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Evaluation of the safety and efficiency of novel metallic ultrasonic scaler tip on titanium surfaces

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Key words: maintenance therapy, novel ultrasonic scaler tip, surface roughness implant failures

Abstract

Aim: To evaluate the safety and efficiency of novel ultrasonic scaler tips, conventional stainless-steel tips, and plastic tips on titanium surfaces.

Material and methods: Mechanical instrumentation was carried out using conventional ultrasonic scalers (EMS, Nyon, Switzerland) with novel metallic implant tip (BS), a plastic-headed tip (ES), a plastic tip (PS) and a conventional stainless-steel tip (CS) on 10 polished commercially pure titanium disks (Grade II) per group. Arithmetic mean roughness (R_a) and maximum height roughness (R_y) of titanium samples were measured and dissipated power of the scaler tip in the tip-surface junction was estimated to investigate the scaling efficiency. The instrumented surface morphology of samples was viewed with a scanning electron microscope (SEM) and surface profile of the each sample was investigated using contact mode with a commercial atomic force microscope (AFM).

Results: There were no significant differences in surface roughness (R_a and R_y) among BS, ES, and PS group. However, CS group showed significant higher surface roughness (R_a and R_y). The efficiency of CS tip is twice as much higher than that of BS tip, the efficiency of BS tip is 20 times higher than that of PS tip, and the efficiency of BS tip is 90 times higher than that of ES tip.

Conclusion: Novel metallic copper alloy ultrasonic scaler tips may minimally influence the titanium surface, similar to plastic tip. Therefore, they can be a suitable instrument for implant maintenance therapy.

Long-term clinical studies have revealed that dental implants are a successful and predictable treatment option for both fully and partially edentulous patients (Lindquist et al. 1996). Recently, it seems that clinical concern has turned to the causes of implant failures due to biomechanical or bacterial factors (Mombelli 1997). The pathogenic bacteria around implant-supported prostheses may lead to peri-implantitis, an inflammatory lesion involving both soft and hard tissues around the bone-implant interface. This area seems to be even more susceptible than the periodontium to bacteria (Ericsson et al. 1992), indicating that the maintenance therapy is indispensable after the installation of implant-supported prostheses.

Instruments for cleaning dental implants should be efficient, bring minimal damage to titanium surface, and have durability. Conventional sonic and ultrasonic scalers with metal tips have an advantage in that they can remove plaque and calculus effectively and efficiently, but induce considerable modifications to implant surfaces. A positive correlation between surface roughness and the rate of supragingival and subgingival plaque deposition has been reported (Gildenhuys & Stallard 1975; Shafagh 1986; Quirynen et al. 1990). Therefore, the use of plastic curettes, graphite or nylon-type instruments, rubber polishing cups, brushes with abrasive paste, and air-powder abrasive systems have been recommended (Sato et al. 2004). Although such various instruments have been tested, there is still little consensus as to which instrument is most appropriate for use on implant surfaces. Some authors showed scalers with teflon-coated, plastic, fiber, or carbon tips caused minimal damage to implant surfaces (Ruhling et al. 1994; Kawashima et al. 2007). However, they did not consider mechanical properties of scaler tips, such as fracture resistance or wear resistance,

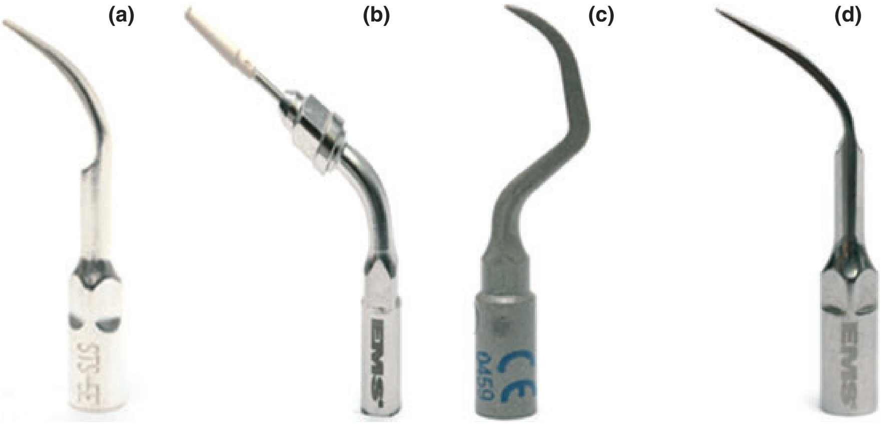

Fig. 1. Four types of scaler tips used in this study. (a)*Novel metallic implant tip (Cetatech, Seoul, Korea); (b)**plastic-headed tip (EMS, Nyon, Switzerland); (c)***plastic tip (Satelec, Merignac, France); (d)****conventional stainless-steel tip (EMS).

and did not compare efficiency. Recently, the ultrasonic scaler tips with new properties have been introduced, that are mainly made of copper alloy, with lesser hardness than pure titanium. The purpose of this study is to evaluate the safety and efficiency of novel metallic ultrasonic scaler tips, conventional stainless-steel tips, and plastic tips on titanium surfaces.

Material and methods

Ultrasonic scaler tip

Mechanical instrumentation was carried out using conventional ultrasonic scalers (EMS, Nyon, Switzerland) with a novel metallic implant tip (BS)* (Fig. 1a), a plastic-headed tip (ES)** (Fig. 1b), a plastic tip (PS)*** (Fig. 1c) and a conventional stainless-steel tip (CS)**** (Fig. 1d). The manufacturer information and specifications for tips are shown in Table 1. In Table 1, the Vickers hardness values of tip were measured from the polished surface.

Fabrication of the samples

Commercially pure titanium disk (Grade II) with 25 mm diameter and a thickness of 1 mm (Setatec, Seoul, Korea) was polished #800 grit SiC sandpaper (Struers A/S, Ballerup, Denmark). Forty (10 per group) titanium disks were embedded in an epoxy resin block (Ortho-Jet, Lang Dental Mfg., Wheeling, IL, USA). Mechanical properties and chemical composition of the titanium alloy are shown in Table 2 that provides all data provided by the manufacturer.

Ultrasonic scaler apparatus

The samples were placed on double pan balance (Ohaus Medical Trip Medical Balance 1550-SD, Ohaus Co., Pine Brook, NJ, USA) using magnetic mold. Each scaling tip was angled approximately 90° to the polished surface sample. Standardized 3-mm horizontal movement (3 Hz cycle) of the tip was achieved with a constant force of 40 g by the vertical moving counter weighed balance similar with the apparatus described by Dentkos et al. (Fig. 2) (Dentkos & Berzins 2008). All scaler tips were used for 30 s on 40% of full power. To cover whole 25 mm diameter disk with scaler tips, 30 s was the most suitable time according to our pilot study. Also 40% of full power was the highest power level in this non-static model without bouncing movement of the scaler tip. All instrumentation was performed by one investigator. All samples were rinsed in running tap water and cleaned in an ultrasonic bath for 20 min and then dried with compressed air.

Surface analysis

Arithmetic mean roughness (R_a) and maximum height roughness (R_y) of titanium samples were measured using surface roughness tester (SV-C3000, Mitutoyo, Japan). In each case, the measurement was performed with a 0.4 mm cutoff and 1.0 mm measurement length. Each sample was measured five times at 1 mm intervals length-wise; then the average for each sample was recorded. The instrumented surface morphology of samples was viewed with a scanning electron microscope (SEM). Surface profile of the each sample was investigated using contact mode with a commercial atomic force microscope (AFM). V-shaped silicon nitride cantilevers were used, with a bending constant 0.5 N/m as measured by the supplier. One representative zone of 50 μm × 50 μm of each sample was scanned. The images were analyzed with specific software (Nanoscope v613r1; Veeco Metrology Inc., Santa Barbara, CA, USA and WSxM 4.0 Develop11.1; Nanotec Electronica S.L., Tres Cantos, Spain).

Efficiency calculation

To investigate the scaling efficiency, we estimated the dissipated power of the scaler tip in the tip-surface junction. A model of steady-state motion of the cantilever of AFM (Fig. 3) (Cleveland et al. 1998) was employed. Assuming that a rectangular cantilever with a uniform cross-section oscillates at its natural resonance frequency, f_o. In equilibrium, the average rate at which energy is fed into the cantilever ($\overline{P_{in}}$) equals the average rate at which energy is dissipated by the cantilever ($\overline{P_o}$) and the tip end ($\overline{P_{tip}}$): i.e. $\overline{P_{in}} = \overline{P_o} + \overline{P_{tip}}$. We can obtain $\overline{P_o}$ and $\overline{P_{in}}$ by brief calculation based on simple harmonic oscillator model, and thus get $\overline{P_{tip}} = \overline{P_{in}} - \overline{P_o} = \frac{\pi k A^2 f_o}{Q_{cant}}\left[\left(\frac{A_o}{A}\right)\sin\varphi - 1\right]$. Here, k is the spring constant of the cantilever, A and A_o are the damped and free amplitude of the oscillation, respectively, Q_{cant} is the quality factor of the reso-

Table 1. **Basic physical properties of four types of ultrasonic scaler tips used in this study**

	Novel metallic tip (BS)	Plastic-headed tip (ES)	Plastic tip(PS)	Conventional T (CS)
Product name	IS	PI	PHI	A TYPE
Manufacturer	B&L Biotech, Seoul, Korea	EMS, Nyon, Switzerland	Satelec, La Ciotat, France	EMS, Nyon, Switzerland
Hardness (HV)	89	28	37	610
Mass(g)	0.92	1.45	0.43	0.81
Density (g/cm^3)	8.7	1.49*	1.43†	7.8
Elastic modulus (GPa)	103	10*	22†	200

*Mark, J.E. (1996) Physical Properties of Polymers Handbook, p. 332. New York: American Institute of Physics.

†Material Property Data, PolyOne Edgetek PS-30CF/000 HF UV BLACK PBT with 30% Carbon Fiber (http://www.matweb.com/search/DataSheet.aspx?MatGUID=268055abe1324002b80dd82d84792952).

Table 2. **Specification of titanium (Aichi Steel Corp., Tokai-Shi, Aichi-Ken, Japan)**

Mechanical properties Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (HV)
270	405	32	156

Chemical composition (%) H	0	N	Fe	C	V	Al	Ti
0.0009	0.112	0.004	0.034	0.004	–	–	Rem.

Fig. 2. Testing instruments demonstrating the ultrasonic scaler, cyclic axial testing machine, double pan balance, and sample specimen.

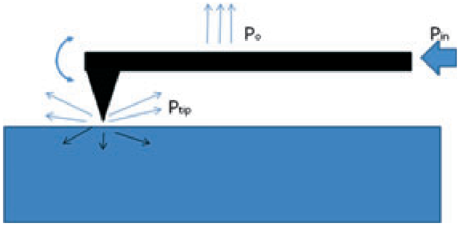

Fig. 3. A diagrammatic model of steady-state motion of the cantilever with the scaler tip.

nance, and φ is the phase of the cantilever relative to the driver. If we replace the cantilever with the various scaler tips and assume that those tips vibrate in the same viscous environment, the relative dissipated power ratio will be approximately only proportional to the product of the spring constant and the resonance frequency: i.e. $\frac{P^{A}_{tip}}{P^{B}_{tip}} \sim \frac{k^{A} f^{A}_{o}}{k^{B} f^{B}_{o}}$ for scaler tip A and B. On the other hand, with the elastic modulus E, the width w, the length L, and the thickness t of the cantilever, we can get the spring constant $k = \frac{Ewt^3}{4L^3}$ (Young & Budynas 2001) and the resonance frequency is $f_o = \frac{1}{2\pi}\frac{t}{L^2}\left(\frac{E}{\rho}\right)^{1/2}$ where ρ is the cantilever density (Cleveland et al. 1993). Consequently, assuming that the dimensions of the cantilevers (scaler tips) are almost the same, the dissipated power ratio between A and B tips will be $\frac{p^{A}_{tip}}{p^{B}_{tip}} \sim \frac{\sqrt{E^3_A/\rho_A}}{\sqrt{E^3_B/\rho_B}}$.

Statistical analysis

SPSS 13.0 for Windows (SPSS Inc, Chicago, IL, USA) was used for the statistical analysis. Means and standard deviations for the R_a and R_y were calculated for each instrument after instrumentation. For the statistical analysis, the results were evaluated using Kruskal–Wallis with Dunn's procedures for the pairwise comparisons. Differences at $P < 0.05$ were considered statistically significant.

Results

There were no significant differences in surface roughness (R_a and R_y) among BS, ES, and PS group (Fig. 3). However, CS group showed significant higher surface roughness (R_a and R_y) (Fig. 4). SEM images on scaled surface of titanium samples showed no marked differences in surface morphology between BS and ES and there were no scratches seen (Fig. 5a and b). But, SEM image of PS group showed a little scratch and furthermore, SEM image of CS group showed remarkable scratches (Fig. 5c and d). AFM images showed no marked differences in surface profile among the BS, ES groups (Fig. 6a and b). However, PS group generated different scratched topographies on scaled surface of titanium samples and furthermore, CS group generated three dimensional, remarkably roughened topographies on scaled surface of titanium samples. In Tables 1 and 2, the hardness value of titanium is higher than that of BS, ES, and PS tips, but, the hardness value of CS tip is about four times higher than that of titanium. Table 3 showed the scaling efficiency as dissipated power ratio between the various scaler tips. In this steady-state motion model, CS group showed the highest dissipated power ratio compared to other scaler tips. The efficiency of CS tip is twice as much higher than that of BS tip, the efficiency of BS tip is 20 times higher than that of PS tip, and the efficiency of BS tip is 90 times higher than that of ES tip.

Discussion

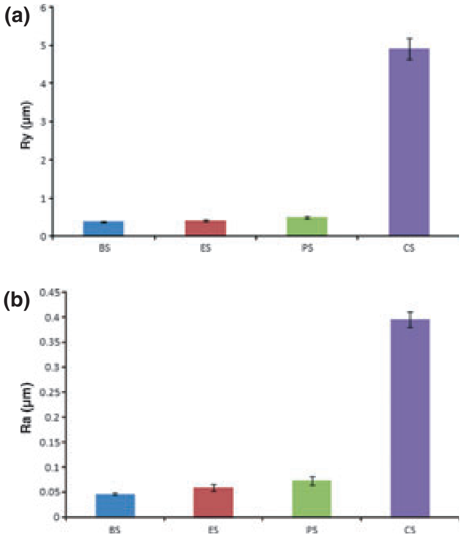

Fig. 4. Arithmetic mean roughness (R_a) and maximum height roughness (R_y) of titanium disk groups(Grade 2) after instrumentation with BS, ES, PS and CS scaler tips, respectively. BS, metallic implant tip; ES, plastic-headed tip; PS, plastic tip; and CS, conventional tip.

The cleaning procedures, especially using ultrasonic scaler, can increase surface roughness of dental restoration and implant, which will influence microbial colonization and induce plaque formation. A positive correlation between surface roughness and the rate of supragingival plaque deposition has been detected *in vivo* (Gildenhuys & Stallard 1975; Shafagh 1986; Quirynen et al. 1990). These observations may be attributable to be the easier initial bacterial adhesion to and its more difficult removal from rough surfaces. Quirynen et al. 1996 showed that bacterial colonization on rough titanium surfaces is greater than that on smooth surfaces and that reduction of surface roughness below a threshold value of $R_a = 0.2$ μm seems to have no further effect on quantitative and qualitative bacterial adhesion and colonization.

In this study, while CS tips showed significantly higher surface roughness, in which R_a exceeded the threshold value, the roughness of other groups was not significantly different and were below a threshold value of R_a = 0.2 μm. Roughness by copper alloy metallic (IS) tips was comparable to that of plastic (BS, PS) tips. As shown in Table 2, it is assumed that these results could be mainly related to lower hardness value of BS, ES, and PS tips than that of the titanium sample. Although the average roughness (R_a) parameter is usually used to express the initial microbial adhesion potential to the surfaces of dental implant, the other factors should be evaluated for these surfaces as well as related to the distance from the microbes, chemical composition, and surface free energy (Elter et al. 2008; Subramani et al. 2009; Burgers

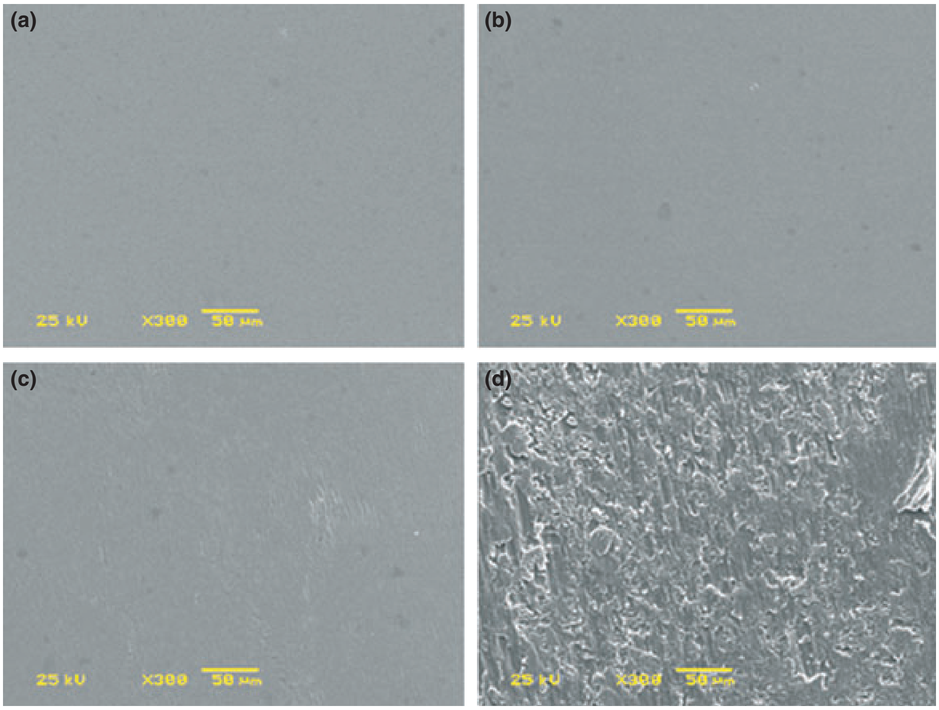

Fig. 5. SEM photographs of instrumented surface of titanium disks according to the scaler tips. (a) Metallic implant tip (BS); (b) plastic-headed tip (ES); (c) plastic tip (PS); and (d) conventional tip (CS).

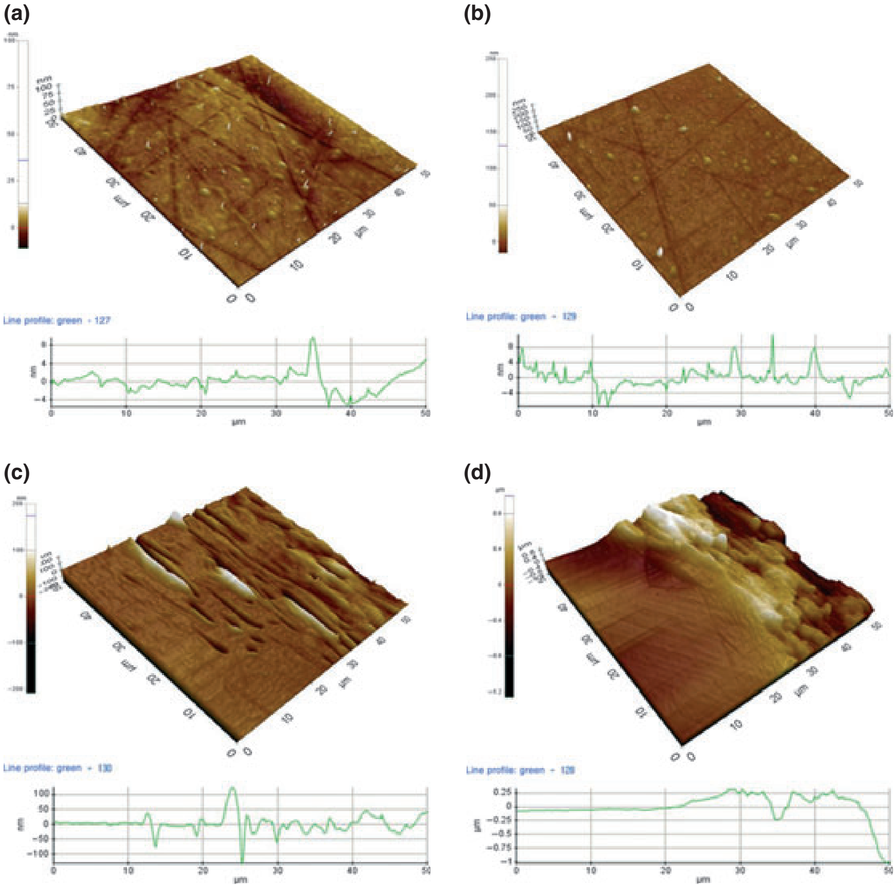

Fig. 6. AFM photographs of instrumented surface of titanium disks according to the scaler tips. (a) metallic implant tip (BS); (b) plastic-headed tip (ES); (c) plastic tip (PS); and (d) conventional tip (CS).

Table 3. Calculated dissipated power ratio between the various scaler tips

Unit	CS	BS	PS	ES
E (Gpa)	200	110	15.2	5.4
m(g)	0.81	0.92	0.43	1.45
Power ratio	1	0.408	0.021	0.004
	2.452	1	0.051	0.011
	47.729	19.46S	1	0.212
	225.4	91.939	4.723	1

CS, conventional tip; BS, metallic implant tip; PS, plastic tip; ES, plastic-headed tip.

et al. 2010). For high resolution surface investigation, AFM and SEM were used together. Whereas SEM provides a two-dimensional image of a sample, AFM provides a three-dimensional surface profile and this makes it possible to detect vertical surface variations even below 0.5 Å. Therefore, Both SEM and AFM techniques were used to qualitatively assess surface texture and morphology of the samples. According to SEM image, large scratches left by the CS tip were observed on pure titanium disk sample. This observation was in agreement with the result of AFM image of CS tip. This finding is supported by surface roughness (R_a and R_y) results as shown in Fig. 4. Although hardness value of PS group was lower than titanium, a little scratch on scaled titanium samples was detected. This scratch may be considered the composition of PS tip, which is reinforced with a carbon composite and can affect surface profile of titanium surface. In AFM images of BS and ES group, interestingly, a lot of particles were observed. This pattern was not shown in cases of PS and CS group. It is assumed that BS and ES tip may cause minimal damage to titanium surface, however, can be susceptible to wear.

One *in vivo* study (Furst et al. 2007) reported that bacterial colonization occurred within 30 min after implant placement and early colonization patterns differed between implant and tooth surfaces based on the colonizing bacterial species. After implantation, bacteria move from periodontal pockets of remaining teeth and oral tissues to colonize the implant surfaces (Takanashi et al. 2004; Quirynen et al. 2006; Heuer et al. 2007). The microbial communities of the mouth are dynamic, creating symbiotic complexes of bacteria which have the ability to respond dynamically to antimicrobial treatment (Norowski & Bumgardner 2009). With plaque maturation and a shift in microbiota to a higher proportion of periopathogens, an inflammatory infiltrate develops in mucosal tissues (Gualini & Berglundh 2003). Continued inflammation and migration of periopathogens toward the base of implant lead to alveolar bone resorption with the loss of permucosal seal (Sanz et al. 1991; Berglundh et al. 2004). Treatment modalities to the peri-implant infection suggested by Lang et al.(Lang et al. 1997) were the cumulative interceptive supportive therapy (CIST) protocol. It includes scaling/root planning or mechanical debridement and antibiotic or antiseptic treatment. There were several studies (Jeffcoat et al. 1998; Mombelli et al. 2001; Persson et al. 2006) to elucidate the efficacy of local administration of antiseptics or antibiotics, however, they generally compare between mechanical debridement only group and mechanical debridement and local drug administration. In other words, the efficacy of the local administration of drugs is limited due to extracellular protective polysaccharides matrix of the biofilm (Ten Cate 2006) as well as difficulty of advancing a delivery device to the bottom of a deep peri-implant pockets (Mombelli 2002). Therefore, when treating the peri-implant disease, it is indispensable to perform debridement to mechanically disrupt the biofilm on the implant surface whether it is nonsurgical or surgical. For this reason, the scaling efficiency is very important while there are concerns about scratching and roughening the implant which may contribute to potential increased plaque reaccumulation (Matarasso et al. 1996).

The efficiency of scaler tip depends on many factors, such as manufactured material, design, frequency generating vibration, power, water flow rate, contact angle, and load. Also, significant variability exists in the vibration of ultrasonic scalers, even if between tips are of the same design (Lea & Walmsley 2009). In this study, we focused only on the power dissipated at the tip end, and employed "efficiency" as the term. This term may be replaced by "power (energy/time)" in engineering literatures. The power of the tip end has the significant meaning for deducting the scaling rate, because the rate of bacterial plaque clearance will surely increase as more energy shall be fed onto the surface by the tip end.

If we are unable to compare the performance between scaler tips straightforwardly due to differences in material and their design, according to a model of steady-state motion of the cantilever of AFM, elastic modulus and mass value of tip may be parameters for predicting performance. Even though the AFM cantilevers have much smaller sizes than the scaler tips, the basis of the classical mechanics of this steady-state motion is the same; in other words, the classical approximation on the AFM cantilever motion can be still valid as on the larger scaler tips'. We employed this model to explain the delivered power from the driver (the oscillator) to the tip end, assuming that the scaler tips were moving and tapping on the sample surface at equilibrium. In this study, efficiency of CS tip is twice as much as higher than that of BS tip, and efficiency of BS tip is 20 times higher than that of PS, and efficiency of BS tip is higher than 90 times higher than that of ES tip. For more accurate evaluation of performance, vibration analysis using scanning laser vibrometry will be required.

According to this study, novel metallic copper alloy ultrasonic scaler tips may minimally influence the titanium surface, similar to plastic tips. Therefore, they can be a suitable instrument for implant maintenance therapy. In addition, though further study is required, the metallic copper alloy tips have an advantage over plastic tips in terms of durability for fracture or wear.

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