth surfaces. Root surface roughness after ultrasonic instrumentation was previously reported to be influenced by several factors such as tip shape, tip angulation and instrument power. The effect of tip wear on surface roughness was investigated in this study.

Principal findings

The results showed that tip wear significantly increased the surface roughness on instrumented root samples.

Practical implications

Tip wear should also be considered as much as the other working parameters to minimize the surface roughness during ultrasonic scaling.

Conflict of interest and source of funding statement

We have no conflict of interests. The study was self-funded by us and our institution.

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