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Effects of root surface debridement using Er:YAG Laser versus ultrasonic scaling – a SEM study

Abstract: *Objective:* Despite promising results of Er:YAG laser in periodontal debridement, to date there is no consensus about the ideal settings for clinical use. This experimental clinical trial aimed to determine the effects of debridement using Er:YAG laser and to compare with ultrasonic treatment. *Materials and methods:* Sixty-four teeth were divided into two *in vivo* and *in vitro* subgroups. Each tooth received ultrasonic treatment on one side and Er:YAG laser debridement at either 60, 100, 160 or 250 mJ pulse^{-1} and at 10 Hz on the other side on a random basis. All samples were morphologically analyzed afterwards under scanning electron microscope for surface changes and dentinal tubules exposure. Treatment duration (d) was also recorded. *Results:* Laser debridement produced an irregular, rough and flaky surface free of carbonization or meltdown while ultrasound produced a relatively smoother surface. The number of exposed dentinal tubules (*n*) followed an energy-dependent trend. The number of exposed tubules among the *in vivo* laser groups was *n* 60 mJ = *n* 100 mJ < *n* 160 mJ < *n* 250 mJ ($P < 0.001$). Also 160 and 250 mJ lasers led to significantly more dentinal exposure than ultrasound under *in vivo* condition. Within the *in vitro* laser groups, dentinal tubules exposure was *n* 60 mJ < *n* 100 mJ < *n* 160 mJ < *n* 250 mJ ($P \leq 0.0015$). Furthermore, *in vitro* laser treatments at 100, 160 and 250 mJ led to significantly more dentinal denudation than ultrasound. Treatment duration (d) for the *in vivo* groups was *d* 60 mJ > *d* 100 mJ > *d* Ultrasound = *d* 160 mJ > *d* 250 mJ ($P \leq 0.046$), while for the *in vitro* groups it was *d* 60 mJ > *d* 100 mJ = *d* Ultrasound = *d* 160 mJ > *d* 250 mJ ($P \leq 0.046$). *Conclusions:* Due to excessive treatment duration and surface damage, Er:YAG laser debridement at 60 and 250 mJ pulse^{-1}, respectively, is not appropriate for clinical use. Although laser debridement at 100 and 160 mJ pulse^{-1} seems more suitable for clinical application, compared to ultrasound the former is more time-consuming and the latter is more aggressive. Using a feedback device or lower pulse energies are recommended when using laser in closed field.

Key words: Er:YAG laser; periodontology; scanning electron microscope

Introduction

The root surfaces of periodontal pockets are contaminated and coated with a biofilm. This biofilm may be calcified as calculus and harbours great numbers of bacteria and bacterial toxins (1). Periodontal treatment

aims at the elimination of the living microorganisms present in the non-calcified and possibly also on the calcified biofilm (2). Complete elimination of such microorganisms by mechanical means appears, however, to be difficult (3).

From a clinical point of view, the volume of dental calculus has to be minimized, providing the basis for optimal plaque control and hence, substantially delaying the re-colonization of the root surfaces that have been debrided as well. The efficiency of calculus removal may be influenced by numerous factors such as the extent of periodontal disease, anatomic factors, the experience and skills of the operator and the instruments used (4, 5). Hand instruments, sonic and ultrasonic scalers and ablative laser therapy may be used for the removal of calculus and plaque. Hand instruments and sonic or ultrasonic scalers produce similar periodontal healing outcomes (6).

The Er:YAG laser is one of the mostly studied lasers in periodontics. Its wavelength lies near the highest peak of absorption by water, minimizing the thermal side effects with appropriate power settings. Ablation is possible without producing a smear layer (7) and both smear layer and endotoxins can be removed from root surface (8, 9). Fibroblasts show enhanced adhesion and proliferation on laser-treated root surfaces (10, 11). Moreover, several studies have reported promising outcomes for both clinical and microbiological aspects showing reduction in pocket depth and inflammation (12–14). However, Er:YAG laser therapy should only be applied as a mono-therapy, as adjunctive use of Er:YAG laser after scaling and root planing failed to show any additional benefits (15, 16).

Overall, there is a lack of a fixed set of parameters for Erbium laser applications in periodontal debridement. Hence, it is difficult to draw a definitive conclusion on the actual value of laser debridement in periodontics. Moreover, there are some contradictory findings among the studies, where the same laser settings lead to different outcomes (17–20). Presently, it is already clear that higher energies of a laser may perform the debridement more effectively, but in the same token, may remove bigger increments of the underlying tooth structure (17, 21, 22). Several studies have quantified the amount of ablation following laser application on the root surface (21, 23). In this regard, different outcome variables such as the crater depths and dentinal tubules denudation have been utilized by some studies (17, 22).

To date and to our knowledge, only Herrero and coworkers (22) used the latter outcome variable to compare the root substance removal by different laser settings. In addition, treatment duration has not sufficiently been investigated in most studies. This may ultimately influence patient discomfort. Moreover, most studies were performed either *in vivo* or *in vitro*. Taking the obvious differences of the two conditions into account leads to a discrepancy between results.

Therefore, the aims of this study were as follows:

1 To investigate the morphologic effects of different laser settings versus ultrasonic scaling at the ultrastructural level,

2 To compare the exposure of dentinal tubules corresponding to tooth substance removal by different laser settings and ultrasonic scaling.

3 To compare the treatment duration of laser debridement using different settings with each other and to ultrasound.

As the laser energy at 160 mJ p^{-1} has been widely applied in clinical studies and favourable outcomes have been reported (13, 16, 19, 24), the research hypothesis of the present randomized controlled trial was that there is no difference in the number of exposed dentinal tubules following Er:YAG laser debridement at 160 mJ p^{-1} or lower energy levels compared to ultrasonic scaling.

Material and methods

The study was conducted in accordance with the Helsinki declaration of 1975 as revised in 2008 and the protocol was approved by the ethical committee of the University Hospital of Ghent (study no. EC/2008/522). Prior to inclusion into the study, all patients received detailed oral and written information and a written consent was obtained from all enrolled individuals before the commencement of the trial.

Study design

This experimental clinical study included a total of 64 teeth, heavily affected by periodontal disease and planned to be extracted during the course of routine periodontal treatment. The teeth had (i) advanced periodontitis, (ii) exhibited bone loss of at least two-thirds of the root length, (iii) similar probing depth on the buccal and lingual surfaces, (iv) radiographic evidence of subgingival calculus and (v) absence of decay or restorations adjacent to the CEJ.

Teeth were assigned to either an *in vitro* or an *in vivo* treatment group of 32 teeth each. Each group was subdivided in four subgroups of eight teeth, which underwent subgingival ultrasonic scaling and root planing on either buccal or lingual side, and subgingival laser debridement with Er:YAG laser with one of the four settings on the opposite side.

In the *in vivo* group, the patients underwent the laser and ultrasonic treatment followed by tooth extraction. Freshly extracted human teeth assigned to the *in vitro* treatment group were stored in sterile saline solution (NaCl 0.9% at 37°C), and the actual treatment was carried out within a maximum of 3 days after extraction.

The enrollment of samples into treatment groups was randomly performed for all groups by means of a computer-generated list using simple randomization by a study member who was not clinically involved in the study (J.C). All treatments were performed by the same operator (S.R.M) at the specialist clinic of the department of periodontology of the university of Ghent, Belgium. The study flowchart is presented in Fig. 1.

Laser and ultrasonic treatment

In vivo group

An Er:YAG laser (λ = 2.94 μm) with a R14 Er:YAG handpiece and a chisel tip of 0.5 × 1.5 mm (AT Fidelis, Fotona, Ljubljana,

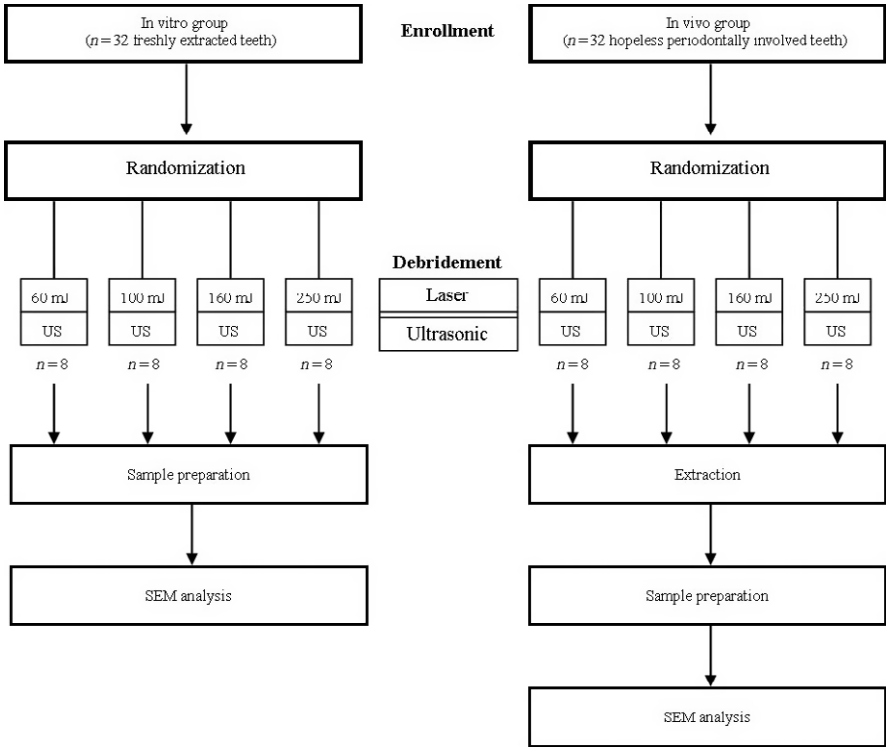

Fig. 1. The study flowchart (US: ultrasonic debridement).

Slovenia) were selected for laser debridement. Samples were irradiated at energy levels of either 60, 100, 160 or 250 mJ pulse^{-1} (effective energy density: 6.7 J cm^{-2} per pulse, 12.0 J cm^{-2} per pulse, 18.7 J cm^{-2} per pulse and 30.7 J cm^{-2} per pulse, respectively), and a repetition rate of 10 Hz with water irrigation and air cooling according to the instructions given by the manufacturer (70% water, 30% air). Laser application was performed using the handpiece [R14 Er:YAG Handpiece (R14-C), Fotona, Ljubljana, Slovenia] attached to a chisel tip (fibre optic tip of 0.5 × 1.5 mm). The fibre tip was moved from coronal to apical in parallel paths with an inclination of approximately 20°–25° in relation to the long axis of the root. The opposite side was treated with an ultrasonic scaler using the two available tips (1-S and 10Z, Satelec P5 Newtron ®, Acteon group, Bilbao, Spain). The endpoint of both treatments was achieving a hard, smooth, clinically calculus-free root surface as determined by tactile sensation with a pocket probe. No time limits were imposed for the treatments and the treatment duration was recorded in minutes.

The teeth were carefully extracted immediately after the treatment and placed under cold running tap water for about 1 min to remove blood and loosely adherent debris and then placed in a container with 10% buffered formalin solution at 37°C.

In vitro group

Following laser and ultrasonic debridement of the extracted teeth outside the mouth, the samples were placed in a container with 10% buffered formalin solution at 37°C.

SEM analysis

Tooth specimens were dehydrated in ethanol/water mixtures. Step by step, the ethanol concentration of these mixtures was increased from 60, 70, 80, 96 to 100%. Specimens were kept for 24 h in each of the ethanol solutions mentioned. Finally, the specimens were dried for 48 h in a desiccator prior to analysis.

Scanning electron microscope (SEM) analysis is performed in a JEOL JSM-5600 (Jeol, Tokyo, Japan) with progressive magnifications (25×, 100×, 750×, 1500×, 3000×). The apparatus was used in the secondary electron mode (SEI). Prior to analysis, all samples were coated with a thin gold layer (roughly 25 nm) via plasma magnetron sputter coating. Acceleration voltages between 10 and 15 keV were applied.

For each treated site, two images of 1500× magnification (corresponding to two rectangular zones of ~0.048 mm^2 each, placed in the center of hypothetical midline with 1 and 3 mm distance to CEJ) were used to measure the number of exposed dentinal tubules. Following this, a mean for these two numbers was calculated, which represented the mean number of exposed dentinal tubules per site. This phase was performed twice with 48 h in between. The dentinal tubules denudation measurements yielded an intra-examiner reproducibility of 96.2%. The morphologic changes and the number of exposed dentinal tubules were considered as primary outcome variables, whereas treatment duration was secondary.

Statistical analysis

SPSS 17.0 statistical software (SPSS, Inc., Chicago, IL, USA) licensed to the University of Ghent, Belgium was used for

statistical analysis. Mean values and standard deviations for the number of exposed dentinal tubules and treatment duration were calculated for laser- and ultrasonically treated areas.

Differences between ultrasonic and the laser debrided groups (intra-group) were evaluated by Wilcoxon Signed Ranks Test. Values of $P < 0.05$ were accepted as statistically significant. Comparison between different laser settings was performed by the Kruskall-Wallis test and the Mann-Whitney Test. After the Bonferroni correction, $P < 0.003$ was the criterion for significance.

Results

Patients were recruited to the study between October 2009 and January 2010. For the *in vivo* group, 19 patients (mean age: 53.6, ranging from 41 to 74) with untreated advanced chronic periodontitis contributed a total of 32 teeth consisting of three incisors, four canines, 12 premolars and 13 mandibular molars. Probing pocket depths ranged from 6 to 11 mm (mean: 7.7 mm ± 2.6 mm).

For the *in vitro* group, 32 freshly extracted teeth obtained from 21 patients (mean age: 54.1, ranging from 45 to 70) were used. These teeth were consisting of four incisors, five canines, 10 premolars and 13 mandibular molars. Probing pocket depths ranged from 7 to 11 mm (mean 7.9 mm ± 2.2 mm). In both *in vivo* and *in vitro* groups, there were no significant differences between the sides undergoing ultrasonic and laser treatment in terms of mean pocket depth ($P \geq 0.44$).

Morphology

Calculus removal was mostly complete with partial or complete removal of subjacent cementum that, in the latter case, was accompanied with exposure of dentinal tubules. However, under SEM, various surface alterations were observed. Ultrasonic scalers produced a relatively smooth and homogenous surface (Fig. 2) while in all laser-treated samples, root surfaces were irregular, rough and flaky, free of carbonization or meltdown or any other visible thermal changes. They showed large ablated defects, with a tendency to get deeper with increasing energies (Fig. 3). Sporadically, areas containing remaining calculus were found on the treated regions and particularly on the apical end of very deep pockets. Moreover, the apical parts of samples which were not treated, showed cementum, tiny soft tissue remnants and often remnants of calculus. The apical and lateral borders of the treated surfaces were well-defined in form of a step which tended to be relatively deep and increasing in depth with increasing laser energies. The traces of the chisel tip were clearly visible in the laser-treated groups and sometimes, untreated areas between these traces were observed. The morphology of laser-treated surfaces is shown in the Figs 4 and 5 (a–d). In comparison with laser-treated sites, surfaces treated ultrasonically were more regular and smoother and without any other surface alterations as shown in Figs 4 to 5 (e). Exposures of dentinal tubules were rarely observed. Small particles of remaining calculus were scarcely spotted on treated surfaces. The borders of treated surfaces were less pronounced and were mostly gradual.

Exposure of dentinal tubules

In general, the number of exposed tubules increased with higher levels of energy, and *in vitro* samples tended to show more exposed tubules than *in vivo* samples. The mean number of exposed dentinal tubules per two areas of ~0.048 mm^2 ranged between 3.12 and 19.75 for the *in vivo* laser-treated group and 3.50 and 48.87 for the *in vitro* laser-treated group.

For *in vivo* ultrasonic scaling, the number of exposed dentinal tubules ranged from 3 to 5 and from 2.62 to 3.50 for the *in vitro* specimens. Intra-group comparisons within *in vivo* groups showed statistically significant differences between the two higher pulse energies of laser (160 and 250 mJ) and the ultrasonically treated group regarding exposed dentinal tubules ($P = 0.011$ and $P = 0.012$, respectively).

Also, *in vitro* laser treatment at 100, 160 and 250 mJ showed statistically significant differences with ultrasonically treated surfaces ($P = 0.012$). This is documented in Fig. 6. Intergroup comparisons between *in vivo* laser groups revealed that 60 and 100 mJ lasers produced significantly less exposures of dentinal

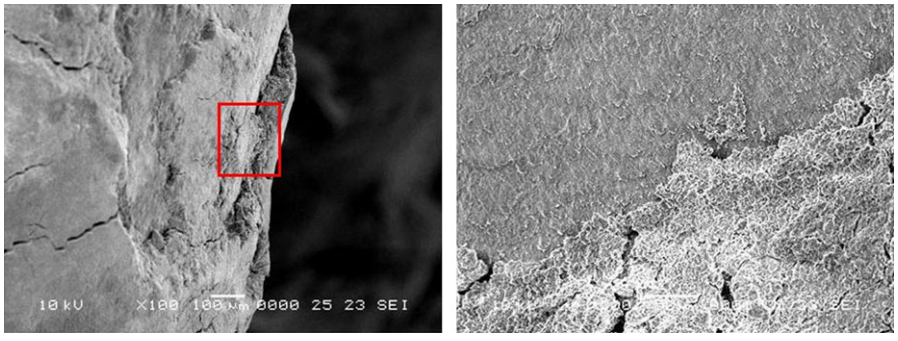

Fig. 2. Scanning electron microscope micrographs of samples treated *in vivo* using ultrasonic scaler. The right image is a magnification of the area within the red rectangle. (Magnifications: ×100 left image, ×500 right image).

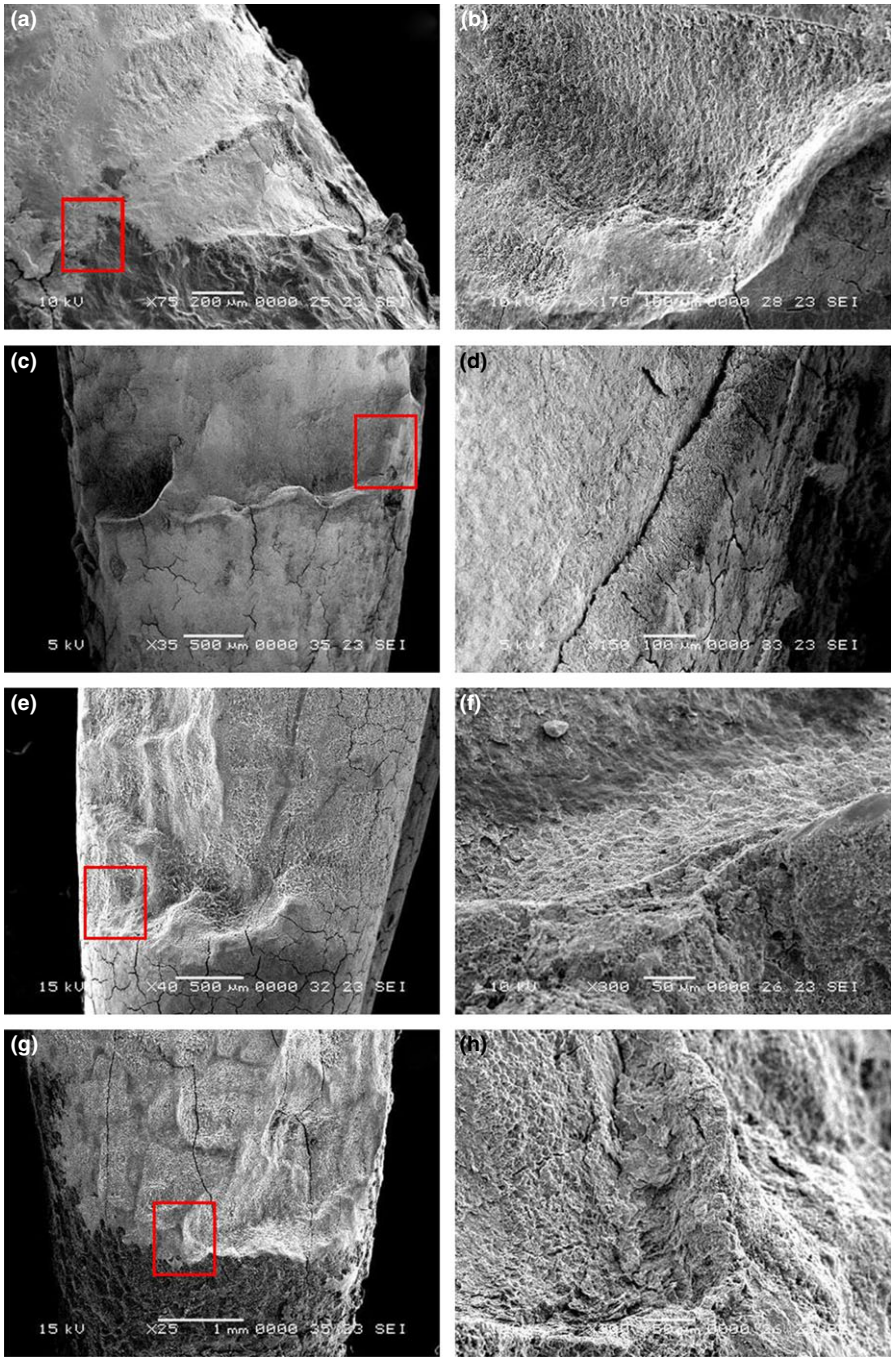

Fig. 3. Scanning electron microscope micrographs of samples treated *in vivo* using laser at: (a) and (b) 60 mJ, (c) and (d) 100 mJ, (e) and (f) 160 mJ, (g) and (h) 250 mJ. Images on the right are magnification of the areas within the red rectangles on the left side. (Magnifications: (a) ×75, (b) ×170, (c) ×35, (d) ×150, (e) ×40, (f) ×300, (g) ×25, (h) ×300).

tubules than 160 and 250 mJ ($P < 0.001$), and 160 mJ lead to significantly less exposures than 250 mJ ($P = 0.001$).

The same comparisons within *in vitro* laser-treated groups, showed that each laser subgroup had a significantly less number of exposed tubules than the next higher pulse energy. Furthermore, performing intergroup comparison of each *in vivo* laser setting with its *in vitro* counterpart, 100, 160 and 250 mJ laser treatment showed significant differences ($P < 0.001$, $P = 0.010$ and $P < 0.001$, respectively).

Treatment duration

The mean duration of laser treatment *in vivo* ranged between 0.62 and 3.12 min while for the *in vitro* group, it was between 0.87 and 1.87 min. The duration ranged between 1 and 1.50 min for *in vivo* ultrasonic treatment and between 1 and 1.37 min for *in vitro* ultrasonic treatment. Intragroup comparisons within the *in vivo* groups showed statistically significant differences between laser treatment at 60 mJ, 100 mJ, 250 mJ

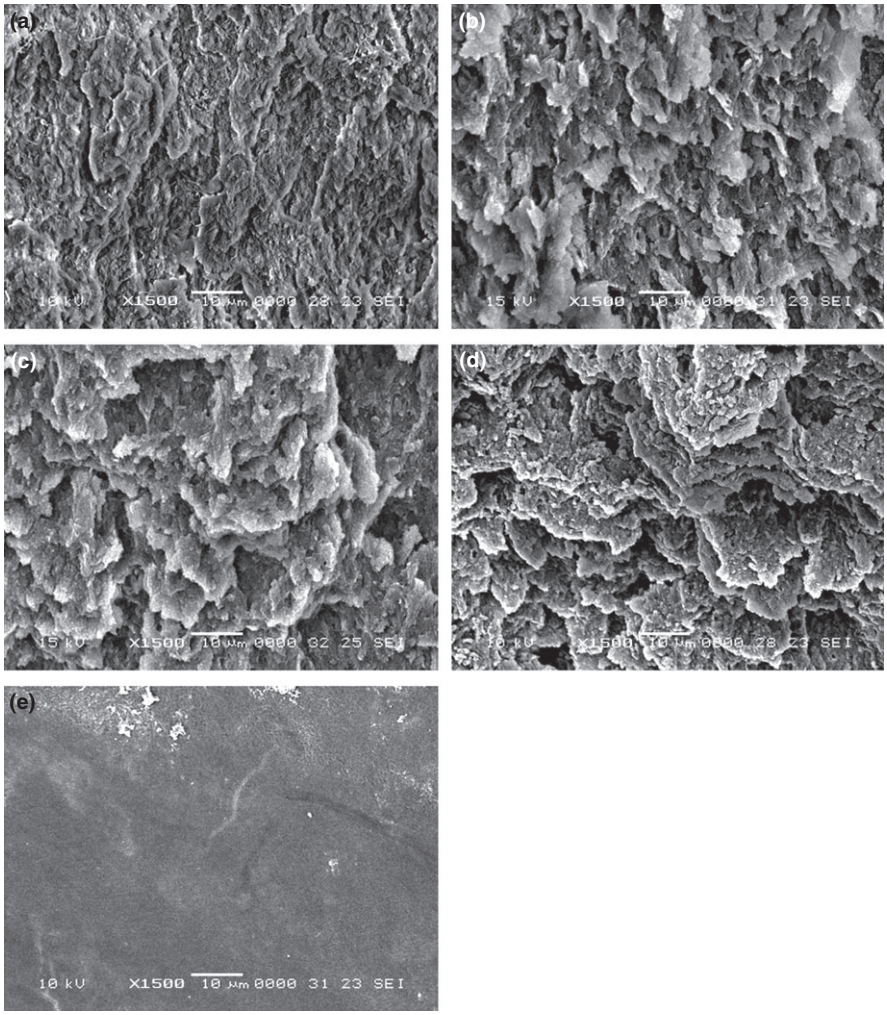

Fig. 4. Scanning electron microscope micrographs of samples treated *in vivo* using laser or ultrasonic scaler: (a) laser at 60 mJ, (b) laser at 100 mJ, (c) laser at 160 mJ, (d) laser at 250 mJ, (e) ultrasonic. (Magnification: ×1500).

and ultrasonic scaling ($P = 0.011$, 0.046 and 0.034, respectively). In the *in vitro* group, there were statistically significant differences between the two laser-treated groups of 60 and 250 mJ and ultrasonic scaling ($P = 0.008$ and 0.046, respectively). Intergroup comparisons between *in vivo* laser-treated groups, showed that 60 mJ laser treatment took significantly more time than other settings. The same comparisons for *in vitro* laser-treated groups showed significant differences between 60 mJ laser and 160 mJ and 250 mJ ($P = 0.002$ and $P = 0.001$ respectively). These results are summarized in Fig. 7.

Discussion

In the current trial, each subgroup consisted of eight teeth. This was a feasible sample size based on a somewhat similar study (22), as the studies investigating the dentinal tubules exposure as a measure for dentin denudation were very scarce.

The results of this study revealed that Er:YAG was highly effective for hard tissue ablation. The rough and irregular surface, free of carbonization and melting, produced with all laser settings, is in line with the morphological findings in several other studies (17, 22, 24, 25). It appears that the use of Er:YAG laser under water irrigation with all the confounding factors involved in clinical applications even at a high energy of 250 mJ pulse^{-1} does not cause thermal effects such as carbonization, melting and re-solidification.

Despite the general acceptance of surface roughening by laser treatment, there is a range of diverse factors affecting the surface morphology such as application time and tip angulation (26). This renders the interpretation of the morphologic data difficult. In this study, calculus was effectively ablated along with partial or complete ablation of the underlying cementum in all samples. Several other studies applying Er:YAG laser at 40–160 mJ and 10 Hz (22, 27, 28), reported similar calculus removal efficiency of laser and ultrasonic debridement.

There is controversy on the ideal settings of laser parameters to perform effective calculus removal while keeping the ablation of intact tooth substance to a minimum. The laser debridement at 60–160 mJ pulse^{-1}, is effective in calculus removal as indicated in the present as well as other studies

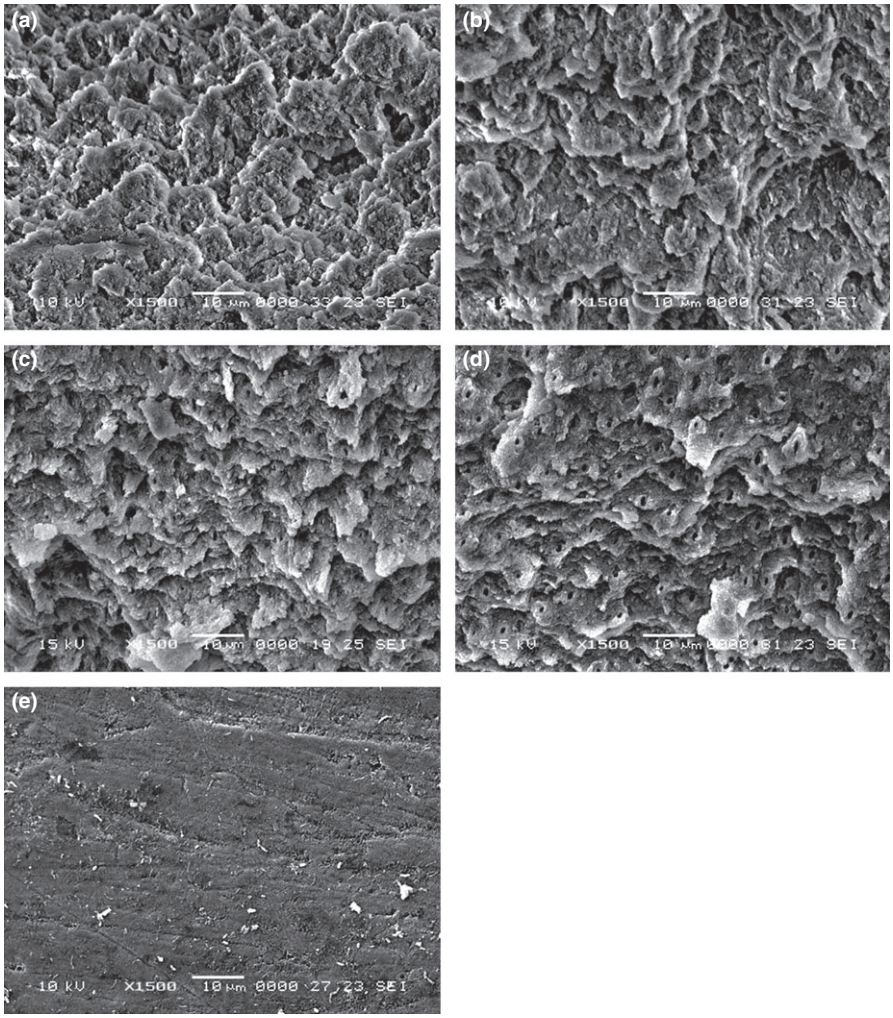

Fig. 5. Scanning electron microscope micrographs of samples treated *in vitro* using laser or ultrasonic scaler: (a) laser at 60 mJ, (b) laser at 100 mJ, (c) laser at 160 mJ, (d) laser at 250 mJ, (e) ultrasonic. (Magnification: ×1500).

(23, 29, 30). However, these settings appear to ablate intact underlying tooth structures as well.

On the other hand in this study, 250 mJ pulse^{-1} laser was chosen to evaluate the effects of laser treatment with an extremely high pulse energy. Calculus removal and root substance ablation had both a similar threshold that was at approximately 37 mJ pulse^{-1}. Hence, selective calculus removal without ablating cementum in clinical practice appears to be impossible (31).

Using lower pulse energies may help to limit the ablation of root cementum. Aoki and coworkers (23) removed the calculus effectively from root surface at 30 mJ pulse^{-1}. Using energies of up to 120 mJ pulse^{-1}, tooth substance ablation was generally observed within the cementum. Yet in another study, 100 and 120 mJ pulse^{-1} laser treatment removed calculus efficiently, but lead to increased loss of cementum and dentin (17). Although, reducing the energy may reduce the efficacy and increase the treatment duration.

In our study, the number of exposed dentinal tubules followed an energy-dependent trend. This resulted in significantly more exposed dentinal tubules by *in vivo* laser use at 160 and 250 mJ pulse^{-1} and *in vitro* laser use at 100, 160 and 250 mJ pulse^{-1} than noticed after ultrasonic treatment.

This trend was also generally noted when comparing laser energies with each other. However, the differences did not always reach statistical significance. Furthermore, the differences between the results of laser energies were more pronounced under *in vitro* condition. This energy-dependent pattern of ablation was observed in several studies (21, 22, 32). Nevertheless, the amount of substance removal differed extensively between reports. Some studies performed selective calculus removal with energies up to 100 mJ pulse^{-1} observing only slight superficial changes. With higher energies of 120–180 mJ pulse^{-1}, the ablation occurred totally within cementum (21, 30). Moreover, one study using laser treatment at 160 mJ pulse^{-1} and 15 Hz, achieved more dentin denudation following manual scaling (33). Nonetheless, several other studies reported complete local cementum removal following laser debridement at 80–160 mJ pulse^{-1} (17, 22, 32).

Data regarding quantitative assessment of substance removal by laser are controversial. In one study utilizing laser energies of

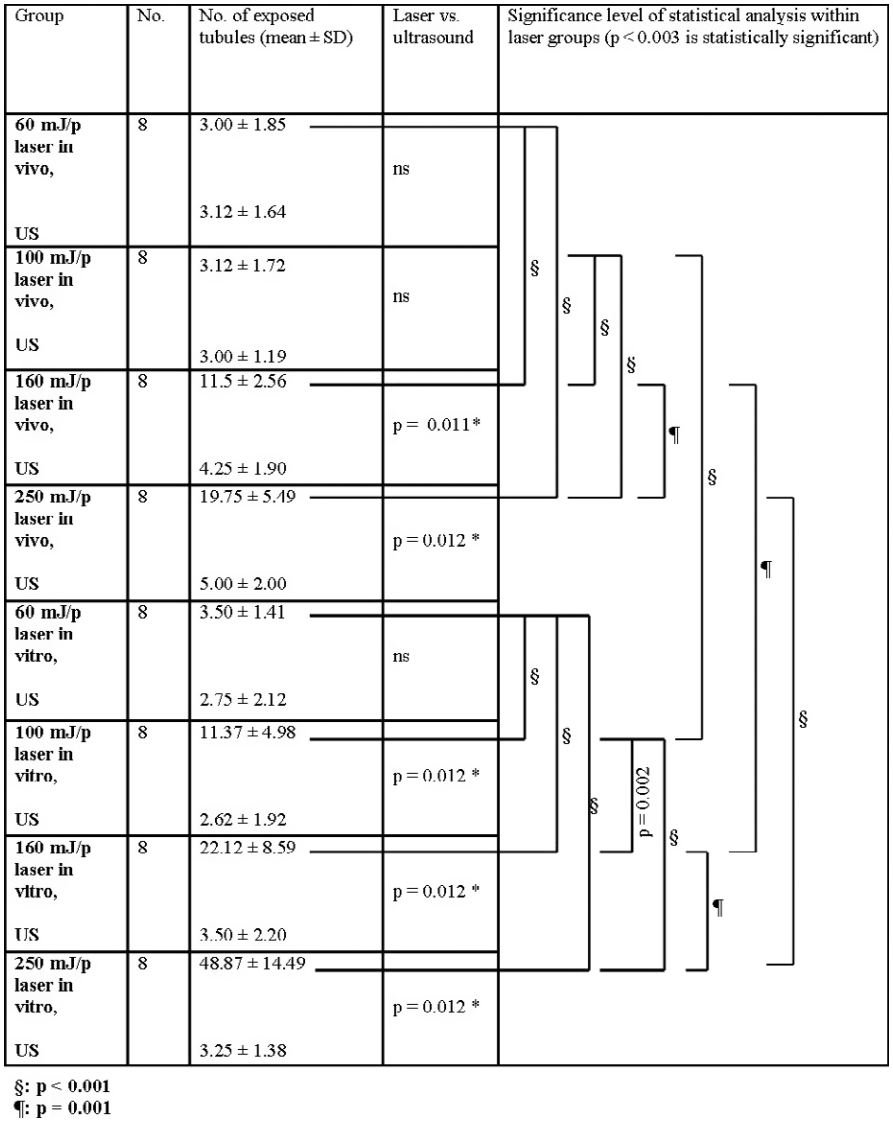

Fig. 6. Intragroup and intergroup comparisons of the difference in number of exposed dentinal tubules by laser and ultrasonic scaler using uni-variate analysis.

80–150 mJ pulse^{-1}, average substance removals of 174.38 (±16.13) μm – 501.85 (±111.01) μm and 37.78 (±14.03) μm – 484.44 (±80.63) μm were observed for teeth with and without calculus, respectively (21). Another study, using laser energies of 120 and 160 mJ pulse^{-1}, reported maximum crater defect depths of 77.1 (±42.8) μm which were within the range of ultrasonic and hand instruments (17, 34–36).

In other trials, laser at 10–120 mJ pulse^{-1}, 120 and 40 mJ pulse^{-1} were used, and a cementum ablation of 40–136 μm, 100 μm and 15–30 μm was reported, respectively (23, 28, 31). Similar to the outcomes of the present study, one study utilized 120, 140 and 160 mJ pulse^{-1} lasers and observed more exposed dentinal tubules after laser debridement than after ultrasonic treatment in an energy-dependent manner. However, statistically significant differences were only found for 160 mJ pulse^{-1} laser (22). Such differences are partly due to the factors affecting cementum thickness such as age, periodontal condition, previous periodontal treatments and probably functional stimuli (37, 38). Furthermore, the differences may have been related to treatment conditions, such as treating *in vivo* or *in vitro* and tip angulation (26).

The amount of substance removal following conventional treatments is, to date, a matter of controversy, ranging from 12 to 410 μm among different studies (17, 39, 40). Another confounding factor is the amount of pristine cementum deposited ranging between 5 and 800 μm in molar teeth (39). This, in turn, means that one root debridement may lead to various outcomes in different teeth or various regions on one tooth, particularly causing more or less denudation of dentinal tubules. Considering the results of this and previous studies, it may be concluded that higher energies of laser than around 160 mJ are probably ablating more substance than known for that of ultrasonic debridement.

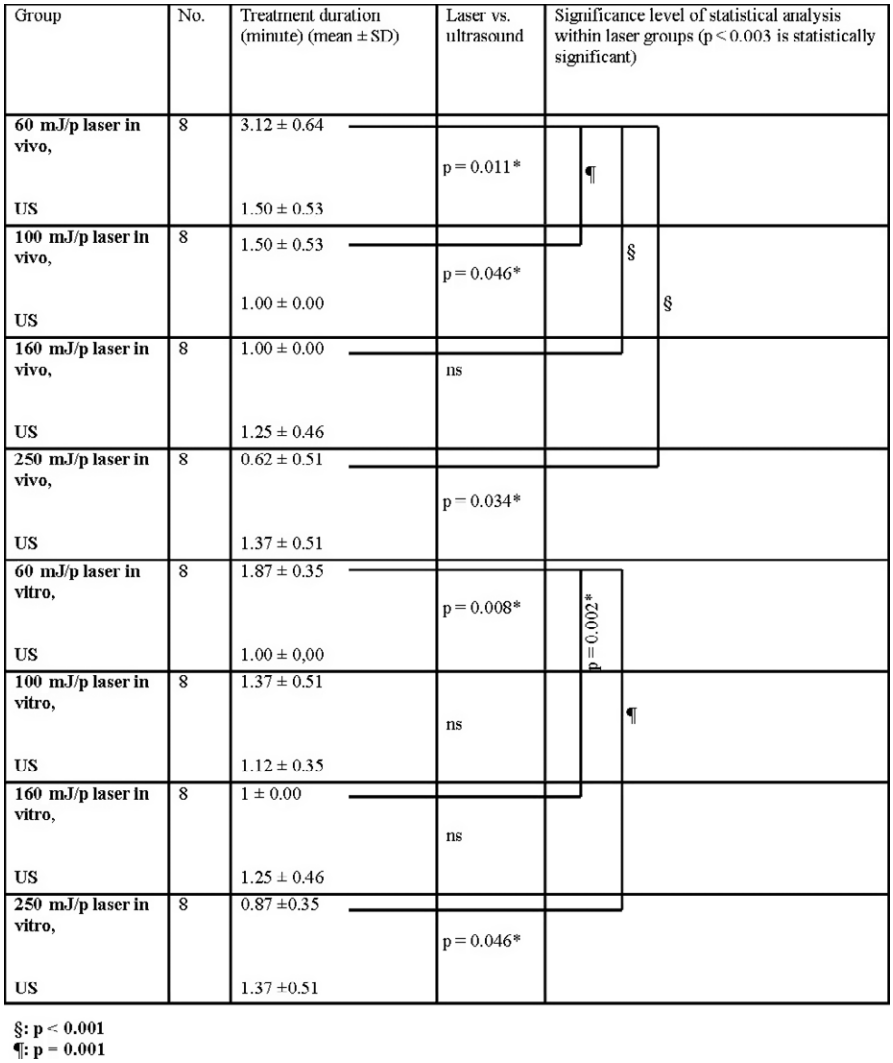

Fig. 7. Intragroup and intergroup comparisons of the treatment duration by laser and ultrasonic scaler.

Comparing *in vivo* laser settings with their *in vitro* counterparts, all *in vivo* laser treatments removed less cementum than *in vitro*. However, only at 100 and 250 mJ pulse^{-1} a statistically significant difference was observed. This may be interpreted as more effective selective calculus removal under *in vivo* conditions. This postulate was confirmed by Schwarz and coworkers who utilized laser at 120, 140, 160 and 180 mJ pulse^{-1}. They found more surface defects under *in vitro* than under *in vivo* condition (30). This more selective calculus removal under *in vivo* conditions, may be due to better heat diffusion within the pocket. Considering that the *in vitro* samples showed less selective calculus removal, extrapolating *in vitro* results to *in vivo* situations and drawing clinical conclusions from *in vitro* data is obviously doubtful.

The same energy-dependent pattern was present when analyzing treatment duration. Within the *in vivo* groups, 60 and 100 mJ pulse^{-1} laser took significantly more time than ultrasonic debridement, while for the *in vitro* group only 60 mJ pulse^{-1} laser was significantly slower than ultrasonic treatment. In both *in vivo* and *in vitro* groups, 250 mJ pulse^{-1} laser was significantly faster than ultrasonic debridement. Studies by Schwarz and coworkers (16, 41) presented the treatment duration using laser at 120–180 mJ pulse^{-1} as 9 min treating four sides of single-rooted teeth under *in vivo* and *in vitro* conditions. The same group required 5–10 min for treating single- and multirooted teeth using either laser at 160 mJ pulse^{-1} and 10 Hz or ultrasonic debridement. In other studies using the same laser parameters, the treatment took 5–6.5 min for single-rooted and 9–11 min for multirooted teeth (19, 42). The ultrasonic treatment took 4–8.2 min for single-rooted teeth and 9–14.6 min for multirooted teeth in the same studies. Comparing the treatment durations of 100–160 mJ pulse^{-1} laser in our study with outcomes of previous studies, the durations were in the same range. The intergroup comparisons of different *in vivo* laser treatment groups with each other, showed that 60 mJ pulse^{-1} laser treatment took significantly more time than the other laser groups.

According to the outcome of this study, a 60 mJ pulse^{-1} laser was not significantly less aggressive than 100 mJ pulse^{-1}, simply because the process required more time. Hence, it seems that this setting is impractical for clinical use. Generally, laser irradiation took more time *in vivo* than *in vitro*. This may partly be related to the difficulties associated with using a chisel attached to the arm of the laser machine and the form and thickness of the chisel which renders complete treatment of interproximal areas more demanding than ultrasonic debridement. For the same reason, the current trial focused mostly on the buccal and lingual aspects of teeth.

Recent studies have used a wide range of pulse energies for root surface debridement. While in some trials lower pulse energies around 30–50 mJ pulse^{-1} (43, 44) have been utilized, others used relatively higher pulse energies like 100–160 mJ pulse^{-1} (45–47). However, our observations suggest that erbium laser at pulse energies higher than 100 mJ without a calculus detection system may be too aggressive for root surface debridement.

Although an efficient treatment outcome is dependent on biofilm and calculus removal, while preserving as much non-infected tooth substance as possible, there is to date no consensus about the necessary amount of cementum removal to achieve periodontal healing (40, 48). Excessive removal of intact tooth substance may lead to denudation of dentinal tubules which means various painful stimuli may cause sudden fluid shifts in such tubules and elicit a painful sensation and patient's discomfort (49, 50). Moreover, studies have demonstrated that sensitive teeth have an increased number of dentinal tubules with greater diameters (51–53). However, it is not possible to precisely predict the consequences of excessive tooth substance removal, as root sensitivity remains a subjective experience.

The results of the current trial should be interpreted with caution, as the sample size was relatively small. Moreover, due to variability of cementum thickness, analyzing more areas along the root for dentinal tubules exposure might be recommended for future studies.

Conclusion

According to the results of this study, laser debridement at 160 mJ pulse^{-1} or higher was more aggressive than ultrasonic treatment. Hence, clinical application of laser debridement at 100 mJ pulse^{-1} may be considered safe as it was significantly less aggressive than 160 mJ and higher pulse energies, although as time-efficient as 160 mJ pulse^{-1}. Using higher pulse energies without a calculus detection system cannot be recommended for root surface debridement.

Clinical relevance

Scientific rationale for study

Excessive removal of intact tooth substance is a possible consequence of treatment when using Er:YAG laser for root surface debridement. The ideal pulse energy of erbium lasers for this purpose is to date a matter of debate.

Principal findings

Laser debridement at pulse energies higher than 100 mJ can be too aggressive, while not always yielding better treatment or time-efficiency.

Practical implications

One hundred millijoule per pulse seems to be more suitable for periodontal treatment in closed field. Using higher energies without a calculus detection system cannot be encouraged.

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References

1 Adriaens PA, Edwards CA, De Boever JA, Loesche WJ. Ultrastructural observations on bacterial invasion in cementum and radicular dentin of periodontally diseased human teeth. *J Periodontol* 1988; **59**: 493–503.

2 Rylander H., Lindhe J. Cause-related periodontal therapy. In: Jan Lindhe NPL, Karring T. *Clinical Periodontology and Implant Dentistry*. Oxford, Blackwell Munksgaard, 2003, pp. 432–448.

3 Rabbani GM, Ash MM Jr, Caffesse RG. The effectiveness of subgingival scaling and root planing in calculus removal. *J Periodontol* 1981; **52**: 119–123.

4 Fleischer HC, Mellonig JT, Brayer WK, Gray JL, Barnett JD. Scaling and root planing efficacy in multirooted teeth. *J Periodontol* 1989; **60**: 402–409.

5 Brayer WK, Mellonig JT, Dunlap RM, Marinak KW, Carson RE. Scaling and root planing effectiveness: the effect of root surface access and operator experience. *J Periodontol* 1989; **60**: 67–72.

6 Tunkel J, Heinecke A, Flemmig TF. A systematic review of efficacy of machine-driven and manual subgingival debridement in the treatment of chronic periodontitis. *J Clin Periodontol* 2002; **29** (Suppl. 3): 72–81.

7 Takeda FH, Harashima T, Kimura Y, Matsumoto K. A comparative study of the removal of smear layer by three endodontic irrigants and two types of laser. *Int Endod J* 1999; **32**: 32–39.

8 Folwaczny M, Aggstaller H, Mehl A, Hickel R. Removal of bacterial endotoxin from root surface with Er:YAG laser. *Am J Dent* 2003; **16**: 3–5.

9 Yamaguchi H, Kobayashi K, Osada R *et al*. Effects of irradiation of an erbium:YAG laser on root surfaces. *J Periodontol* 1997; **68**: 1151–1155.

10 Feist IS, De Micheli G, Carneiro SR, Eduardo CP, Miyagi S, Marques MM. Adhesion and growth of cultured human gingival fibroblasts on periodontally involved root surfaces treated by Er:YAG laser. *J Periodontol* 2003; **74**: 1368–1375.

11 Schwarz F, Aoki A, Sculean A, Georg T, Scherbaum W, Becker J. *In vivo* effects of an Er:YAG laser, an ultrasonic system and scaling and root planing on the biocompatibility of periodontally diseased root surfaces in cultures of human PDL fibroblasts. *Lasers Surg Med* 2003; **33**: 140–147.

12 Schwarz F, Aoki A, Becker J, Sculean A. Laser application in non-surgical periodontal therapy: a systematic review. *J Clin Periodontol* 2008; **35** (8 Suppl.): 29–44.

13 Schwarz F, Sculean A, Berakdar M, Georg T, Reich E, Becker J. Periodontal treatment with an Er:YAG laser or scaling and root planing. A 2-year follow-up split-mouth study. *J Periodontol* 2003; **74**: 590–596.

14 Ando Y, Aoki A, Watanabe H, Ishikawa I. Bactericidal effect of erbium YAG laser on periodontopathic bacteria. *Lasers Surg Med* 1996; **19**: 190–200.

15 Schwarz F, Sculean A, Berakdar M, Georg T, Reich E, Becker J. Clinical evaluation of an Er:YAG laser combined with scaling and root planing for non-surgical periodontal treatment. A controlled, prospective clinical study. *J Clin Periodontol* 2003; **30**: 26–34.

16 Sculean A, Schwarz F, Berakdar M, Romanos GE, Arweiler NB, Becker J. Periodontal treatment with an Er:YAG laser compared to ultrasonic instrumentation: a pilot study. *J Periodontol* 2004; **75**: 966–973.

17 Frentzen M, Braun A, Aniol D. Er:YAG laser scaling of diseased root surfaces. *J Periodontol* 2002; **73**: 524–530.

18 Tomasi C, Schander K, Dahlen G, Wennstrom JL. Short-term clinical and microbiologic effects of pocket debridement with an Er:YAG laser during periodontal maintenance. *J Periodontol* 2006; **77**: 111–118.

19 Crespi R, Cappare P, Toscanelli I, Gherlone E, Romanos GE. Effects of Er:YAG laser compared to ultrasonic scaler in periodontal treatment: a 2-year follow-up split-mouth clinical study. *J Periodontol* 2007; **78**: 1195–1200.

20 Crespi R, Romanos GE, Cassinelli C, Gherlone E. Effects of Er:YAG laser and ultrasonic treatment on fibroblast attachment to root surfaces: an *in vitro* study. *J Periodontol* 2006; **77**: 1217–1222.

21 Folwaczny M, Mehl A, Haffner C, Benz C, Hickel R. Root substance removal with Er:YAG laser radiation at different parameters using a new delivery system. *J Periodontol* 2000; **71**: 147–155.

22 Herrero A, Garcia-Kass AI, Gomez C, Sanz M, Garcia-Nunez JA. Effect of two kinds of Er:YAG laser systems on root surface in comparison to ultrasonic scaling: an *in vitro* study. *Photomed Laser Surg* 2010; **28**: 497–504.

23 Aoki A, Ando Y, Watanabe H, Ishikawa I. *In vitro* studies on laser scaling of subgingival calculus with an erbium:YAG laser. *J Periodontol* 1994; **65**: 1097–1106.

24 Keller U, Hibst R. Effects of Er:YAG laser in caries treatment: a clinical pilot study. *Lasers Surg Med* 1997; **20**: 32–38.

25 Gaspirc B, Skaleric U. Morphology, chemical structure and diffusion processes of root surface after Er:YAG and Nd:YAG laser irradiation. *J Clin Periodontol* 2001; **28**: 508–516.

26 Folwaczny M, Thiele L, Mehl A, Hickel R. The effect of working tip angulation on root substance removal using Er:YAG laser radiation: an *in vitro* study. *J Clin Periodontol* 2001; **28**: 220–226.

27 Schwarz F, Sculean A, Berakdar M, Szathmari L, Georg T, Becker J. *In vivo* and *in vitro* effects of an Er:YAG laser, a GaAlAs diode laser, and scaling and root planing on periodontally diseased root surfaces: a comparative histologic study. *Lasers Surg Med* 2003; **32**: 359–366.

28 Aoki A, Miura M, Akiyama F *et al*. *In vitro* evaluation of Er:YAG laser scaling of subgingival calculus in comparison with ultrasonic scaling. *J Periodontal Res* 2000; **35**: 266–277.

29 Keller U, Hibst R. Experimental removal of subgingival calculus with the Er:YAG laser. *Proc SPIE* 1987; **2623**: 189–198.

30 Schwarz F, Putz N, Georg T, Reich E. Effect of an Er:YAG laser on periodontally involved root surfaces: an *in vivo* and *in vitro* SEM comparison. *Lasers Surg Med* 2001; **29**: 328–335.

31 Stock K, Hibst R, Keller U. Er:YAG removal of subgingival calculi: efficiency, temperature and surface quality. *Proc SPIE* 1996; **2922**: 98–106.

32 Gomez C, Bisheimer M, Costela A, Garcia-Moreno I, Garcia A, Garcia JA. Evaluation of the effects of Er:YAG and Nd:YAG lasers and ultrasonic instrumentation on root surfaces. *Photomed Laser Surg* 2009; **27**: 43–48.

33 Eberhard J, Ehlers H, Falk W, Acil Y, Albers HK, Jepsen S. Efficacy of subgingival calculus removal with Er:YAG laser compared to mechanical debridement: an *in situ* study. *J Clin Periodontol* 2003; **30**: 511–518.

34 Coldiron NB, Yukna RA, Weir J, Caudill RF. A quantitative study of cementum removal with hand curettes. *J Periodontol* 1990; **61**: 293–299.

35 Flemmig TF, Petersilka GJ, Mehl A, Hickel R, Klaiber B. Working parameters of a magnetostrictive ultrasonic scaler influencing root substance removal *in vitro*. *J Periodontol* 1998; **69**: 547–553.

36 Zappa U, Smith B, Simona C, Graf H, Case D, Kim W. Root substance removal by scaling and root planing. *J Periodontol* 1991; **62**: 750–754.

37 Hürzeler B, Zander HA. Cementum apposition in periodontally diseased teeth. *Helv Odont Acta* 1959; **3**: 1–3.

38 Dastmalchi R, Polson A, Bouwsma O, Proskin H. Cementum thickness and mesial drift. *J Clin Periodontol* 1990; **17**: 709–713.

39 Stamfelj I, Vidmar G, Cvetko E, Gaspersic D. Cementum thickness in multirooted human molars: a histometric study by light microscopy. *Ann Anat* 2008; **190**: 129–139.

40 Nyman S, Sarhed G, Ericsson I, Gottlow J, Karring T. Role of "diseased" root cementum in healing following treatment of periodontal disease. An experimental study in the dog. *J Periodontal Res* 1986; **21**: 496–503.

41 Schwarz F, Sculean A, Georg T, Reich E. Periodontal treatment with an Er:YAG laser compared to scaling and root planing. A controlled clinical study. *J Periodontol* 2001; **72**: 361–367.

42 Derdilopoulou FV, Nonhoff J, Neumann K, Kielbassa AM. Microbiological findings after periodontal therapy using curettes, Er:YAG laser, sonic, and ultrasonic scalers. *J Clin Periodontol* 2007; **34**: 588–598.

43 Theodoro LH, Garcia VG, Haypek P, Zezell DM, Eduardo Cde P. Morphologic analysis, by means of scanning electron microscopy, of the effect of Er:YAG laser on root surfaces submitted to scaling and root planing. *Pesqui Odontol Bras* 2002; **16**: 308–312.

44 Yilmaz S, Kut B, Gursoy H, Eren-Kuru B, Noyan U, Kadir T. Er:YAG laser versus systemic metronidazole as an adjunct to nonsurgical periodontal therapy: a clinical and microbiological study. *Photomed Laser Surg* 2012; **30**: 325–330.

45 Soo L, Leichter JW, Windle J *et al*. A comparison of Er:YAG laser and mechanical debridement for the non-surgical treatment of chronic periodontitis: a randomized, prospective clinical study. *J Clin Periodontol* 2012; **39**: 537–545.
46 Lopes BM, Theodoro LH, Melo RF, Thompson GM, Marcantonio RA. Clinical and microbiologic follow-up evaluations after non-surgical periodontal treatment with erbium:YAG laser and scaling and root planing. *J Periodontol* 2010; **81**: 682–691.
47 Rotundo R, Nieri M, Cairo F *et al*. Lack of adjunctive benefit of Er:YAG laser in non-surgical periodontal treatment: a randomized split-mouth clinical trial. *J Clin Periodontol* 2010; **37**: 526–533.
48 Smart GJ, Wilson M, Davies EH, Kieser JB. The assessment of ultrasonic root surface debridement by determination of residual endotoxin levels. *J Clin Periodontol* 1990; **17**: 174–178.
49 Pashley DH. Dynamics of the pulpo-dentin complex. *Crit Rev Oral Biol Med* 1996; **7**: 104–133.
50 Brannstrom M. Sensitivity of dentine. *Oral Surg Oral Med Oral Pathol* 1966; **21**: 517–526.
51 Holland GR, Narhi MN, Addy M, Gangarosa L, Orchardson R. Guidelines for the design and conduct of clinical trials on dentine hypersensitivity. *J Clin Periodontol* 1997; **24**: 808–813.
52 Rimondini L, Baroni C, Carrassi A. Ultrastructure of hypersensitive and non-sensitive dentine. A study on replica models. *J Clin Periodontol* 1995; **22**: 899–902.
53 Absi EG, Addy M, Adams D. Dentine hypersensitivity. A study of the patency of dentinal tubules in sensitive and non-sensitive cervical dentine. *J Clin Periodontol* 1987; **14**: 280–284.