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Efficiency of the Vector™-system compared with conventional subgingival debridement in vitro and in vivo

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Abstract

Objective: To assess the efficacy of the novel ultrasonic Vector™-system system for subgingival debridement and to compare the results with conventional periodontal instrumentation in vitro and in vivo.

Material and Methods: Forty extracted human teeth were treated in vitro: Vector™-system with polishing (VP) and abrasive fluid (VA), conventional ultrasonic system (U) and hand instrument (H). At intervals of 40 s, calculus removal was assessed using a 3D laser scanning device. Eight single-rooted teeth were treated in vivo with the Vector™-system or hand instruments. Subgingival plaque samples were obtained for microbiological evaluation. After extraction, residual calculus was assessed by means of digitized planimetry.

Results: In vitro efficiency of hand instruments was statistically higher compared with the conventional ultrasonic system ($p<0.05$) and the Vector™-system with no difference between U and VA ($p>0.05$) and VA and VP ($p>0.05$). Residual calculus following in vivo instrumentation was not different in the Vector™ and the hand instrument group ($p>0.05$) but treatment time with the Vector™-system was statistically higher ($p<0.05$). A similar reduction of periopathogenic bacteria could be observed in both groups.

Conclusions: Using the Vector™-system, root surfaces can be debrided as thoroughly as with conventional instruments. However, treatment is more time consuming than conventional debridement.

Key words: 3D laser scanning; calculus removal; planimetry; subgingival plaque; ultrasonic instrumentation

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During the initial treatment of periodontitis, most time is spent for mechanical debridement. Firmly adhering subgingival calculus has to be removed, containing a variety of microorganisms and endotoxins capable of producing periodontal disease (Schenkein 1999). Thus, treatment of periodontitis is directed primarily towards the reduction of pathogens embedded in subgingival adhering mineralized deposits and the removal of the periopathogenic biofilm. Completion of calculus removal coincides with endotoxin levels associated with clinically healthy teeth (Cadosch et al. 2003). Calculus can be removed by using hand scalers, ultrasonic instruments, air-powder abrasive scalers, diamond burs and lasers. Sonic and ultrasonic scalers were originally designed for removal of supragingival calculus (Johnson & Wilson 1957). Modifying the instrument's tips to obtain smaller diameters and longer working lengths, better access to deep-probing sites and more efficient instrumentation could be achieved (Holbrook & Low 1994). No difference concerning clinical outcome between ultrasonic and manual debridement in the treatment of chronic periodontitis was found (Drisko et al. 2000, Tunkel et al. 2002). A primary mechanism for calculus removal is the mechanical chipping action of the scaler tip. Additionally, hydrodynamic forces such as high-energy shock waves produced by cavitation within the cooling water supply (Walmsley et al. 1990) and acoustic microstreaming patterns formed close to the surface of the scaler tip are supposed to contribute to calculus removal (Khambay & Walmsley 1999).

A recently introduced novel ultrasonic device is the Vector™-system (Duerr Dental, Bietigheim-Bissingen, Germany). Ultrasonic vibrations are generated at a frequency of 25 kHz and then converted by a resonating ring, deflecting a horizontal oscillation vertically (Hahn 2000). The instrument tip moves parallel to the tooth surface and avoids vibrations applied horizontally on the root surface. As a result, treatment has been shown to be less painful than treatment with conventional methods for periodontal therapy (Braun et al. 2003, Hoffman et al. 2005). However, reducing the power settings of a conventional ultrasonic device, comparable pain sensations were recorded for both the Vector™-system and a conventional device in maintenance therapy (Kocher et al. 2005). Clinical parameters such as pocket depths and bleeding on probing improved in a similar way, following the use of the Vector™-system or hand instruments for periodontal debridement (Klinger et al. 2000, Sculean et al. 2004). Using the device for the treatment of peri-implantitis, there was no clinical difference between the ultrasonic system and carbon fibre curettes (Karring et al. 2005).

It is recommended to use the device in conjunction with either a hydroxyl-apatite-containing polishing fluid or a silicon-carbide-containing abrasive fluid. Using a 3D laser scanning device, it could be shown that the amount of root substance removal with the Vector™ -system was significantly dependent on the selection of these irrigation fluids (Braun et al. 2005b). It is assumed that the efficiency in removal of adhering deposits may also depend on this parameter. Evaluating digitized photographs in a two-dimensional study design, this hypothesis could be confirmed (Braun et al. 2005a). Thus, the aim of the present study was to assess calculus removal by this novel ultrasonic system using a 3D laser scanning device in vitro and to compare the results with conventional debridement. Additionally, the amount of residual calculus should be assessed in situ, comparing the Vector™-system with the polishing fluid with hand instrumentation. Evaluating subgingival plaque samples, the impact of these two treatment methods on periopathogenic bacteria should be assessed.

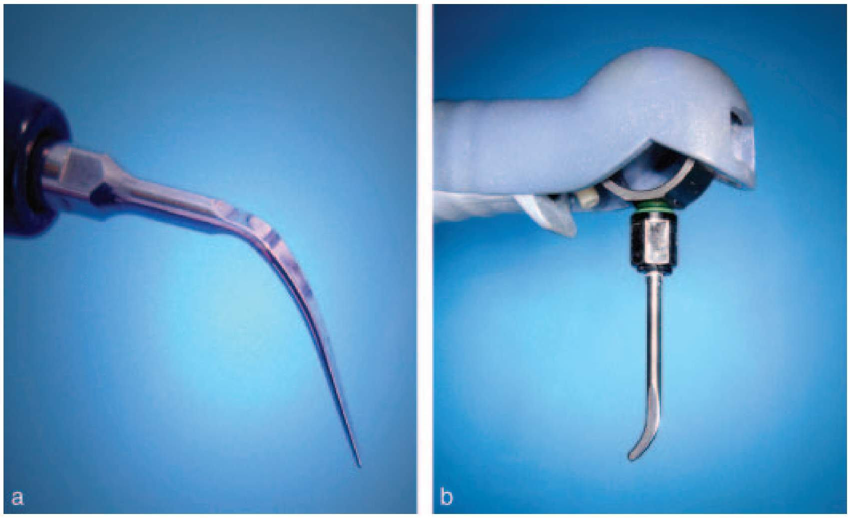

Fig. 1. Ultrasonic insert tips used in the present study. Tip ''P'' of the EMS device (a) and metal curette insert of the Vector™-system (b).

Materials and Methods

3D laser scanning

Forty extracted human teeth covered with subgingival calculus on the root surface were collected from different patients and stored in a physiological saline solution. The time span between tooth extraction and the following treatment of the teeth did not exceed 1 week. According to an experimental set-up described previously (Braun et al. 2005b), baseline scanning images of the root surfaces were captured and subsequently, incisors, pre-molars and molars were evenly assigned to four groups of 10 teeth with regard to tooth type and the amount of subgingival calculus present. These groups were then assigned to the treatment methods using computer-generated random numbers to avoid personal bias: Vector™-system with hydroxyl-apatite-containing polishing fluid and metal curette insert (Fig. 1) at 25 kHz (VP), Vector™-system with a silicon-carbide-containing abrasive fluid and metal curette insert at 25 kHz (VA), a conventional ultrasonic system (EMS, Nyon, Switzerland) (U) turned to the ''high'' setting with insert tip ''P'' (Fig. 1) at 31 kHz and a hand instrument (H) (Gracey curette, Hu-Friedy, Leimen, Germany). According to the manufacturer's instruction, operation of the Vector™-system was set at an amplitude of 30 μm for all applications, corresponding to the first seven LEDs lighting up on the intensity display. Ultrasonic instruments were used with the tip parallel to the root surface and with continuous adaptation to the root surface. In the hand instrument group, a new curette was used for each tooth to avoid dulling of the instruments. The instrumentation of all teeth was performed by one investigator well trained in periodontal treatment, who used all instruments with a clinically appropriate force of application. Before the instrumentation of the teeth in the experimental groups, lateral force measurements had been performed (Braun et al. 2005a). Evaluating a 200 s treatment period at intervals of 10 s, this preliminary survey showed that the operator applied a lateral force of 4.76 ± 0.24 N with the hand instrument, and 0.83 ± 0.11 N (U), 0.68 ± 0.10 N (VP) and 0.69 ± 0.09 N (VA) while treating the root surfaces.

Root instrumentation with hand and ultrasonic instruments was performed using an artificial periodontal pocket model according to the experimental set-up described previously (Braun et al. 2005a, b), using glass slides covered with a non-transparent rubber dam (Coltène/Whaledent, Langenau, Germany). At intervals of 40 s, treatment was interrupted and volumes of the teeth were measured by a second investigator until the surfaces were cleaned completely. The endpoint of calculus removal was visible cleanliness of the root surface, assessed by the second investigator. Measurement of volumes was performed using a 3D laser scanning device (Willytec, Munich, Germany). Each sample was prepared for laser scanning with a dye surface coating (Met-L-Chek, Santa Monica, CA, USA) and scanned from apical to coronal by a laser beam, projected via an optic system onto the root surface. The reflection of the beam was observed at an angle of 20° by a high-resolution CCD camera with an accuracy of 28 μm (width), 25 μm (length) and 2.5 μm (height). To facilitate a reproducible position of the

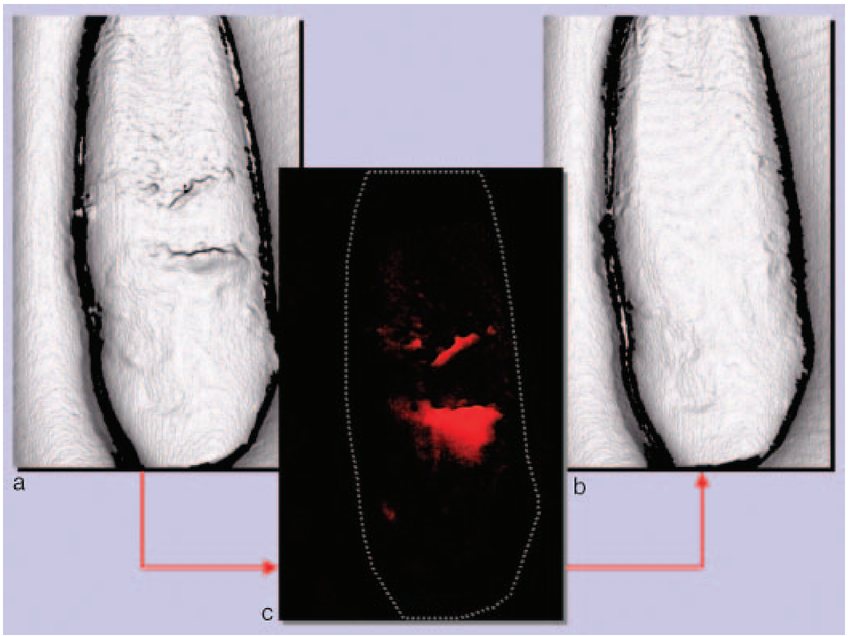

Fig. 2. Scanned root surface before (a) and after (b) calculus removal. Difference computed with the Match 3D software (c).

teeth in the scanning device, teeth were fixed by means of a silicone impression material (Voco, Cuxhaven, Germany). To evaluate calculus removal, scanning images from the root surfaces were superimposed and subtracted using the Match 3D superimposition software (Willytec) (Fig. 2). A control group of 10 teeth was included in the study design to assess the impact of the dye surface coating. Therefore, teeth were coated with dye and mounted in the scanning device. After laser scanning of the untreated surface, dye was removed, avoiding any kind of debridement procedure. This protocol was performed 10 times each for every tooth.

For statistical analysis, normal distribution of the values was analysed with the Shapiro–Wilk test. Analysis of variances (ANOVA) and subsequent comparison of means (Scheffé) were used to analyse the amount of calculus removal depending on the different treatment methods, as all values were normally distributed. Differences were considered as statistically significant at $p<0.05$.

Planimetric evaluation

Eight single-rooted teeth in eight patients with untreated advanced chronic periodontitis were included in the study. The teeth were designated for extraction and showed radiographically and/or clinically apparent subgingival calculus. Probing depths both mesial and distal were at least 4 mm and bone loss of at least one-third of the root length could be observed radiographically. Informed consent was obtained from each patient after the nature of the study was explained and before the initiation of treatment. The study was approved by the local ethics committee.

Before each treatment procedure, teeth were evaluated using a periodontal probe (Florida Probe®, Florida Probe Corporation, Gainesville, FL, USA) with controlled pressure (15 grams) to measure and electronically record pocket depths at six sites per tooth: mesio-buccal, mesio-oral, oral, disto-oral, disto-buccal and buccal. After local anaesthesia, a groove was placed around the circumference of the teeth at the level of the gingival margin with a diamond bur. Either the mesial or the distal root surface was treated with the Vector™-system (Duerr Dental) turned to the usual ''70%'' setting with hydroxyl-apatite containing polishing fluid and a metal curette insert at 25 kHz (VS). The opposite root surface of the tooth was debrided using hand instruments (Gracey curettes, Hu-Friedy). The endpoint of debridement was determined by tactile means with a dental explorer. The instrumentation was performed by two experienced periodontists. One operator performed either ultrasonic or hand instrumentation on one tooth surface, while the second treatment on the opposite tooth surface was carried out by the other operator. A third operator measured the treatment time without revealing it to the persons performing debridement procedures. The sequence of the different treatments was randomly assigned to the teeth using a computer-generated random number table. Before and after debridement, subgingival plaque samples were harvested for microbiological evaluation.

After treatment, teeth were extracted, stored in physiological saline solution and stained with 1% methylene blue for 1 min to distinguish attached connective tissue. In combination with the recorded probing depths, the apical edge of instrumentation could be determined. The area under investigation was determined coronally by the gingival groove. Laterally, the margins were set 1 mm apart from the line angle of the tooth to avoid inaccuracies because of linear distortions. Standardized photographs of the teeth were taken with a magnification of 1:1. The digitized photographs were assessed with a surface analysis software (MegaCAD 4.8b, Megatech Software GmbH, Berlin, Germany), measuring the amount of residual calculus with an accuracy of $0.1\ mm^2$.

For statistical analysis, normal distribution of the values was analysed with the Shapiro–Wilk test. As not all values were normally distributed, the amount of residual calculus in the different groups was compared with a non-parametric test (Wilcoxon's). Treatment times were also not normally distributed and thus compared non-parametrically (Wilcoxon's). Differences were considered as statistically significant at $p<0.05$.

Microbiological evaluation

Subgingival plaque samples were obtained before and immediately after treatment of the eight single-rooted teeth intended for planimetric evaluation. Before obtaining the samples, the selected sites were cleaned supragingivally to avoid contamination. At each site, two sterile paperpoints were inserted, kept in place for 30 s and transferred to vials containing transport medium (Cary-Blair-Transport medium, Hain Diagnostika, Neheren, Germany). After homogenizing in pre-reduced trypticase-soy-boullion (Becton & Dickinson, Heidelberg, Germany), one half of the solution was used for culturing. Aliquots of 0.1 ml of serial solutions were plated on supplemented tryticase-soy-agar and incubated for 3 days in air +10% CO_2 to select microaerophilic microorganisms and for 5 days to select anaerobic microorganisms (Gas Pac, Becton & Dickinson).

DNA probe analysis was performed with the other half of the solution to identify *Porphyromonas gingivalis* (P.g.), *Bacteroides forsythus* (B.f.), *Prevotella intermedi*a (P.i.) and *Treponema denticola* (T.d.). For this purpose, DNA was extracted by the High Pure DNA Preparation Kit (Roche, Mannheim, Germany). The bacterial DNA was processed according to the manufacturer's instructions for the identification of specific periopathogens (Mikrodent-Kit, Hain Diagnostika). Internal standardization enabled the expression of the results as colony-forming units (CFU/ml).

Results

3D laser scanning

Superimposed images of teeth repositioned in the laser scanning device without debridement revealed an accuracy of 0.00001 mm^3 (Table 1). Using all methods, complete removal of adhering calculus could be achieved within the limits of clinical inspection of the root surface, but the time required for debridement differed between the groups. Calculus removal with the Vector™-system depended on the irrigation fluid (VA: 0.014 mm^3/s, VP: 0.008 mm^3/s, Table 1). However, the difference between these two treatment modalities of the Vector™-system was not statistically different ($p = 0.291$, Fig. 3). The efficiency of the hand instrument (0.048 mm^3/s) was statistically higher compared with the conventional ultrasonic system (U: 0.016 mm^3/s, $p < 0.05$, Table 1) and the Vector™-system used with the polishing or the abrasive fluid ($p < 0.05$). No difference could be demonstrated between conventional ultrasonic debridement and treatment with the Vector™-system in conjunction with the abrasive fluid ($p > 0.05$). The least efficiency could be observed when the Vector™-system was used with the polishing fluid, resulting in statistically significantly lower values compared with the conventional ultrasonic system and hand instrumentation.

Planimetric evaluation

Using the Vector™-system, 97% (minimum: 86%, maximum: 99%) of the root surfaces appeared calculus free (Fig. 4). Regarding the hand instrumentation group, 96% (minimum: 84%, maximum: 99%) of the surfaces appeared free of mineralized deposits with no difference in the ultrasonic group ($p > 0.05$). Treatment with the ultrasonic device (VS: 9.7 s/mm^2 (minimum: 3.6 s/mm^2, maximum: 17.3 s/mm^2)) took significantly longer than debridement with the hand instruments (HI: 4.8 s/mm^2 (minimum: 3.6 s/mm^2, maximum: 7.9 s/mm^2), $p = 0.025$, Fig. 4). Representative specimens for both groups are given in Fig. 5.

Table 1. Removal of calculus (mm^3/s) employing the artificial periodontal pocket

	H	U	VP	VA	Control
Mean	0.048	0.016	0.008	0.014	0.000006
Standard deviation	0.010	0.004	0.003	0.005	0.000004
Median	0.046	0.017	0.008	0.013	0.000006
Maximum	0.063	0.024	0.011	0.023	0.000013
Minimum	0.035	0.008	0.003	0.008	0.000001
Number of teeth	10	10	10	10	10

U, conventional ultrasonic instrument; H, hand instrument; VP, Vector™-system with metal curette insert and polishing fluid; VA, Vector™-system with metal curette insert and abrasive fluid and control group without treatment.

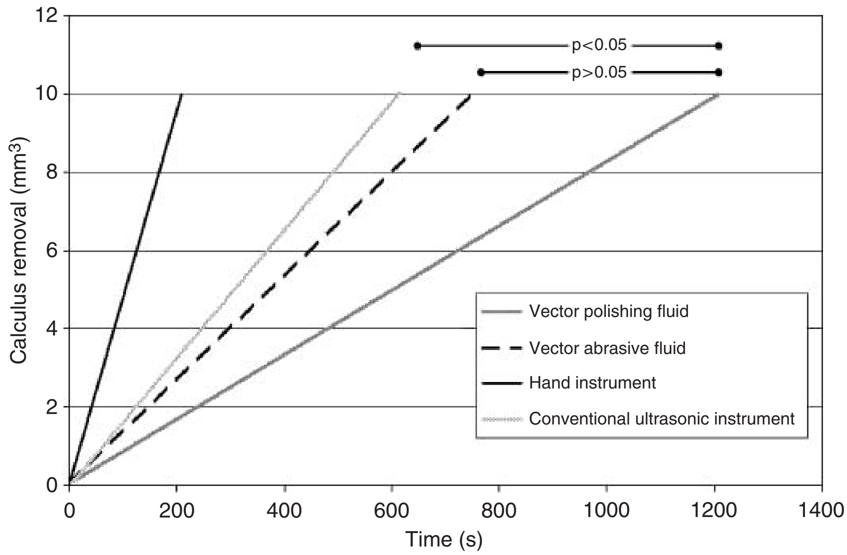

Fig. 3. Amount of remaining calculus depending on the duration of treatment. Every group calculated from 10 measurements. Fastest calculus removal using hand instrument, and slowest removal using Vector™-system with polishing fluid.

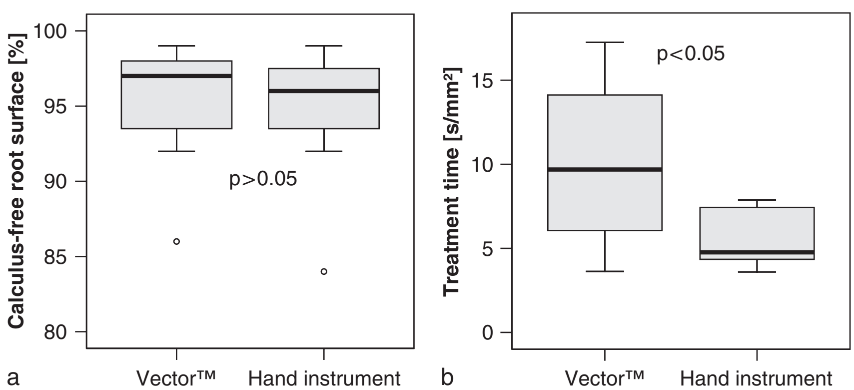

Fig. 4. In vivo treatment with the Vector™-system and hand instruments. Calculus-free root surface related to the overall treated surface was not different in the ultrasonic and the hand instrument group ($p > 0.05$) (a). Ultrasonic treatment took statistically longer than hand instrumentation ($p < 0.05$) (b).

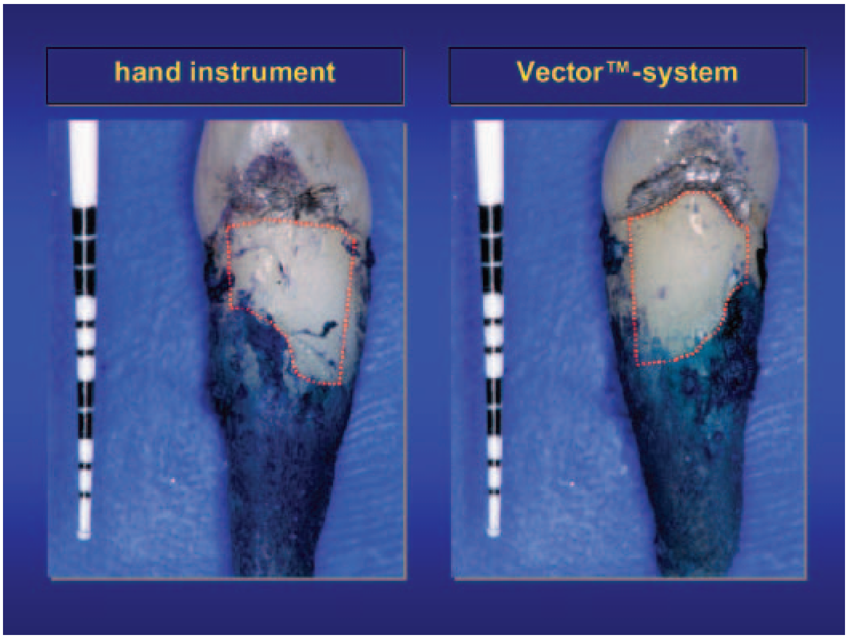

Fig. 5. Representative specimens for teeth treated with hand instruments and the ultrasonic device in vivo. The red lines indicate the area of interest, determined by the coronal groove, lateral margins 1 mm apart from the line angle of the tooth and the border of the connective tissue attachment.

Table 2. Colony forming units (CFU/ml) of periopathogenic microorganisms before and after treatment with the Vector™-system and hand instrumentation

Vector™									Hand instrument							
								Porphyromonas gingivalis								
								culturing								
0	0	0	4	5	5	6	6	before	6	6	6	5	5	4	0	0
0	0	0	0	5	6	6	6	after	6	5	5	4	0	0	0	0
								DNA probe								
0	0	0	5	5	6	6	6	before	6	6	6	6	6	4	0	0
0	0	0	0	5	6	6	6	after	6	6	5	4	0	0	0	0
								Prevotella intermedia								
								culturing								
0	0	4	4	4	5	5	6	before	5	5	5	5	4	4	4	4
0	0	0	0	0	3	3	5	after	4	4	0	0	0	0	0	0
								DNA probe								
0	0	0	0	0	0	0	4	before	4	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	after	0	0	0	0	0	0	0	0
								Bacteroides forsythus								
								culturing								
0	0	3	4	4	6	6	6	before	5	5	5	0	0	0	0	0
0	0	0	4	4	4	5	6	after	4	4	0	0	0	0	0	0
								DNA probe								
0	0	0	0	0	4	5	6	before	5	4	4	0	0	0	0	0
0	0	0	0	0	0	0	5	after	0	0	0	0	0	0	0	0
								Treponema denticola								
								DNA probe								
0	0	0	0	0	4	5	6	before	6	4	0	0	0	0	0	0
0	0	0	0	0	0	4	5	after	4	0	0	0	0	0	0	0

Numbers indicate the log number of every microorganism. Data are not linked to specific sites. The darker the shadowing of the boxes, the higher the amount of microorganisms. Data presentation according to Mombelli et al. (1995) and Bollen et al. (1998).

Microbiological evaluation

Using both the ultrasonic device or hand instruments, a similar reduction in the periopathogenic microorganisms P.g., B.f., *Prevotella intermedia* and *Treponema denticola* could be observed (Table 2). Focusing on *P. intermedia*, a quantitative discrepancy between culturing and DNA probe analysis became evident. A similar difference between the outcomes of the analytical tools could not be found for any other micro-organism in the present study.

Discussion

In the present study, the time required for subgingival calculus removal differed significantly among the methods investigated. As the Vector™-system avoids a hammering action of the insert tip against the tooth surface and the insert tips lack a true cutting edge, this might explain the low efficiency in calculus removal when the device is used with the polishing fluid. Compared with the conventional ultrasonic device, the Vector™-system showed the same efficiency when it was used with the abrasive fluid but less efficiency when it was used with the polishing fluid. Thus, efficiency seems to be influenced by the choice of the irrigation fluid, although there was no statistically significant difference between the two treatment modalities of the Vector™-system. These outcomes confirm the results of a previous study, using two-dimensional analysis of root surfaces (Braun et al. 2005a). Evaluating root substance removal with hand instruments, with an increasing number of strokes the amount of root substance removed per stroke can become less (Zappa et al. 1991). The authors ascribed this effect to the dulling of the curettes. As it is not known which force has to be applied to remove firmly adhering deposits, the amount of root substance loss cannot be unreservedly equated with the removed calculus volume (Kocher et al. 2001). However, in the present study, for all treatments, new instruments were used to avoid dulling effects as far as possible. It could be demonstrated that lateral forces and power settings could influence the efficiency of instruments used for debridement (Flemmig et al. 1997, 1998a, b, Gagnot et al. 2004). To control for these effects, in the present study, instruments were used always with the same power settings. Adjustment of applied lateral forces allowed an inter-instrumentation comparison within the experimental set-up. Values of the preliminary survey were comparable with those published for calculus removal using sonic scalers (Petersilka et al. 2003). The mean debridement force was 0.87 ± 0.27 N for a novel paddle-like scaler tip and 0.79 ± 0.22 N for a conventional scaler tip. In the present study the preliminary survey showed a lateral pressure of 0.83 ± 0.11 N for treatment with the conventional ultrasonic system, 0.68 ± 0.10 N for the Vector™-system with the polishing fluid and 0.69 ± 0.09 N for the Vector™-system with the abrasive fluid.

Comparisons between studies dealing with calculus removal are difficult, as there is no consistency between study designs and methodologies. Overall, ultrasonic and sonic scalers appear to lead to results similar to hand instruments for removing plaque, calculus and endotoxin (Drisko et al. 2000). Evaluating diamond-coated ultrasonic tips on single-rooted teeth in vivo, the times for removing calculus were recorded. The mean time to reach the clinical endpoint of treatment was 289 ± 193 s for hand curettes, 194 ± 67 s for standard smooth ultrasonic tips, 167 ± 71 s for fine grit and 147 ± 92 s for medium grit diamond-coated ultrasonic tips (Yukna et al. 1997). As the amount of calculus present before treatment could not be recorded due to the in vivo design of the study, these treatment times only show that diamond-coated inserts tended to take less time for debridement. Comparing the ultrasonic Cavitron™-system and hand instrumentation, the ultrasonic system required 8.2 ± 1.9 min, whereas for hand instrumentation 10.2 ± 2.9 min were needed to achieve visible cleanliness of the root surface (Lee et al. 1996). In this study, exact amounts of calculus were not measured before treatment. Only examination by eye indicated similar amounts of calculus on the root surfaces. In the present study, the highest efficiency of hand instruments may be due to the in vitro design, measuring exact volumes of removed calculus using laser scanning.

In a previous study, it could be demonstrated that the amount of root substance removal depended on the irrigation fluid, used with the Vector™-system (Braun et al. 2005b). The device is intended to be used for non-surgical periodontal treatment and should therefore remove a maximum amount of subgingival calculus and a minimum amount of root substance. Using the abrasive fluid, a similar degree of efficiency in subgingival calculus removal can be obtained as for conventional ultrasonic systems, but the amount of root substance removal was similar to the debridement with hand instruments (Braun et al. 2005b). Using the polishing fluid, the amount of root substance removal has been shown to be lower than with hand instruments or the Enac®-system (Kishida et al. 2004) and similar to the EMS ultrasonic device (Braun et al. 2005b). However, the present study showed that least efficiency in calculus removal could be observed, comparing the Vector™-system with a conventional ultrasonic system and hand instrumentation. Hence, the device did not improve the efficiency of mechanical periodontal debridement.

In vivo root debridement resulted in almost complete removal of subgingival calculus. However, due to the non-surgical in vivo study design, it was not possible to assess the exact amount of subgingival calculus before root surface instrumentation. The inclusion criterion was that the teeth showed radiographically and/or clinically apparent subgingival calculus. Using a random allocation for the sequence of the different treatments, major differences between the initial amounts of calculus should be avoided. The result of the present study is in agreement with other clinical studies (Sherman et al. 1990, Yukna et al. 1997, Eberhard et al. 2003). Some studies showed that the amount of residual calculus might depend on the pocket depths (Rabbani et al. 1981, Brayer et al. 1989). The present study included only teeth with similar pocket depths at the mesial and the distal site. Thus, the impact of different pocket depths did affect both treatment groups similarly. The results were not analysed depending on the different tooth types, as the amount of residual calculus was shown not to be dependent on this parameter (Rabbani et al. 1981, Caffesse et al. 1986). Regarding the in vivo treatment time, the ultrasonic device took more time than hand instrumentation to achieve a clinically clean root surface. This result is in contrast to a study evaluating clinical parameters to assess periodontal healing in vivo (Sculean et al. 2004). In this study, 6 min were required to treat single-rooted teeth with the Vector™-system and 8 min with hand instruments. For multi-rooted teeth, ultrasonic treatment took 10 min and hand instrumentation was performed for 12 min. However, in this study only non-surgical treatment procedures were performed and the amount of residual calculus could not be verified exactly.

In conclusion, the present study indicates that the efficiency of the Vector™-system is similar to conventional ultrasonic systems regarding residual calculus and periopathogenic bacteria. However, treatment is more time consuming than conventional debridement. The benefit of the device may be the possibility to adapt the efficiency to the treatment needs by the selection of the irrigation fluid.

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Clinical Relevance

Scientific rationale of the study: Ultrasonic devices are used to facilitate periodontal debridement procedures. The novel ultrasonic Vector™-system is supposed to be used with specific instrument tips and irrigation fluids, but the device's characteristics are currently poorly evaluated.

Principal findings: The amount of residual calculus and impact on periopathogenic bacteria after treatment with the novel device is comparable to the findings after conventional debridement but treatment is more time consuming.

Practical implications: One can perform reliable non-surgical periodontal debridement procedures with the Vector™-system but has to expect a longer treatment time for calculus removal than with conventional devices.