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Root surface removal and resultant surface texture with diamond-coated ultrasonic inserts: an in vitro and SEM study

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Abstract

Background: A new diamond-coated ultrasonic insert has been developed for scaling and root planing, and it was evaluated in vitro for the amount of root surface removed and the roughness of the residual root surface as a result of instrumentation.

Methods: 48 extracted single-rooted human teeth were ground flat on one root surface and mounted (flat side up) in PVC rings of standard height and diameter with improved dental stone. Each tooth surface was treated with either a plain ultrasonic insert (PI), an ultrasonic insert with a fine grit diamond coating (DI) or sharp Gracey curettes (HI). The mounted teeth were attached to a stepper motor which drove the teeth in a horizontal, reciprocal motion at a constant rate. The thickness from the flattened bottom of the ring to the flattened tooth surface was measured before and after 10, 20, and 30 instrumentation strokes for each root surface with each of the experimental instruments. A number of treated teeth were randomly selected for examination with SEM and a profilometer. Statistical analysis (analysis of co-variance) was performed to compare the amounts of tooth structure removed among the 3 instruments and t-test was used to compare the roughness of the treated root surfaces.

Results: The mean depth of root structure removed was PI 10.7 μm, HI 15.0 μm, and DI 46.2 μm after 10 strokes; and PI 21.6 μm, HI 33.2 and DI 142.0 μm after 30 strokes, respectively. On average, 0.9 μm, 1.3 μm, and 4.7 μm of root surface was removed with each stroke of PI, HI and DI, respectively. PI and HI were not different from each other for all the stroke cycles, while DI was significantly different from PI and HI for all the stroke cycles ($p < 0.0001$). Analysis with the profilometer showed that the smoothest surface was produced by the PI followed by the HI. The DI produced a surface that was significantly rougher than the surface produced by the PI or HI.

Conclusion: These results suggest that diamond-coated ultrasonic instruments will effectively plane roots, and that caution should be used during periodontal root planing procedures. Additionally, the diamond-coated instruments will produce a rougher surface than the plain inserts or the hand curettes.

Key Words: dental instruments; diamond-coated; microscopy; root planing; ultrasonic therapy; profilometer

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Adequate root preparation in the treatment of periodontal disease typically involves mechanical instrumentation to remove plaque, calculus, and perhaps contaminated cementum and dentin (Barnes & Schaffer 1960, Schaffer 1967, Aleo et al. 1974, Ruben & Shapiro 1978, Waerhaug 1978, Aleo & Vandersall 1980, Fine et al. 1980, Daly et al. 1982, O'Leary & Kafrawy 1983, O'Leary 1986, McCoy et al. 1987). Meticulous mechanical preparation of the root surface appears to be an important aspect of the surgical techniques associated with gingival attachment and advanced regenerative periodontal procedures (Yukna 1992, Trombelli et al. 1994).

Other important considerations in periodontal therapy include the amount of root surface removed as a result of instrumentation and the roughness of the residual root surface after treatment (Kerry 1967, Rosenberg & Ash 1974, Lie & Meyer 1977, Ritz et al. 1991, Leknes et al. 1994). Periodontal root planing procedures aimed at removing dental plaque and calculus from the root surface also, by design, remove a portion of the root surface (Riffle 1952, Allen & Rhoads 1963, Belting & Spjut 1964, Clark et al. 1968, Wilkinson & Maybury 1973, Van Volkinburg et al. 1976, Garrett 1977, D'Silva et al. 1979, Lie & Leknes 1985, Coldiron et al. 1990, Ritz et al. 1991, Zappa et al. 1991).

Root surface instrumentation with hand instruments is often difficult and time consuming, and requires a substantial amount of physical effort. In addition to hand instruments, various powered instruments are available to the clinician for mechanical root preparation including sonic and ultrasonic scalers and rotary instruments (Allen & Rhoads 1963, Clark et al. 1968, Jones & O'Leary 1978, Lie & Leknes 1985, Ritz et al. 1991). Several studies have evaluated the amount of tooth structure removed mechanically by hand scalers (Riffle 1952, Jones et al. 1972, Pameijer et al. 1972, Van Volkinburg et al. 1976, Swan 1979, Hunter et al. 1984, Bye et al. 1986, Berkstein et al. 1987, Borghetti et al. 1987, Coldiron et al. 1990, Ritz et al. 1991, Zappa et al. 1991), ultrasonic scalers, (Belting & Spjut 1964, Clark et al. 1968, Jones et al. 1972, Pameijer et al. 1972, Wilkinson & Maybury 1973, Van Volkinburg et al. 1976, Hunter et al. 1984, Ritz et al. 1991), and air abrasives (Berkstein et al. 1987).

Each of these instruments has disadvantages ranging from decreased tactile sensitivity (Allen & Rhoads 1963, Moskow & Bressman 1964), uncontrolled damage to the root surface (Belting & Spjut 1964, Bye et al. 1986), and inadequate edge retention (Berkstein et al. 1987, Coldiron et al. 1990). While each of these instruments has shown clinical effectiveness, none has proven the most effective in typical clinical situations where short application times are required to remove plaque, calculus, and diseased tooth structure while leaving a relatively smooth root surface (Moskow & Bressman 1964, Jones & O'Leary 1978, Bye et al. 1986, Coldiron et al. 1990, Jotikasthira et al. 1992).

Diamond-coated ultrasonic (Lavespere et al. 1996, Yukna et al. 1997, Scott et al. 1999) or sonic (Kocher & Plagmann 1997, Kocher & Plagmann 1999a, b, Kocher et al. 2001) inserts have been designed in an attempt to increase the speed and efficiency of mechanical root preparation. Ultrasonic diamond-coated inserts have been shown to be substantially faster in calculus removal in furcations in vitro (Scott et al. 1999) and periodontal pockets in vivo (Yukna et al. 1997). Lavespere et al. (1996) found that use of diamond-coated ultrasonic inserts (DI) resulted in greater surface removal and greater residual root surface roughness compared with similarly shaped regular ultrasonic inserts in vitro. However, the microscopic nature of the residual root surface after use of the diamond-coated ultrasonic tips requires further investigation.

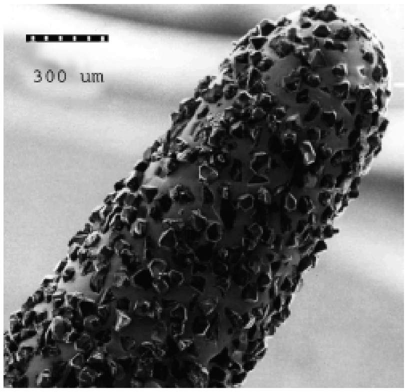

Fig. 1. × 50 photomicrograph (SEM) of the diamond insert. The bar represents distance of 300 μm.

The purpose of this study was:

1. To evaluate and compare in vitro the amount of root surface removal of a fine grit DI (DIAMONDCOAT™, Dentsply Professional Division, York, PA, USA) (Fig. 1) compared with smooth cavitron inserts and hand curettes.
2. To compare residual root surface topography after use of each instrument in vitro using scanning electron microscopy and a profilometer.

Materials and Methods

Collection process

After approval by the Louisiana State University Health Science Center Institutional Review Board, 48 human single-rooted teeth were collected. The teeth had to be able to present a healthy surface after being ground flat parallel to and along the root surface. Once collected, the teeth were stored in a 1:1 solution of distilled water and sodium benzoate (Plax, Pfizer Inc., New York, NY, USA) until mounted.

Mounting procedure

Each tooth was cleaned free of visible debris and then flattened on one surface by grinding on fine sand paper. Then they were mounted in PVC rings of standard height and diameter (flat side up) using an improved die stone mixed according to manufacturer's directions (Velmix, Kerr Manufacturing Co, Romulus, MI, USA). A metallic jig was used to ensure reproducible mounting of the teeth. This technique positioned the teeth in an elevated position relative to the mounting ring. In addition, the underside of the mounting ring was flattened parallel to the mounted tooth to ensure a completely flat surface. Three points (A, B, and C) from the area that was to be instrumented (corresponding to 20%, 50%, and 80% of the length of the test area, along the stroke of the instrument) were identified on the flattened root surface for measuring with the caliper. In order to ensure repeatable measurements, the flat surface of the plaster at the bottom of the ring (opposite to the flattened tooth surface) was marked for each of these points. These marks permitted repositioning the caliper to within a quarter of a millimeter of the chosen measurement position. After each tooth was mounted, it was returned to storage in the solution previously described until instrumented.

Benchtop instrumentation

The instruments examined in this study were fine grit DI, plain ultrasonic inserts (PI), and hand curettes (HI). The inserts were applied one side at a time to the root surface. Each instrument was used for three teeth, and then replaced by a new instrument. The hand curettes were of the Gracey 11/12 shape (Dentsply Professional Division). All the ultrasonic inserts had a standard shape (Dentsply P-10; Dentsply Professional Division). The Dentsply Cavitron Model SPS (Dentsply Professional Division) was used for all procedures according to manufacturer's directions at medium setting.

The rings with the mounted teeth were attached to a stepper motor, which drove the teeth in a horizontal, reciprocal motion at a constant rate of 3.2 mm/s over a 10 mm length forming the test area of the tooth. Concomitantly, a three-point balance beam held the various instruments rigidly and provided a normal force of $100 \times g$ (for PI and DI) or $300 \times g$ (for HI) onto the test surfaces with the working (lateral) side of the tips contacting the test area of the tooth.

Each type of instrument was tested on a group of 16 teeth each. Appropriate irrigation was used for all instruments. The ultrasonic handpiece, with the various experimental instruments in place, was activated continuously as the test tooth was moved reciprocally in three separate 10-stroke intervals. The height of the root surface was measured with calipers prior to instrumentation and after 10, 20, and 30 strokes. Care was taken to ensure that the three points being measured were within the range of the reciprocal motion.

Data collection

Quadruplicate measurements were made at each of the three points (A, B, and C) within the area of treatment along the test surfaces before instrumentation and after 10, 20, and 30 instrumentation strokes for each root surface with each of the instruments. Measurements were made to the nearest 0.001 mm using a digital caliper (Starrett #230, L. S. Starrett Company, Athol, MA, USA) which was modified to facilitate accurate measurements at specific points along the test surface. A 1 mm sapphire sphere was secured to the head of the digital caliper contacting the test surface so single point measurements could be performed at specific areas of the test surfaces. The flat tail end of the digital caliper was in contact with the flat, inferior surface of the mounting ring during all measurements. All measurements during the bench top analysis were made by a single investigator. Differences in measurements between baseline and those obtained after instrumentation were calculated and analyzed statistically.

SEM and profilometer evaluation

After the benchtop analysis was complete, two teeth were randomly chosen from each test group for SEM evaluation of the residual test surface. The teeth were rinsed clean with distilled water, air dried, secured to mounting stubs, and sputter-coated with 16 nm gold/palladium in an sputter-coater (Hummer® 6.2 Sputter Coater, Anatech Ltd, Springfield, VA, USA). The scanning electron microscope (JEOL T300, JEOL Institute, Peabody, MA) operated at 15 kV and the specimens were observed with a 0° tilt angle. Standardized photomicrographs (Polaroid Corporation, Waltham, MA, USA) were obtained at $\times 50$ and $\times 200$ for each specimen.

Five teeth from each group were randomly selected for profilometer analysis. An area of 2 mm $\times$ 2 mm within the area of instrumentation was scanned by a microneedle, the profile of the surface was recorded and an average roughness value (R_a) was produced for each tooth.

Statistical analysis

Statistical analysis was performed using SAS statistical software (SAS institute, Cary, NC, USA). Analysis of covariance was performed to compare the amounts of tooth structure removed among the three instruments, adjusting for baseline differences between the teeth used in the experiment. Also, differences in tooth surface removal at positions A, B, and C for each tooth were evaluated. In order to compare the tooth surface roughness among the three different groups, analysis of variance with Tukey's HSD post-hoc test followed by the Kruskal–Wallis test was used. Significance was defined as $p < 0.05$.

Results

There were no significant differences in tooth surface removal at positions A, B, and C for each tooth, so these data were combined. The mean depth of root structure removed after 10 strokes was 10.7 μm for PI, 15.0 μm for HI, and 46.2 μm for DI. After 20 strokes, it was 18.2 μm for PI, 25.7 μm for HI, and 95.4 μm for DI. Finally, after 30 strokes, the mean depth of root structure removed was 21.6 μm for PI, 33.2 for HI, and 142.0 μm for DI (Fig. 2). On average, 0.9, 1.3, and 4.7 μm of root surface was removed with each stroke of PI, HI, and DI, respectively. PI and HI were not different from each other for all the stroke cycles, while DI was significantly different from PI and HI for all the stroke cycles ($p < 0.0001$) (Table 1).

SEM findings

Under SEM, teeth treated with hand instruments showed a generally smooth surface with few rather parallel grooves. Plain US inserts showed a very similar surface, which was generally smooth with few areas exhibiting irregular grooves. For tooth surfaces treated with HI and PI, the instruments had a polishing effect; they produced a surface that was apparently smoother than the root surfaces that were treated with fine-grit sand paper (before the actual experiment) (Figs. 3b, c). On the contrary, teeth treated with diamond-coated US tips had a very characteristic picture: these teeth exhibited a surface that was evenly ribbed and had several parallel grooves running in the direction of the instrumentation (Fig. 3a). SEM and microphotographic evaluation revealed that PI and HI produced a relatively smooth root surface, while the DI pro-

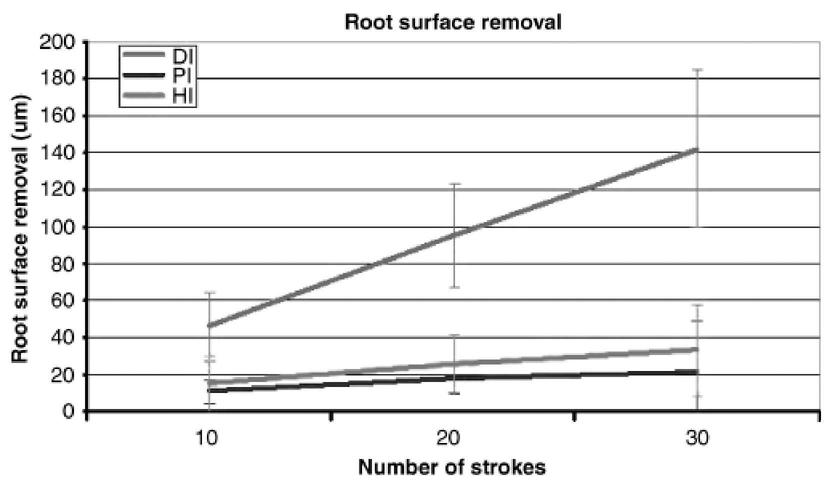

Fig. 2. Root surface removal at 10, 20, and 30 strokes. DI, diamond-coated ultrasonic insert; PI, plain ultrasonic insert; HI, hand instrument (Gracey curette). The standard deviation is shown.

Table 1. The mean depth of root structure (expressed in μm) removed at 10, 20, and 30 strokes

	10 strokes	20 strokes	30 strokes	Per stroke
DI	46.2 ± 18.4	95.4 ± 28.3	142.0 ± 42.3	4.7
PI	10.7* ± 6.5	18.2* ± 8.7	21.6* ± 27.1	0.9
HI	15.0* ± 14.8	25.7* ± 15.5	33.2* ± 24.6	1.3

The standard deviation is shown. The average depth of root structure removed per stroke is also shown. DI, diamond-coated ultrasonic insert; PI, plain ultrasonic insert; HI, hand instrument (Gracey curette).
*Significantly different from DI.

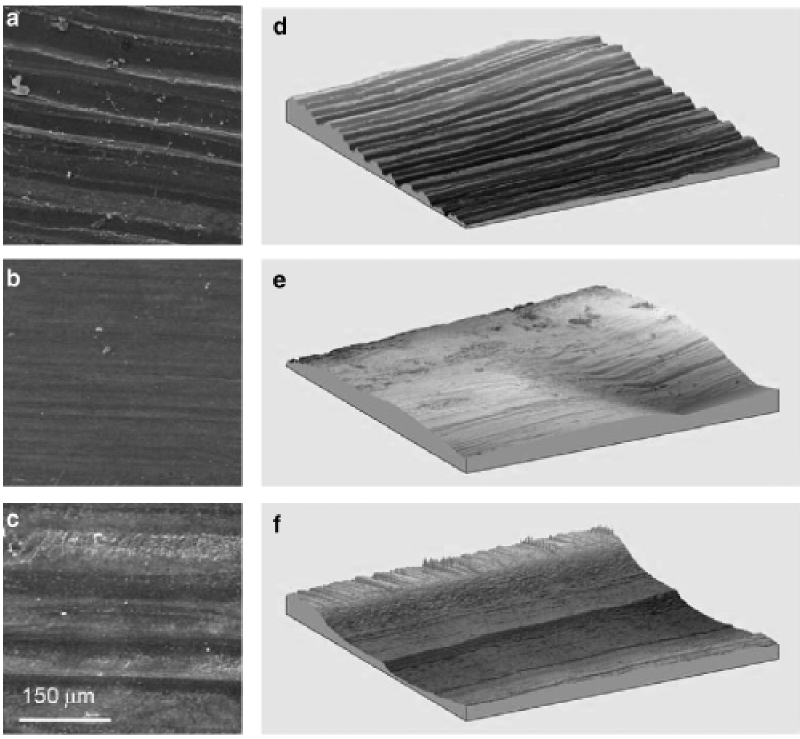

Fig. 3. × 200 photomicrograph (SEM) of root treated with: (a) *Diamond-coated ultrasonic insert*. Note the grooves running parallel to the direction of action and absence of smear layer. (b) *Plain ultrasonic insert*. Note the burnished and gnarled appearance of the root surface. (c) *Hand instrument*. Note the burnished appearance of the root surface. The bar represents distance of 150 μm for the SEM images. Three-dimensional reconstruction (from profilometer data) of an area 2 mm × 2 mm of root surface treated with (d) *Diamond-coated ultrasonic insert*. Note the accentuated instrument marks with peaks and valleys. (e) *Plain ultrasonic insert*. Note the relatively few instrument marks. (f) *Hand instrument (Gracey curette)*. Note the relatively few instrument marks.

duced characteristic grooves running parallel to the direction of action.

Profilometer findings

The profilometer findings paralleled the SEM findings. Again, areas treated with HI and PI exhibited a smooth surface, while areas treated with DI showed the same grooving observed with the SEM (Figs. 3d–f). The average roughness (R_a) for each tooth surface was calculated. Root surface analysis showed that the smoothest tooth surface was produced by the PI, followed by the HI, while the roughest surface was produced by the DI. The average roughness (R_a) was 0.68 μm with the PI, 0.78 μm with the HI, and 4.39 μm with the DI. There was no significant difference in average roughness of surfaces treated with either the HI or with the PI ($p = 0.08$). Also, the DI produced surface that was significantly rougher from both the PI and HI ($p < 0.0001$) (Table 2, Fig. 4).

Discussion

Standardization of experimental conditions is important in studies concerned with evaluation of instrumentation and their effects on the root surfaces. Care was taken in this study to maintain strict standardization with regard to normal force of instrumentation onto the test surface and the rate of horizontal reciprocal movement of the test surfaces.

Flemmig et al. (1998a, b) found that with ultrasonic scalers, increased lateral forces and angulations resulted in greater substance removal, while increasing instrument power settings did not. They recommended that the scaler tip should be angulated parallel to the root surface and the forces used should not exceed 1 N (100 × *g*). The force of instrumentation used in our study was the same and is similar to what is usually recommended for ultrasonic instrumentation (Bjorn & Lindhe 1962, Clark et al. 1968, Ritz et al. 1991, Flemmig et al. 1998b). It has been suggested that heavier forces of application may cause dampening of the action of sonic or ultrasonic instruments (Ritz et al. 1991, Kocher et al. 2001). The company's directions for use of ultrasonic instrumentation recommend a ''featherlight touch both supra- and subgingivally.'' As for hand instruments, we chose higher forces (300 × *g*, 3 N) that are close, but less than the clinical norm since it has been demonstrated that dentists and hygienists use similar forces for scaling (5.7 N, dentists; 5.4 N, hygienists) and root planing (4.6 N, dentists and hygienists) (Zappa et al. 1991).

Substance loss reflects the effectiveness of the instruments under standard conditions (Kocher et al. 2001). It was important for this analysis, despite its in vitro nature, to quantify the amount of relative root surface removal among experimental instruments to determine the root surface effects of the diamond-coated ultrasonic instruments compared with the other instruments.

The finding that PI removes very little root surface is in agreement with current clinical belief as well as the available literature (Clark et al. 1968, Stewart et al. 1971, Lie & Meyer 1977, Ritz et al. 1991, Jotikasthira et al. 1992, Rees et al. 1999, Schmidlin et al. 2001). The amount of root surface removed by the diamond inserts should be regarded as clinically significant. Other investigators found similar amounts of root surface removal with various instruments: Lavespere et al. (1996) (58–83 μm), Coldiron et al. (1990) (60–90 μm), Borghetti et al. (1987) (20–60 μm), Ritz et al. (1991) (109 μm), and Zappa et al.

Table 2. Average Surface Roughness (R_a) and standard deviation of R_a in µm, per group

	DI	PI	HI
R_a	4.39	0.68*	0.78*
SD	0.63	0.43	0.34

DI, diamond-coated ultrasonic insert; PI, plain ultrasonic insert, HI, hand instrument (Gracey curette).
*Significantly different from DI ($p < 0.0001$).

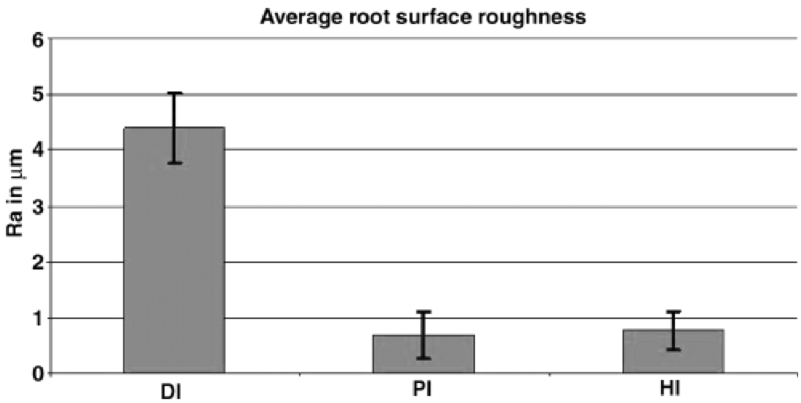

Fig. 4. Average surface roughness (R_a) in μm per group. DI, diamond-coated ultrasonic insert; PI, plain ultrasonic insert; HI, hand instrument (Gracey curette). The standard deviation is shown.

(1991) (100 µm). In a study evaluating substance loss caused by scaling with different sonic scaler inserts, Kocher et al. (2001) suggested that the diamond coating removes substance in a grinding action; the diamond splinters give the tool a multitude of edges (Fig. 1) and every individual cutting grain forms part of the multifaceted tool. Because every diamond grain contacting the tooth exerts an impulse, more hard dental tissue is removed as microshavings than with the plain inserts. The substance removed resembles that from the diamond-coated, rotating abrasive instrument (Kocher et al. 2001). The results of this study agree with results from previous studies that suggested that the diamond-coated sonic or ultrasonic tips can remove substantial amounts of root surface, and may damage the root surface if improperly handled (Lavespere et al. 1996, Kocher et al. 2001). Caution should be exercised when utilizing these instruments during periodontal root debridement procedures. The manufacturer does not recommend use of these diamond-coated instruments for closed (non-surgical) treatment.

Several studies have investigated the effect of various instruments on the smoothness of the root surface. A number of studies found that the smoothest surface was produced with hand instruments (Kerry 1967, Wilkinson & Maybury 1973, Rosenberg & Ash 1974, Hunter et al. 1984) and some with ultrasonic instruments (Jones et al. 1972, Pameijer et al. 1972). This controversy (Lea et al. 2003) could be attributed to differences in study designs, such as in vivo or in vitro, lack of standardization, etc. Thus, in a in vivo study, Lavespere et al. (1996) found that the smoothest surface was produced by the regular PI insert followed by the diamond coated inserts as determined by SEM evaluation. In a similar in vitro model, Kocher et al. found that the diamond-coated sonic inserts produced a fine, evenly ribbed surface and several short grooves running in the direction of instrumentation. The plain sonic inserts produced defects without directional orientation, while the hand instruments produced parallel grooves on the dentin surface (Kocher & Plagmann 1997, Kocher et al. 2001).

The destruction observed in other studies with the SEM images with plain inserts seems to be a result of burnishing and hammering (Yukna et al. 1997). The ultrasonic inserts (PI and DI) are moved reciprocally by the motor, but also have oscillation in relation to the test specimen. The characteristic parallel grooves produced by the DI are probably because of the reciprocal movement produced by the stepper motor.

A number of previous studies used the profilometer to evaluate the roughness and the amount of root surface removal after scaling and root planing (Meyer & Lie 1977, Zappa et al. 1991, Mengel et al. 1994). The benefit of using the profilometer in this study consists in the objective measurement of average roughness for each tooth surface. Roughness average (R_a), is the arithmetic mean of the deviations of the roughness profile about the centerline (the section through the profile that cuts off equal areas above and below it) (Buchalla et al. 2000).

Numerous studies have demonstrated that the most important prerequisite for healing after periodontal treatment is a root surface free of plaque and calculus (Nyman et al. 1975, Tagge et al. 1975, Rosling et al. 1976, Froum et al. 1982). Oberholzer and Rateischack during conventional periodontal flap surgery, root planed teeth and then used coarse diamond stones to roughen the root surfaces, or Gracey curettes to achieve a surface that would be as smooth as possible. Clinical healing was the same for both groups. They concluded that a smooth root surface is not a critical factor for a successful treatment result (Oberholzer & Rateitschak 1996). Similarly, Khatiblou & Ghodssi (1983) found no differences in periodontal healing between smooth teeth and teeth with 1 mm deep horizontal grooves after modified Widman periodontal surgery. An animal study suggested that intentionally grooving the root surface may enhance initial cell adhesion and proliferation, there by accelerating new attachment formation (Blumenthal & Singiser 1993). However, a smooth root surface may be advantageous near the gingival margin, since a smooth surface is less likely to accumulate plaque than a rough surface. In animal studies by Leknes et al. (1994, 1996) authors concluded that roughness resulting from subgingival instrumentation significantly influenced the subgingival microbial colonization.

The amount of tooth substance removed in this in vitro experimental setting should be interpreted with caution, because it not known how the instruments will perform in vivo. The substance removal in our experiment is a result of reciprocal instrumentation in one direction only, under standardized pressure and speed, on flattened root surfaces where the cementum was removed. This design does not deal with effects of instrumentation on the layered structure of cementum and dentin root surface when the instruments are applied freely by the human hand. This experimental set-up however, allows for comparisons between the instruments, since it is necessary to determine optimal working parameters before clinical use.

Conclusion

Within the limits of this in vitro study, diamond-coated ultrasonic inserts removed a greater amount of root surface compared with the plain inserts and hand curettes. There was no statistically significant difference in the amount of root surface removed between the plain inserts and the hand curettes. The amount of root surface removed with diamond-coated ultrasonic inserts used with very short application time suggests that they should be used with caution.

Acknowledgments

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