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Influence of fluorescence-controlled Er:YAG laser radiation, the Vector™ system and hand instruments on periodontally diseased root surfaces *in vivo*

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Abstract

Objectives: The aim of the present study was to evaluate the effects of fluorescence-controlled Er:YAG laser radiation, an ultrasonic device or hand instruments on periodontally diseased root surfaces in vivo.

Material and Methods: Seventy-two single-rooted teeth ($n = 12$ patients) were randomly treated in vivo by a single course of subgingival instrumentation using (1–3) an Er:YAG laser (ERL1: 100 mJ; ERL2: 120 mJ; ERL3: 140 mJ; 10 Hz), or (4) the Vector™ ultrasonic system (VUS) or (5) hand instruments (SRP). Untreated teeth served as control (UC). Areas of residual subgingival calculus (RSC) and depth of root surface alterations were assessed histo-/morphometrically.

Results: Highest values of RSC areas (%) were observed in the SRP group (12.5 ± 6.9). ERL(1–3) (7.8 ± 5.8, 8.6 ± 4.5, 6.2 ± 3.9, respectively) revealed significantly lower RSC areas than SRP. VUS (2.4 ± 1.8) exhibited significantly lower RSC areas than SRP and ERL(1, 2). Specimens treated with SRP revealed conspicuous root surface damage, while specimens treated with ERL(1–3) and VUS exhibited a homogeneous and smooth appearance.

Conclusion: Within the limits of the present study, it may be concluded that ERL and VUS enabled (i) a more effective removal of subgingival calculus and (ii) a predictable root surface preservation in comparison with SRP.

Key words: comparative studies; Er:YAG laser/therapeutic use; root cementum; scaling/root planing; ultrasonic therapy

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Instrumentation of periodontally involved root surfaces is aimed at effectively removing plaque and calculus (Claffey et al. 2004). However, such instrumentation calls for advanced clinical skills and sometimes, the anatomy of the root often complicates the achievement of the desired biologically compatible root surface (Sherman et al. 1990). Moreover, extensive cementum removal may lead to increased surface roughness in both supra- and subgingivally located areas, which might enhance plaque retention (Kerry 1967, Ritz et al. 1991). In recent years, power-driven instruments, such as sonic and ultrasonic scalers have been proposed to mechanize the procedure of scaling and root planing. Indeed, several studies have reported on an increased efficiency of power-driven instruments for calculus removal in general and in furcation sites (Leon & Vogel 1987, Kepic et al. 1990, Takacs et al. 1993, Kocher et al. 1997, 2000). Recent systematic reviews have indicated a similar improvement in clinical parameters following hand instrumentation and the use of power-driven systems (Tunkel et al. 2002; Oda et al. 2004). So far, however, a complete removal of subgingival calculus does not seem to be predictably attainable following non-surgical instrumentation with both treatment approaches (Caffesse et al. 1986, Matia et al. 1986, Kepic et al. 1990, Chan et al. 2000).

Recently, a newly developed ultrasonic device (Vector™, Dürr, Bietigheim–Bissingen, Germany) has been introduced in order to enable a less aggressive and more effective root surface debridement than hand instruments (Hahn 2000, Hoffman et al. 2005). The horizontal vibration of the device is converted by a resonating ring in vertical vibration, resulting in a parallel movement of the working tip to the root surface. The energy from the vertical vibration of the instrument is transmitted to the root surface and the periodontal tissues by a suspension of hydroxyapatite (HA) particles and water. Subsequently, calculus removal is supposed to be achieved because of hydrodynamic forces rather than by the chipping action of the working tip (Hahn 2000, Braun et al. 2005a). Although preliminary clinical data suggest that non-surgical periodontal therapy with this device may lead to clinical improvements comparable with those obtained with conventional hand instruments (Sculean et al. 2004b), there are currently no data available evaluating this device for subgingival calculus removal in vivo.

In recent years, the use of laser radiation has also been expected to serve as an alternative or adjunctive treatment to conventional periodontal therapy. Various hypothetical advantageous characteristics, such as hemostatic effects, improved calculus removal and bactericidal effects against periodontopathic pathogens might lead to improved treatment outcomes (Aoki et al. 2004). Close attention has been paid to the clinical applicability of the Er:YAG laser with a wavelength of 2.940 nm in the near infrared spectrum (Ishikawa et al. 2004). This laser system provides a capability to effectively remove calculus from periodontally diseased root surfaces without producing thermal side effects to adjacent tissues (Aoki et al. 1994, Schwarz et al. 2001a, 2003b, Eberhard et al. 2003). The absence of thermal damages was most likely owing to the optical characteristics of its wavelength of 2.940 nm, as the Er:YAG laser theoretically has a 10 and 15,000–20,000 times higher absorption coefficient of water than the CO_2 and the Nd:YAG lasers, respectively (Hale & Querry 1973, Buchanan & Robertson 1987). Additionally, recently published studies have reported a lack of cementum removal when laser instrumentation was performed under in vivo conditions (Eberhard et al. 2003, Schwarz et al. 2003b). Furthermore, several studies have reported antimicrobial effects against periodontopathic bacteria and the removal of lipopolysaccharides by Er:YAG laser radiation (Ando et al. 1996, Yamaguchi et al. 1997, Sugi et al. 1998, Folwaczny et al. 2002b, 2003). Controlled clinical trials have also demonstrated that non-surgical as well as surgical periodontal treatment with an Er:YAG laser resulted in significant clinical attachment levels gains comparable with treatment with hand or ultrasonic instruments (Schwarz et al. 2001b, 2003a,c, Sculean et al. 2004a, c). In order to improve the outcome of non-surgical periodontal treatment, a subgingival calculus detection (''feedback'') system with fluorescence induced by 655 nm InGaAsP (indium–gallium–arsenide–phosphate) diode laser radiation has been recently included in an Er:YAG laser device. Preliminary in vitro results have shown that 655 nm diode laser radiation induces significantly stronger fluorescence in subgingival calculus than in cementum (Folwaczny et al. 2002a, Krause et al. 2003). However, until now no published data are available evaluating the efficiency of this system for subgingival calculus detection and removal under in vivo conditions.

Therefore, the aim of the present study was to evaluate the effects of an Er:YAG laser combined with the feedback system, the Vector™ system or hand instruments on the removal of subgingival calculus and subsequently the morphology of periodontally diseased root surfaces following non-surgical periodontal treatment in vivo.

Material and Methods

Patient sample

A total of 12 patients (seven women, five men, mean age: 44.8 years), attending the Department of Oral Surgery at the Heinrich Heine University for multiple tooth extractions owing to severe periodontal destruction, were recruited for the study. Each patient exhibited six experimental teeth satisfying the following inclusion criteria: (1) probing pocket depths (>6 mm) on at least two aspects (mesio-buccal/mesio-lingual and disto-buccal/disto-lingual) as measured from the gingival margin to the bottom of the pocket, (2) no signs of carious or artificial damage on the root surface, (3) no periodontal root surface treatment within the last 12 months and (4) no root fractures or anatomical abnormalities. Patients suffering from systemic diseases were excluded from the study. The study protocol was approved by the Ethics Committee of the Heinrich Heine University and all participants signed informed consent forms.

Randomization procedure

The experimental teeth of each patient were equally and randomly assigned to the following test and control groups: (1–3) an Er:YAG laser using three different energy settings, or (4) an ultrasonic system, or (5) scaling and root planing using hand instruments, or (6) untreated control. Accordingly, each patient received all test and control procedures. The randomization process, performed according to a computer-generated protocol (RandList®, DatInf GmbH, Tübingen, Germany), led to comparable mean clinical parameters at baseline (i.e. probing pocket depth (PD), gingiva recession (GR), clinical attachment level (CAL)) in all groups (Fig. 1).

Treatments

Immediately before subgingival root surface instrumentation, all experimental teeth received a supragingival professional tooth cleaning. Small notches marking the gingival margin were prepared on the mesial and distal root surfaces of each tooth using a small round bur (diameter: 1 mm) to identify the most coronal extension of root surface instrumentation.

An Er:YAG laser (KEY3®, KaVo, Biberach, Germany) (ERL) device emitting a pulsed infrared radiation at a wavelength of 2.940 nm was selected for laser treatment. The laser beam was guided onto the root surfaces under water irrigation with a specially designed periodontal handpiece (2061, KaVo) and a modified chisel-shaped glass fibre tip (size 0.4×1.65 mm, transmission factor: 0.85) (''blue tip'', KaVo). Laser parameters were set at (1) 100 mJ/pulse, (2) 120 mJ/pulse and (3) 140 mJ/pulse and 10 pulses/s (panel setting). Respective pulse energies at the tip were approximately 85, 102 and 119 mJ/pulse (energy density: 12.8, 15.4 and 18 J/cm^2), respectively. The treatment was performed from coronal to apical in parallel paths with an inclination of the fibre tip of 15–20° (Folwaczny et al. 2001) to the root surface. An exciting laser radiation was delivered by an InGaAsP diode laser as red light at a wavelength of 655 nm. The diode laser beam was delivered onto the root surface

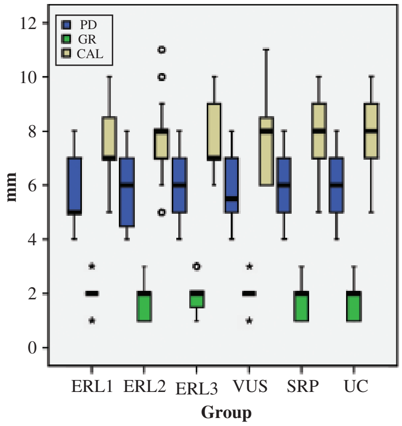

Fig. 1. Boxplots with outliers for the medians and Q1–Q3 quartiles of probing pocket depth (PD), gingival recession (GR) and clinical attachment level (CAL) of mesial and distal root surfaces measured at two aspects (buccal/lingual) per tooth at baseline in different treatment groups ($n = 12$ patients).

with the above-mentioned periodontal handpiece and the prismatically cut glass fibre tip. The mode of detection of fluorescence has been previously described (Lussi et al. 2001). In brief, the InGaAsP diode laser radiation induces fluorescence in the irradiated-mineralized substance. The laser radiation is guided to the angulated chisel-shaped glass fibre tip within a central fibre. Additional surrounding fibres are arranged around this central fibre that collect the fluorescent light emitted from the irradiated tissue. The fluorescent light is guided together with the reflected radiation as well as the ambient light from the surrounding fibres (Folwaczny et al. 2002a). When the receiver no longer gets any fluorescence signals, the therapeutical laser beam is switched off.

For the treatment of test group 2, a specially designed ultrasonic system (Vector™, Dürr, Bietigheim-Bissingen, Germany) (VfUS) and a polishing fluid (hydroxylapatite particles $<10\,\mu$m) was used according to the instructions given by the manufacturer (70% power setting). The straight Vector™ probe, in shape similar to a periodontal probe, was used for the instrumentation of all buccal and lingual surfaces, while the Vector™ curet was used for the cleaning of approximal surfaces. The energy from the instrument is transmitted to the root surface by a water film. The water is not sprayed in an aerosol by the instrument, but held hydrodynamically on the instrument by the linear ultrasonic movement.

The mechanical subgingival instrumentation of test group 3 was accomplished using Gracey curets (Hu-Friedy Co., Chicago, IL, USA) (SRP).

Root surface instrumentation was performed under local anaesthesia by one investigator well trained in periodontal treatment using all procedures employed in the present study (K. B.).

In the laser groups (ERL 1–3), the end point of treatment was defined as the inability of the feedback system to detect residual calculus. In the VUS and SRP groups, the end point of treatment was performed until the operator felt that the root surfaces were adequately debrided and planed. This was evaluated by tactile sensation with the Vector™ probe in the VUS group and with a periodontal probe (PCP12, Hu-Friedy Co.) in the SRP group.

In all groups, the amount of time that was needed for instrumentation of mesial and distal root surfaces was recorded using a stopwatch. Immediately after instrumentation, experimental teeth were extracted avoiding any contact of the forceps with the instrumented root surface. All root surfaces appeared unaltered by the extraction procedure.

Measurement of residual subgingival calculus (RSC)

Immediately after extraction, all teeth ($n = 72$) were gently cleaned by saline water irrigation. For image acquisition a digital camera (Nikon D100, Nikon GmbH, Düsseldorf, Germany) was mounted on a binocular light microscope (Olympus BX50, Olympus, Hamburg, Germany). Digital images (original magnification $\times 40$) were evaluated using a software program (SIS analySIS Auto Software 3.2, Soft imaging System GmbH, Münster, Germany). Areas of RSC were measured as a percentage of the mesial and distal root surfaces, using the notches as coronal and residues of the periodontal ligament (PDL) as apical extensions of root surface instrumentation. Laterally the margins were set 1 mm apart from the line angle of the tooth. All measurements were performed by one experienced investigator masked to the specific experimental conditions (V. S.).

Histomorphometric analysis of root surface morphology

All teeth were dehydrated using ascending grades of alcohol, infiltrated and embedded in methylmethacrylate (MMA, Technovit 7200, Heraeus Kulzer, Wehrheim, Germany) for non-decalcified sectioning. After 18–24 h the specimens were completely polymerized. Sections were taken along the long axis of each tooth in mesio-distal direction (Eberhard et al. 2003) using a diamond wire saw (Exakt®, Apparatebau, Norderstedt, Germany) resulting in three specimens of approximately 500 μm in thickness (Donath 1985). Subsequently, all specimens were glued with acrylic cement to opaque Plexiglas and ground to a final thickness of approximately 40 μm. All sections were stained with toluidine blue. Histomorphometrical analyses as well as microscopic observations were performed by one experienced investigator masked to the specific experimental conditions. For histomorphometrical measurements, images were obtained using a light microscope (BX50) at a magnification of $\times 200$, associated with a video camera (SIS Color View3, Soft imaging System GmbH). Digital images were evaluated using a software program (SIS analySIS Auto Software 3.2, Soft imaging System GmbH). The following parameters were assessed histomorphometrically: (a) extent and (b) depth of surface alterations, (c) exposure of dentin. Both extent of surface alterations and exposure of dentin were expressed as percent of the distance from the coronal notch to the apical margin of the periodontal tissue attachment. Depth of surface alterations was measured by drawing a perpendicular line connecting the margins of the crater at the point of maximum depth (Fig. 2). All measurements were performed by one experienced investigator masked to the specific experimental conditions (V. S.).

Intra-examiner reproducibility

Five teeth/sections each were used to calibrate the examiner. The examiner evaluated the specimens on two separate occasions, 48 h apart. Calibration was accepted if measurements at baseline and at 48 h were similar at $>90\%$ level.

Statistical analysis

A software package (SPSS 12.0, SPSS Inc., Chicago, IL, USA) was used for the statistical analysis defining the patient as statistical unit. Mean values and standard deviations of PD, GR, CAL, RSC areas, depth of root surface alterations and treatment time were calculated for each tooth in each patient. The data rows were examined with the Kolmogorow–Smirnow test for normal distribution. As the data were not normally distributed, non-parametric Kruskal–Wallis test for multiple independent samples was used to determine if PD, GR, CAL, RSC areas, depth of root surface alterations and treatment time vary by test and control groups. As significant differences with respect to the test and control groups were apparent for RSC areas, depth of root surface alterations, and treatment time ($p<0.001$; respectively), the Mann–Whitney *U*-test was used for pairwise group comparisons. Results were considered statistically significant at $p<0.05$.

Results

Areas of residual subgingival calculus

The mean percentages of RSC areas for each group are presented in Fig. 3. In general, all treatment procedures resulted in statistically significant lower RSC areas than untreated control teeth ($p<0.001$, respectively). However, highest percentages of RSC areas on mesial and distal root surfaces were assessed for SRP, followed by ERL(1–3) and VUS. In particular, mean total value of RSC areas for SRP was $12.5 \pm 6.9\%$. In the ERL(1–3) groups, mean RSC areas (7.8 ± 5.8, 8.6 ± 4.5, 6.2 ± 3.9, respectively) were statistically significant lower compared with SRP ($p = 0.010$, 0.046, 0.001, respectively). Although mean values tended to be lowest in the ERL3 group, the differences compared with ERL1 and ERL2 groups did not reach statistical significance ($p = 0.403$, 0.056, respectively). Root surfaces treated with VUS exhibited a mean total value of RSC areas of $2.4 \pm 1.8\%$, which was statistically significant lower compared with SRP, and ERL(1–3) ($p<0.001$, respectively) (Fig. 3). Mean percentages of RSC areas in different treatment groups with respect to PD are presented in Fig. 4. The extent of residual calculus seemed to be directly correlated to PD in the ERL(1–3) as well as in the SRP groups, even though this trend seemed to be less pronounced in the ERL3 group. In contrast, specimens treated with VUS exhibited comparable RSC areas, irrespective of PD (Fig. 4).

Treatment time

Mean treatment time in different groups is presented in Fig. 5. Statistical analysis revealed that the time that was needed for root surface instrumentation in the VUS group was statistically significant longer than in the ERL(1–3) and SRP groups ($p<0.001$, respectively). The differences between ERL1, ERL2, ELR3 and SRP were statistically non-significant ($p>0.05$, respectively).

Root surface changes

Histomorphometrical analysis of the depth of root surface changes in different test and control groups is presented in Fig. 6. In general, UC specimens revealed no identifiable root surface changes underneath the areas of RSC (Fig. 7a). In contrast, all specimens treated with SRP generally exhibited conspicuous root surface alterations. These changes ranged from shallow scratches, clefts and grooves (minimal depth: 6.8 μm) to sharp-edged crater-like defects (maximal depth: 51.6 μm) covering almost 65% of the instrumented root surfaces. These defects were mainly localized to the layer of cementum, but occasionally also resulted in an exposure of dentin. However, remaining areas (45%) seemed to be smoothly cleaned, exhibiting no remarkable surface changes (Fig. 7b). Statistical analysis revealed that mean depth of root surface changes in the SRP group was significantly higher than in the UC, ERL(1–3) and VUS groups ($p<0.001$, respectively). In contrast, root surfaces treated with VUS generally exhibited a homogeneous and smooth appearance. There were no signs of any crater formation. However, all specimens exhib-

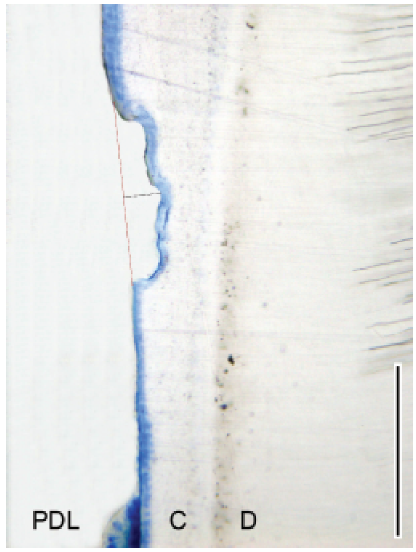

Fig. 2. Depth of surface alterations was measured at a magnification of $\times 200$ by drawing a perpendicular line connecting the margins of the crater at the point of maximum depth (toluidine blue stain, bar = 200 μm).

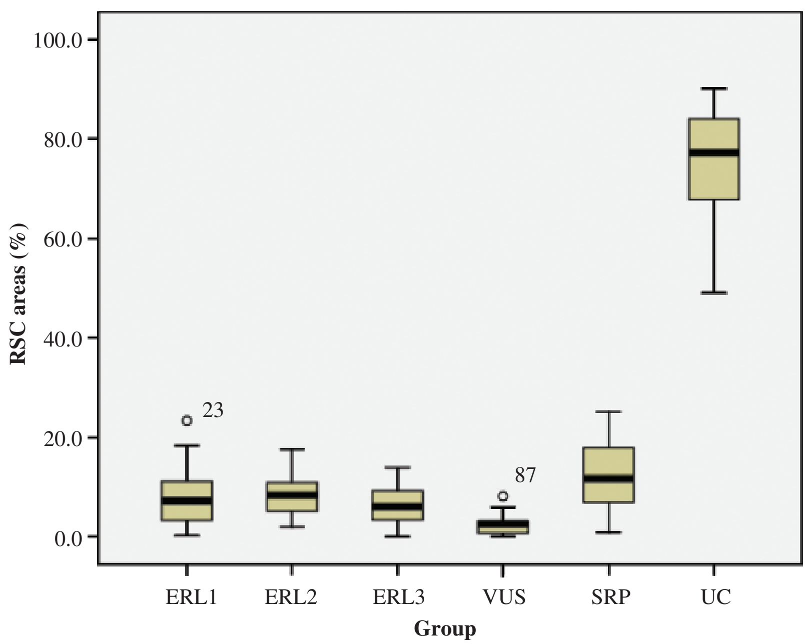

Fig. 3. Boxplots with outliers for the medians and Q1–Q3 quartiles of residual subgingival calculus (RSC) areas (%) in different treatment groups ($n = 12$ patients).

ited some slight superficial irregularities covering almost 100% of the instrumented root surface areas. These irregularities reached a maximal depth of 22.1 μm (Fig. 7c). Irrespective of the energy setting, ERL produced homogeneous and smooth root surfaces without visible traces of the used fibre tip. Loss of cementum was generally non-existent, indicating that subgingival calculus was almost selectively removed. Occasionally there were some slight superficial root surface alterations, covering merely 15% of the instrumented root surfaces. These irregularities reached a maximal depth of 5.6–6.5 μm (ERL (1–3), $p > 0.05$ compared with UC; respectively) (Fig. 7d). Statistical analysis revealed that mean depth of root surface changes in the VUS group was significantly higher than in the UC and ERL (1–3) groups ($p < 0.001$, respectively). Histomorphometric analysis revealed no signs of any thermal damages, such as carbonization, melting or cracking in the different treatment groups (Fig. 7b–d).

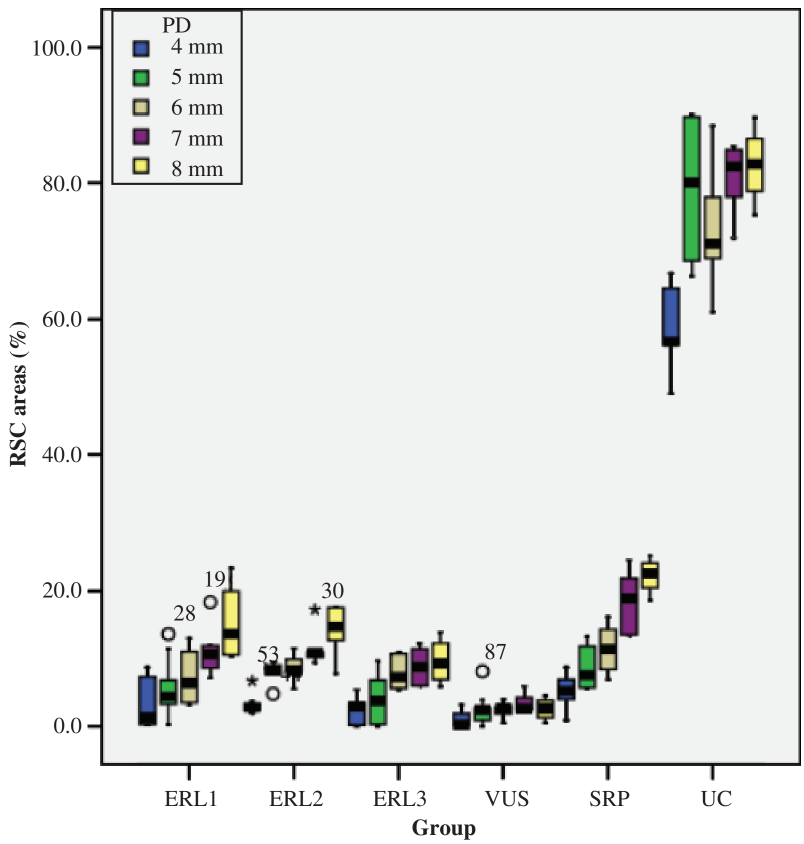

Fig. 4. Boxplots with outliers for the medians and Q1–Q3 quartiles of residual subgingival calculus (RSC) areas (%) in different treatment groups with respect to probing pocket depths (PD) ($n = 12$ patients).

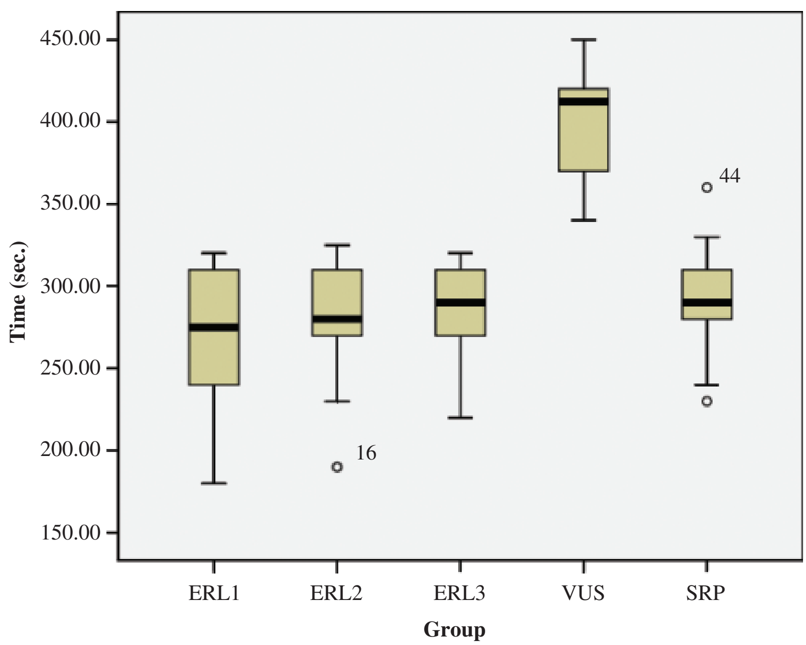

Fig. 5. Boxplots with outliers for the medians and Q1–Q3 quartiles of time (seconds) needed for instrumentation in different treatment groups ($n = 12$ patients).

Discussion

The results of the present study have shown that VUS seemed to be more suitable to obtain an almost complete removal of subgingival calculus from periodontally diseased root surfaces during non-surgical periodontal treatment of single-rooted teeth than ERL and SRP. However, depending on energy setting, comparable results were also obtained in the ERL group, as there was no statistical significant difference in terms of RSC areas between VUS and ERL3. Moreover, the results in the ERL3 group were obtained after a statistically significant shorter treatment time than in the VUS group. Although treatment time in the SRP group was within the range of the ERL groups, this treatment modality resulted in statistically significant highest RSC areas. There might be several explanations for the present findings. First of all, it has to be pointed out that in the SRP group, residual calculus was located by tactile sensation with the curet combined with a conventional periodontal probe. In this context, however, it must be emphasized that the completeness of root surface instrumentation and calculus removal is usually assessed using an explorer, even though the inter- and intra-examiner clinical agreement in detecting calculus has been reported to be low (Sherman et al. 1990). Indeed, the clinical assessment using an explorer seems to be inaccurate as considerable amounts of subgingival calculus were found with scanning electron micro-

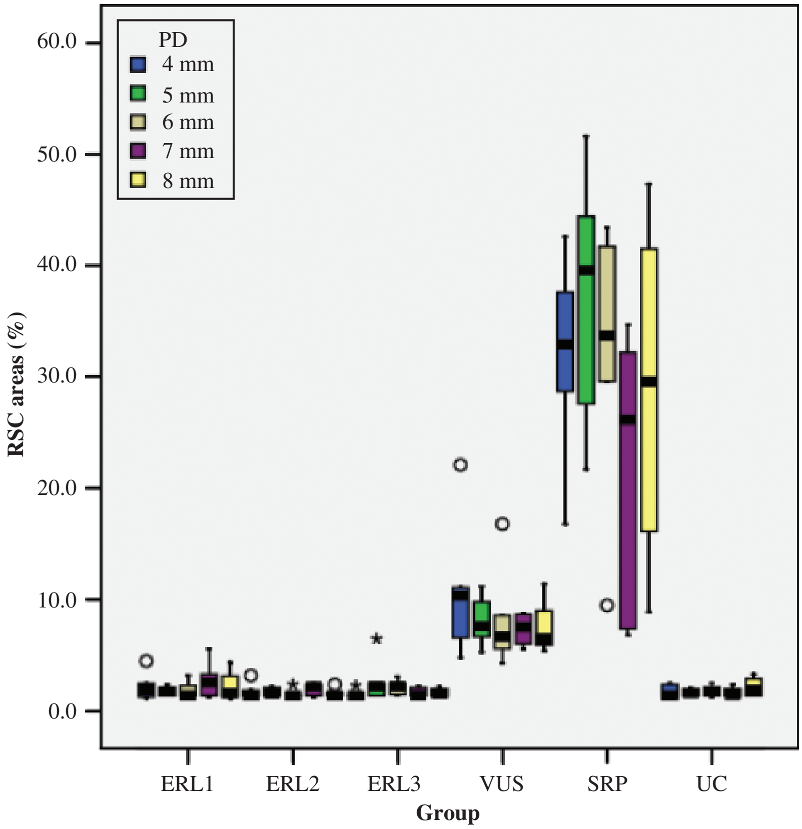

Fig. 6. Boxplots with outliers for the medians and Q1–Q3 quartiles of root surface changes (depth μm) in different treatment groups with respect to probing pocket depths (PD) ($n = 12$ patients).

scopy analysis on root surfaces which had been treated until they were clinically smooth (Jones et al. 1972, Walker & Ash 1976). Several examinations have also shown that the extent of residual calculus was highest following non-surgical hand instrumentation on proximal surfaces and in deep sites (Caffesse et al. 1986, Buchanan & Robertson 1987, Rateitschak-Plüss et al. 1992). Caffesse et al. (1986) reported that the percentage of root surfaces without calculus following SRP in 1–3 mm pockets was 86%, 43% in 4–6 mm pockets, and 32% in pockets greater than 6 mm. The extent of residual calculus seemed to be directly related to PD, and was greatest in association with grooves, fossae or furcations (Caffesse et al. 1986). Similar results were also reported by Buchanan & Robertson (1987), as pockets greater than 8 mm exhibited 45% calculus positive root surfaces following conventional SRP. However, Rateitschak-Plüss et al. (1992) reported that 29 of 40 root surfaces were free of residues following SRP. On the remaining 11 surfaces, only minute amounts of plaque and calculus were detected (Rateitschak-Plüss et al. 1992). The observation that higher RSC areas were observed at deeper pockets is also in agreement with the results of the present study. The extent of residual calculus seemed to be directly related to PD in the ERL(1–3) as well as in the SRP groups, even though this trend seemed to be less pronounced in the ERL3 group. Contradictory, however, Eberhard et al. (2003) have reported that the effectiveness of ERL, used without feedback system, and SRP for subgingival calculus removal seemed not to be related to initial PD. When interpreting the present results, it has also to be noted that specimens treated with VUS exhibited comparable RSC areas, irrespective of PD. Some possible explanations for this observation may be a better tactile sensation of the metal curet on the one hand and the hydrodynamic forces of the device in combination with the polishing fluid on the other hand facilitating calculus removal even at deeper pockets. To the best of our knowledge, there are currently no data evaluating the effectiveness of VUS for subgingival calculus removal in vivo. However, the present clinical findings corroborate, to a certain extent, results from previous experimental studies (Hartschen & Frentzen 2002, Braun et al. 2005a, b). It was reported that instrumentation of root surfaces in vitro with VUS using the straight metal probe and the polishing fluid resulted in a less effective removal of subgingival debris, but preservation of more tooth substance than a conventional ultrasonic system (Hartschen & Frentzen 2002). Similar results were also reported by Braun et al. (2005a), as hand instrumentation enabled a higher amount of subgingival calculus removal (mm^2) per second (i.e. efficiency) (0.340 mm^2/s) than VUS and the polishing fluid using either the metal probe (0.036 mm^2/s) or the metal curet inserts (0.122 mm^2/s). Efficiency of VUS using the metal curet seemed to be as efficient as a conventional ultrasonic system when the abrasive fluid was used (0.209 *versus* 0.199 mm^2/s) (Braun et al. 2005a). One possible explanation for the differences noted between in vitro and in vivo efficiency of VUS for subgingival calculus removal may be the environment of a closed periodontal pocket, enabling the generation of the above-mentioned hydrodynamic forces. However, with respect to substance removal on calculus-free root surfaces in vitro, it was observed that hand instruments (0.0055 mm^3/s) as well as VUS using the metal curet and the abrasive fluid (0.0044 mm^3/s) resulted in a statistically significant higher removal of root substance than VUS using the metal curet and the polishing fluid (0.0022 mm^3/s) (Braun et al. 2005b). These findings corroborate, to a certain extent, histomorphometrical analysis of root surface changes following SRP and VUS in the present study. It was observed that SRP generally exhibited conspicuous root surface alterations ranging from shallow scratches, clefts and grooves to sharp-edged crater-like defects covering almost 65% of the instrumented root surfaces. In contrast, specimens treated with VUS exhibited some slight superficial irregularities covering almost 100% of the instrumented root surface areas. In this context, it must also be pointed out that studies investigating the degree of surface roughness following the use of hand and ultrasonic instruments are difficult to interpret owing to a lack of critical variables such as forces applied during instrumentation (Zappa

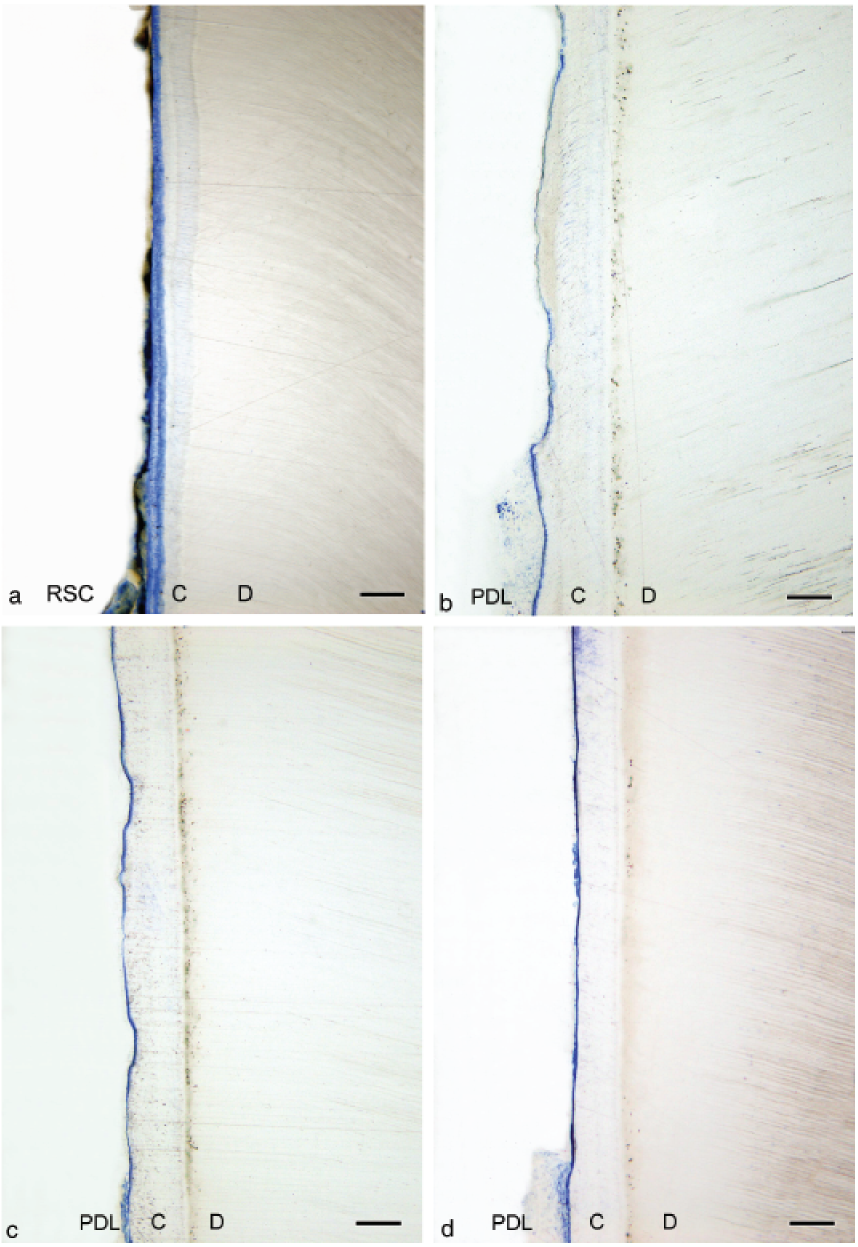

Fig. 7. Representative longitudinal sections of root surfaces in different treatment groups (toluidine blue stain, bar = 20 μm). (a) Untreated control specimen exhibiting considerable amounts of RSC.
(b) Crater-like defects with sharp-edged borders next to smooth root surface areas following SRP.
(c) Slightly roughened root surface following treatment with Vector™ ultrasonic system (VUS).
(d) Smooth root surface morphology irrespective of energy setting in the Er:YAG laser (ERL) groups (e.g. 100 mJ).
C, cementum;
D, dentin;
PDL, periodontal ligament;
RSC, residual subgingival calculus.

et al. 1991). All these data taken together with the present results seem to indicate that from a clinical point of view, VUS should be used in combination with the polishing fluid in order to preserve root cementum. To the best of our knowledge, there exists only one study comparing the effects of ERL used with the ''feedback system'' or hand instruments on the removal of subgingival calculus and root surface alterations following non-surgical periodontal treatment in vivo (Schwarz et al. 2003b). It was observed that ERL provided a selective subgingival calculus removal on a level equivalent to that provided by SRP (areas of RSC: 24% *versus* 22%). However, the end point of treatment in the ERL group was determined as the inability to locate residual calculus with a periodontal probe instead of the ''feedback system''. Histomorphometrical analysis of root surfaces instrumented with ERL exhibited no detectable surface alterations. In contrast, root surfaces treated with SRP exhibited considerable surface changes such as scratches and shallow craters (mean crater depth: 26.4 μm) (Schwarz et al. 2003b). The lack of cementum removal following in vivo irradiation with ERL in contrast to SRP is also in agreement with previous findings (Schwarz et al. 2001a, 2003b, Eberhard et al. 2003). However, in these studies ERL was used without feedback system. Although ERL seemed to possess an in vivo capability to remove calculus from periodontally diseased root surfaces, its effectiveness did not reach a level that was achieved by SRP (Eberhard et al. 2003). When interpreting the present results, however, it has to be noted that ERL used with the feedback system and a modified chisel-shaped fibre tip (''blue tip'') seemed to be more effective for the localization and removal of subgingival calculus than SRP, even reaching the level of VUS when energy was set at 140 mJ/pulse. There might be several explanations for the present findings. First, it must be emphasized that laser fluorescence induced by the 655 nm diode-laser radiation was reliably used for detection of subgingival calculus on extracted teeth (Folwaczny et al. 2002a, Krause et al. 2003). In this context, however, one must keep in mind that higher RSC areas were observed at deeper pockets, outlining that there seems to be a lack of reliability of the fluorescence signal in these areas. Secondly, the chisel-shaped fibre was modified to allow for a more homogeneous transmission of the laser beam, especially at the fibre tip, resulting in a more effective ablation of subgingival calculus even at lower energy settings. Based on the present results, it might be hypothesized that ERL may be used at a panel setting of 140 mJ and 10 Hz in order to optimize calculus ablation but also to prevent undesirable root surface alterations. However, the effects and safety of this modified system on periodontal wound healing must also be proven in histological and clinical studies.

Within the limits of the present study, it may be concluded that ERL and VUS enabled (i) a more effective removal of subgingival calculus, and (ii) a predictable root surface preservation in comparison with SRP.

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Clinical Relevance

Scientific rationale for the study: The use of an Er:YAG laser combined with a calculus detection system with fluorescence induced by 655 nm InGaAsP diode laser radiation (ERL) might facilitate the localization and ablation of bacterial deposits from periodontally diseased root surfaces particularly during non-surgical treatment approaches.

Principal findings: The present results have indicated that ERL provided an almost selective subgingival calculus removal on a level equivalent to that provided by an ultrasonic device and even superior to that provided by hand instruments. However, there seemed to be a lack of reliability of the fluorescence signal in deeper pockets.

Practical implications: Fluorescence-controlled Er:YAG laser radiation might be a valuable tool to improve subgingival calculus removal and preserve root cementum during non-surgical periodontal treatment.