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The effect of the Vector® scaler system on human teeth: a systematic review

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Abstract: *Aim:* To review the available literature, considering the effect of instrumentation with the Vector® ultrasonic scaler on human teeth *in vitro* and *in vivo* compared to conventional ultrasonic instruments and/or hand instrumentation. The assessed effects are calculus removal, time of instrumentation, root surface aspects, cell attachment, patients' perception, bleeding upon probing, pocket depth, clinical attachment loss and microbiological effects. *Materials and methods:* MEDLINE–PubMed and the Cochrane Central register of controlled trials (CENTRAL) were searched up through January 2008 to identify appropriate studies. *Results:* Independent screening of the titles and abstracts of 270 MEDLINE–PubMed and 15 Cochrane papers resulted in 15 suitable publications. The studies differed in design and outcome, so this review summarizes the outcomes in a descriptive manner. Comparisons are presented against conventional ultrasonic system and scaling and root planing. *Conclusion:* The Vector® ultrasonic scaler provided comparable clinical and microbiological periodontal healing results as scaling and root planing and conventional ultrasonic system in moderately deep pockets. The Vector® ultrasonic scaler may be used as a gentle root debridement device for supportive periodontal therapy, as an alternative to other conventional ultrasonic system. The operator should however consider the extra time needed for instrumentation.

Key words: systematic review; ultrasonic; ultrasonic scaler; Vector

Introduction

Manual scaling and root planing (S/RP) is the most commonly utilized periodontal therapy to obtain healing of periodontally

diseased sites (1). As the vast majority of clinical trials relating to periodontitis therapy have been conducted using curettes and/or scalers, manual instruments are generally regarded as the golden standard (2–5). Manual instrumentation can be difficult and time-consuming due to the complex and unfavourable root morphology when working subgingivally at deep sites (1, 6). In recent years, sonic and ultrasonic scalers have become widely accepted by the dental profession because of their ease of use, their efficiency, reduced physical effort/stress of the operator and improved cleaning effect in furcations (1, 7, 8).

Ultrasonic scalers were originally designed for removal of supragingival calculus (9). Modifying the instrument tips to obtain smaller diameters and longer working lengths, better access to deep-probing sites and more efficient instrumentation could be achieved (10). Concerning clinical outcome between ultrasonic and manual debridement in the treatment of chronic periodontitis no differences have been observed (5, 11). The 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 (12) and acoustic microstreaming patterns formed close to the surface of the scaler tip are supposed to contribute to calculus removal (13).

Since 2000 the latest development in dental ultrasonic scaling systems is the Vector® (Dürr Dental, Bietigheim-Bissingen, Germany), this unit generates vibrations at a frequency of 25 kHz. The horizontal vibration of the device is converted by a resonating ring in a vertical vibration, resulting in a parallel movement of the working tip to the tooth surface. Furthermore, the energy from the instrument is transmitted to the root surface and the periodontal tissues by a suspension of hydroxyapatite particles and water. The suspension is applied by intermittant pulsation and held hydrodynamically on the instrument by the linear ultrasonic movement (14). The suspension is available in two types of fluid: (i) the Vector® polish fluid with a hydroxyappatite particle size of <10 μm and (ii) the Vector® abrasive fluid with a hydroxyappatite particle size of approximately 50 μm. The Vector® can be used with various tips. For periodontal treatment, there is a probe-like or curette-like tip. By minimizing vibrations applied directly to the root surface, the Vector® system may, according to the manufacturer, provide advantages to the patient over conventional ultrasonic systems (CUS). Firstly, they claim that the Vector® scaling system will make treatment less painful. Secondly, the treatment reduces pocket depth to a significantly greater degree and will lend to a significantly greater attachment gain in comparison to conventional S/RP. The advised areas of application in treatment are professional prophylaxis, initial periodontal therapy, maintenance therapy and treatment of peri-implantitis. The manufacturer states that the Vector® will be the instrument of choice for the professional after allowing for a short period of familiarization. The present review was undertaken to evaluate in a systematic manner what the evidence is for the claimed effects with the Vector® ultrasonic scaler system for the instrumentation of human teeth.

Materials and methods

Focused question

What is the effect of instrumentation with the Vector® ultrasonic scaler on human teeth *in vitro* and *in vivo* compared to conventional ultrasonic instruments and/or hand instrumentation?

Search strategy

Two internet sources of evidence were used in search of appropriate papers satisfying the study purpose: the national Library of Medicine, Washington DC (MEDLINE–PubMed) and the Cochrane Central register of controlled trials.

All reference lists of the selected studies were screened for additional papers which could meet the eligibility criteria of the study. The databases were searched up to and including January 2008 using the following terms for the search strategy:

MEDLINE and Cochrane CENTRAL search

Intervention:

(<[text word] vector AND <[MeSH terms /all subheadings] ''ULTRASONICS'' OR [text words] ultrasound OR ultrasonic OR ultrasonics>)

AND

Outcome:

([MeSH terms /all subheadings] ''PERIODONTAL DISEASES'' OR [text words] Periodontitis OR periodontal disease OR periodontal diseas* OR pocket depth OR periodontal attachment loss OR microbiology OR pain sensation OR periodontal pocket OR effectiveness OR efficiency OR time OR instrumentation OR microflora OR temperature)

Screening and selection of papers

Only papers written in English language were accepted. Case reports, letters, and narrative or historical reviews were

not included in the search. Papers without abstract of which the title suggested that they were related to the objectives of this review were selected so that the full text could be screened of eligibility. The papers were screened independently by two reviewers (TJGK and GAW). At first, they were screened by title and abstract. As a second step, full text papers were obtained when they fulfilled the eligibility criteria of the study aim. Any disagreement between the two reviewers was resolved after additional discussion. For full text screening, the following criteria were taken into consideration:

- Intervention: Vector® Ultrasonic Scaler (VUS).
- Control: Conventional Ultrasonic Scaler (CUS) and/or S/RP.
- The effect on human teeth *in vitro* or *in vivo*.
- The effect on time of instrumentation, calculus removal, root surface effects, and cell attachment.
- The effect on clinical parameters for periodontal disease: bleeding on probing (BOP), probing pocket depth (PPD), clinical attachment level (CAL), microbiological findings and Patients' perception.
- Treatment time.

After the definitive selection, the papers were processed for this review (TJGK, DES and GAW) and data were extracted by the three reviewers.

Results

Search and selection results

Table 1 shows an overview of the search results. In January 2008, the PubMed search resulted in 270 papers, the Cochrane search resulted in 15 papers. Out of these 12 were duplicates, leaving 273 papers for further screening. The screening of the titles/abstracts initially resulted in 15 full papers. Based on the full-text, two papers were excluded because they did not include an appropriate control group (15, 16). Searching of reference lists of the 13 selected studies resulted in two additional papers (Table 2). Consequently, 15 papers remained that fulfilled the inclusion criteria.

Table 1. **Search results and selection outcome**

	PubMed	Cochrane
Search	270	15
Identical	12	
Titles and abstracts	273	
Excluded by title and abstract	258	
Selected papers for full reading	15	
Excluded papers after full reading	2	
Extra included from reference list (Table 2)	2	
Included after selection for data extraction	15	

Table 2. **Additional papers included after searching the reference lists of selected papers**

Study	From reference list
Rupf *et al.* (17)	Christgau *et al.* (18); Kawashima *et al.* (19)
Sculean *et al.* (20)	Christgau *et al.* (18); D'Ercole *et al.* (21); Sculean *et al.* (22)

Heterogeneity and outcome

An overview of the selected studies and their characteristics is presented in Table 3. It provides a short summary of the study design, the type of intervention and authors' conclusions. The different studies do not provide comparable data, so it was decided by the authors of this review to summarize the outcomes in a descriptive manner (Table 4–6).

Effect in vitro

Five of the 15 selected studies (#I, II, III, X, XII) were carried out using dental specimens *in vitro* (Table 4). These papers provided data on calculus removal, instrumentation time, efficiency, root surface removal after instrumentation and number of attached cells/fibroblasts. Paper #XII demonstrated that the vector ultrasonic system (VUS) with polish fluid left significant more remnants of calculus on the root surface than the CUS ($P < 0.05$). All treatments were carried out until no calculus was visible, and the surface felt smooth (#XII). Using these same criteria as treatment outcome study #X reported that the treatment time with CUS was significantly shorter as compared to VUS. The efficiency of calculus removal in relation to time is significantly less with the VUS as compared to CUS and S/RP (#I, III). The effect of the VUS depended on the type of irrigation fluid used. The use of an abrasive fluid appeared to relatively improve calculus removal (#I, III). Root surface substance removal was less with the VUS as compared to the CUS and S/RP (#X, XII). Study #II support this only for CUS with polishing fluid compared to S/RP. In study #X, the teeth were cut in slabs after treatment. Subsequently, these were incubated in a suspension of human fibroblasts. When assessing the number of attached fibroblasts cells the slabs treated with the VUS used with polish fluid showed significant more attached cells than the CUS but a comparable number to S/RP.

Table 3. **An overview of the selected studies and their characteristics**

#	Author(s) (Year)	Title	Patients/teeth	Groups	Intervention	Conclusions
I	Braun *et al.* (2006) (23)	Efficiency of the Vector-system compared with conventional subgingival debridement *in vitro* and *in vivo*	*In vitro:* 40 extracted human teeth covered with subgingival calculus *In vivo:* 8 patients, 1 single rooted tooth with untreated advanced chronic periodontitis scheduled for extraction	1) VUS, metal curette and polish (10 teeth); 2) VUS, metal curette and abrasive (10 teeth); 3) CUS, EMS 400, P-tip at high power setting (10 teeth); 4) S/RP (10 teeth) 1) VUS, metal curette and polish (8 teeth, 1 mesial or distal surface); 2) S/RP (8 teeth, 1 mesial or distal surface)	The endpoint of calculus removal was visible cleanliness of the root surface. At intervals of 40 s, calculus removal was assessed using a 3D laser scanning device (mm^3/s) The endpoint of debridement was determined by tactile means with a dental explorer. Time was measured. Before and after treatment subgingival plaque samples were obtained	Root surfaces can be debrided as thoroughly with VUS as with CUS or S/RP. However VUS treatment is more time consuming than conventional debridement. Similar reduction of periopathogenic bacteria could be observed between CUS and SR/P
II	Braun *et al.* (2005b) (24)	Removal of root substance with the Vector-system compared with conventional debridement *in vitro*	*In vitro:* 40 periodontally involved human teeth	1) VUS, metal curette and polish (10 teeth); 2) VUS, metal curette and abrasive (10 teeth); 3) CUS, EMS 400, P-tip at high power setting (10 teeth); 4) S/RP (10 teeth)	Treatment for a total of 12 min. At 2-min intervals, the removal of dental hard tissues was assessed using a 3D laser scanning device (mm^3/s)	The VUS in combination with polishing fluid or CUS might be used for root debridement without extensive root substance removal
III	Braun *et al.* (2005a) (25)	Efficiency of subgingival calculus removal with the Vector-system compared to ultrasonic scaling and hand instrumentation *in vitro*	*In vitro:* 60 periodontally involved human teeth covered with calculus on the root surface	1) VUS, metal probe and polish (10 teeth); 2) VUS, metal curette and polish (10 teeth); 3) VUS, metal probe and abrasive (10 teeth); 4) VUS, metal curette and abrasive (10 teeth); 5) CUS, EMS 400, P-tip at high power setting (10 teeth); 6) S/RP (10 teeth)	During instrumentation photographs of the root surface were taken at intervals of 10 s. Calculus removal was assessed in mm^2/s until the root surfaces were cleaned completely	The efficiency of calculus removal with the VUS is significantly dependent on the selection of inserts and irrigation fluids
IV	Braun *et al.* (2003) (26)	Subjective intensity of pain during the treatment of periodontal lesions with the Vector-system	*In vivo:* 20 patients, each were contributing 3 teeth with comparable periodontal pocket depths	1) VUS,straight metal probe (1 tooth/ pat); 2) CUS, Siroson, scaler tip S n°. 3 (1 tooth/ pat); 3) S/RP (1 tooth/ pat)	The subjective intensities of pain during the treatment were measured during 200 s with an intermodel intensity comparison. The patient held the bulb of a manometer in his left hand while the display was observed. The patient was told to set the pressure of his hand in proportion to the perceived pain. A visual analog scale was used for the evaluation after treatment	Using the VUS for cleaning periodontal lesions it is possible to reduce pain sensations compared to S/RP and CUS. Using cleaning methods that cause less discomfort and pain, it might be possible to increase the patients' compliance during non-surgical periodontal therapy and maintenance

Table 3. (***Continued***)

#	Author(s) (Year)	Title	Patients/teeth	Groups	Intervention	Conclusions
V	Christgau *et al.* (2007) (18)	Periodontal healing after non-surgical therapy with a new ultrasonic device: a randomized controlled clinical trial	*In vivo:* 20 patients with generalized moderate to severe periodontitis At least 4 teeth per quadrant with minimum 1 pocket ≥4 mm	*Split mouth design:* 1) VUS, metal straight and bent probe and curette with polish (2 contra-lateral quadrants in each jaw) 2) S/RP (the alternative contra-lateral quadrants)	Clinical assessments (BOP, PI, PPD, CAL) and the subgingival microflora were performed at baseline and 1 and 6 months post-treatment Patients were asked about discomfort in relation to the occurrence of postoperative hypersensitivity after 1 and 6 months	Both the VUS and S/RP provided favourable periodontal healing results. In deep pockets S/RP appeared to achieve a significantly better resolution of inflammation. Teeth were more hypersensitive after 1 month in the S/RP group Similar reduction of periopathogenic bacteria could be observed between CUS and S/RP
VI	D'Ercole *et al.* (2006) (21)	Effectiveness of ultrasonic instruments in the therapy of severe periodontitis: a comparative clinical-microbiological assessment with curettes	*In vivo:* 18 patients with mild-to-severe chronic periodontitis	*Split mouth design:* 1) VUS, tip type and paste fluid unknown; 2) S/RP	Clinical assessments (PI, GI, BOP, PPD, CAL) and the subgingival microflora were performed at baseline and 1, 3 and 6 months post-treatment Multiplex PCR was used to determine the presence of the different microbial species	Both VUS and S/RP are equally effective in non-surgical periodontal therapy of severe periodontitis in terms of clinical and microbiological effects
VII	Hoffman *et al.* (2005) (27)	Use of the Vector scaling unit in supportive periodontal therapy: a subjective patient evaluation	*In vivo:* 46 patients observed for SPT with a stabilized chronic periodontitis (after initial treatment)	*Split mouth design:* 1) VUS, metal straight probe, paste fluid unknown with power setting of 7 LED lights on control; 2) CUS, Siroson L, universal 4L tip with max power setting of 40%	A visual analog scale was used to evaluate of pain scores upon completion of treatment A verbal response scale was used to assess discomfort, vibration and noise associated with the scaler system, as well as the volume and taste of the coolant used by these systems	During maintenance therapy the VUS caused reduced discomforting sensations compared with CUS and may be useful in improving patients' compliance with maintenance treatment
VIII	Kahl *et al.* (2007) (28)	Clinical effects after subgingival polishing with a non-aggressive ultrasonic device in; initial therapy	*In vivo:* 20 patients with moderate to advanced chronic periodontitis. At least 2 single rooted teeth with PD between 5–8 mm per quadrant. Only single rooted teeth were tested	*Split mouth design:* 1) VUS, straight metal probe and curette with polish (1 quadrant) 2) Only supra gingival polishing (1 quadrant) 3) S/RP with hand instruments done by a hygienist (1 quadrant) 4) S/RP with handinstruments done by a dentist (1 quadrant)	At baseline, 3 and 6 months after treatment, PPD and attachment levels were measured and BOP was recorded	The VUS with polishing fluid was able to reduce pocket depths, the prevalence of BOP and improve clinical AL in a similar way as handinstruments

Table 3. (***Continued***)

#	Author(s) (Year)	Title	Patients/teeth	Groups	Intervention	Conclusions
IX	Kawashima *et al.* (2007) (19)	A comparison of root surface instrumentation using two piezoelectric ultrasonic scalers and a hand scaler *in vivo*	*In vivo:* 15 patients with advanced periodontal disease and with altogether 30 teeth scheduled for extraction	1) VUS, metal probe and polish (10 teeth); 2) CUS, Enac® type 5 scaler, tip type unknown (10 teeth); 3) S/RP (10 teeth)	The endpoint of debridement was determined with a dental explorer until the root surface felt hard and smooth. No time limit Using SEM the amount of remaining calculus, roughness and loss of tooth substance were estimated using the remaining calculus index and roughness loss of tooth substance index	This study suggests that the VUS produces a smooth root surface with minimal loss of tooth substance. It is a reasonable choice for gentle periodontal maintenance treatment The VUS required up to 4 times longer removing all calculus
X	Kishida *et al.* (2004) (8)	Effects of a new ultrasonic scaler on fibroblast attachment to root surfaces: a scanning electron microscopy analysis	*In vitro:* 80 extracted human single rooted teeth with periodontal disease and visible calculus deposits. Small slabs were made from the cemental enamel junction to the root apex	1) VUS, metal probe tip (20 slabs); 2) VUS, metal probe tip and polish (20 slabs); 3) CUS, Enac® type 5, tip type unknown (20 slabs); 4) S/RP (20 slabs)	The time spent on cleaning was measured. After treatment half of the slabs were examined for surface roughness, the remaining calculus and the roughness and loss of tooth substance index The remaining slabs were incubated with a suspension of human fibroblasts. After measuring the number of attached cells, the attachment of fibroblasts was observed by SEM	Since use of the VUS with polish was able to provide scaling and root planing with minimal damage and tight attachment of fibroblasts, it is suggested that this may be a useful instrument for scaling and root planing
XI	Kocher *et al.* (2005) (29)	A new ultrasonic device in maintenance therapy: perception of pain and clinical efficacy	*In vivo:* 38 patients observed for maintenance therapy with at least 2 pockets of >4 mm	1) VUS, carbon fibre, straight recall probe or recall curette and polish (16 pat); 2) CUS, Dentsply® Cavitron, various tips at blue 10 power setting (22 pat)	Clinical assessments (PPD, BOP, CAL) were performed at baseline, 3 and 6 months post-treatment Patient were asked to report perceived pain during instrumentation with a visual analog scale immediately after treatment, in the evening of the treatment day, and in the evenings 1 and 2 days after treatment	In maintenance therapy, clinical efficacy of the VUS is comparable with that of CUS. It makes no difference whether the CUS at a reduced power setting or the VUS is used, since patients perceive both instruments as causing very little pain
XII	Rupf *et al.* (2005) (17)	*In vitro*, clinical, and microbiological evaluation of a linear oscillating device for scaling and root planing	*In vitro:* 32 human teeth extracted for periodontal reasons with visible aggregations of calculus	1) VUS, metal probe, paste fluid unknown (maximum intensity) (8 teeth); 2) CUS, Satelec, prophy Max, H1 tip (medium intensity) (8 teeth); 3) S/RP (16 teeth)	Instrumentation was continued until no calculus was visible and the root surface appeared to be smooth to tactile sense Root and cross-sections were examined for the efficacy of calculus removal, hard tissue loss, and surface smoothness with a light microscopy and SEM	The VUS was clinically acceptable and microbiologically comparable to S/RP and CUS groups despite microscopic remnants of calculus observed *in vitro*. Unless the VUS required as much as 4 times longer to remove all calculus

Table 3. (***Continued***)

#	Author(s) (Year)	Title	Patients/teeth	Groups	Intervention	Conclusions
		In vivo: 11 patients with chronic periodontitis They had in total 120 single rooted teeth with a clinical attachment level and probing depth of ≥5 mm	*Split mouth design:* 1) VUS, metal probe and polish (1 quadrant per patient); 2) CUS, Satelec, prophy Max, diamond coated tip and metal tip with CHX irrigation (1 quadrant); 3) S/RP (1 quadrant)	Clinical assessments (CAL, BOP,PPD, Suppuration) were performed at baseline and 7, 28, 90 and 180 days post-treatment The subgingival microflora was assessed at baseline, 1 and 28 days		
XIII	Schwarz *et al.* (2006) (30)	Influence of fluorescence-controlled ER:YAG laser radiation, the Vector system and hand instruments on periodontally diseased root surfaces *in vivo*	*In vivo:* 12 patients with multiple teeth with severe periodontal destruction scheduled for extraction. Each patient exhibited 6 experimental teeth (in total 72 single rooted test teeth)	1) VUS, straight metal probe or curette and polish (1 tooth/ pat); 2) S/RP (1 tooth/ pat)	Time spent on cleaning was measured Immediately after treatment the teeth were extracted Areas of residual subgingival calculus and depth of root surface alterations were assessed histo-morphometrically	The VUS enabled a more effective removal of subgingival calculus and a predictable root surface preservation in comparison with S/RP
XIV	Schwarz *et al.* (2003) (31)	*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	*In vitro:* 28 patients with advanced periodontitis; 48 perio involved single rooted teeth scheduled for extraction	1) VUS, straight metal curette and polish fluid (12 teeth); 2) S/RP (12 teeth)	After 5 min (group 1) or 9 min (group 2) of instrumentation teeth were extracted and root slabs were made The root slabs were incubated with human PDL fibroblast cultures The adherent cell density per mm^2 was calculated by a light microscope Additionally, the cell morphology was investigated using SEM on only 8 teeth	The VUS and S/RP promote the attachment of PDL fibroblasts on previously periodontally diseased root surfaces, and the surface structure of the VUS instrumented roots seem to offer better conditions for the adherence of PDL fibroblasts than S/RP
XV	Sculean *et al.* (2004) (20)	Non-surgical periodontal treatment with a new ultrasonic device (Vector ultrasonic system) or hand instruments. A prospective, controlled clinical study	*In vivo:* 38 patients with moderate to advanced chronic periodontitis	1) VUS, straight and curved metal curettes and polish (19 pat; 319 single and 249 multi rooted teeth); 2) S/RP (19 pat; 391 single and 298 multi rooted teeth)	In a 1-stage procedure all teeth were instrumented (Vector 6 and 10 min; SRP 8 and 12 min) for single or multi rooted Clinical assessments (PPD, BOP, gingival recession, CAL) were done prior to and at 6 moths after instrumentation	Non-surgical periodontal therapy with the VUS may lead to clinical improvements comparable to those obtained with S/RP

VUS, Vector Ultrasonic System; CUS, Conventional Ultrasonic System; S/RP, Scaling and Root Planing with hand instruments.

Table 4. ***In vitro* effect of the VUS for calculus removal (CR), time of instrumentation (T), efficiency (E), root surface removal (RSR) and cell attachment (CA) compared to the different treatment approaches**

Study #	Tip	Fluid	CR	T	E	RSR	CA	Comparison
I	C	Po	□	□	**–**	□	□	S/RP
	C	Ab	□	□	**–**	□	□	S/RP
	C	Po	□	□	**–**	□	□	CUS
	C	Ab	□	□	**0**	□	□	CUS
II	C	Po	□	□	□	**+**	□	S/RP
	C	Ab	□	□	□	**0**	□	S/RP
	C	Po	□	□	□	**0**	□	CUS
	C	Ab	□	□	□	**–**	□	CUS
III	P	Po	□	□	**–**	□	□	S/RP
	P	Ab	□	□	**–**	□	□	S/RP
	C	Po	□	□	**–**	□	□	S/RP
	C	Ab	□	□	**?**	□	□	S/RP
	P	Po	□	□	**–**	□	□	CUS
	P	Ab	□	□	**–**	□	□	CUS
	C	Po	□	□	**–**	□	□	CUS
	C	Ab	□	□	**0**	□	□	CUS
X	P	Po	**0**	**0**	□	**+**	**0**	S/RP
	P	**–**	**0**	**0**	□	**+**	**0**	S/RP
	P	Po	**+**	**–**	□	**+**	**+**	CUS
	P	**–**	**+**	**–**	□	**+**	**0**	CUS
XII	P	?	**–**	□	□	**+**	□	S/RP
	P	?	**–**	□	□	**+**	□	CUS

P, probe tip; C, curette tip; Po, additional polish fluid; AB, additional abrasive fluid.
+, positive significant difference; **–**, negative significant difference; **0**, no difference; □, no data available; ?, information not given.

Effect on teeth in vivo

Twelve of the 15 selected studies provided *in vivo* results (#I, IV, V, VI, VII, VIII, IX, XI, XII, XIII, XIV, XV) (Table 5).

Calculus removal: Four studies (#I, IX, XIII, XIV) described effects on removal of dental deposits *in vivo*. Residual calculus following *in vivo* instrumentation was not different in the VUS and S/RP ($P < 0.05$) (#I, IX, XIV). Root surfaces treated with the straight VUS probe and the curette tip in combination with polish fluid without a time limitation of instrumentation exhibited significantly less remaining subgingival calculus than following S/RP (#XIII).

Root surface: Three studies (#IX, XIII, XIV) showed the effect on root surfaces *in vivo*. All three present only positive effects. Evaluation of the root surface texture using the roughness loss of tooth substance index (19) showed that the VUS had significant lower values than the S/RP group. The VUS group had also significantly more remaining cementum than S/RP, measured by the mean thickness of the cementum in micrometre after treatment (#IX). Histomorphometrical analysis of root surface morphology of the extracted teeth, specimens treated with S/RP revealed conspicuous root surface damage, while specimens treated with the VUS exhibited a homogeneous and smooth appearance. The depth of root surface changes was significantly lower by VUS compared to S/RP (#XIII). Root surface friendliness following treatment was assessed after extraction (*ex vivo*) (#XIV). Roots were cut into pieces and placed on a perti dish with a medium containing human PDL fibroblasts. After scanning with an electron microscope, all S/RP-treated specimens exhibited considerable fewer attached and more round cells than with VUS. After S/RP numerous parallel striations on the cementum surface from curette instrumentation were observed but no alterations after VUS (#XIV).

Effect on periodontal disease: Seven studies (#I, V, VI, VIII, XI, XII, XV) describe the effect on periodontal disease parameters assessing the change in BOP, PPD, CAL and/or microbiological findings.

(i) *Clinical parameters*. In all studies (significant), improvements were observed within the groups (VUS, CUS, S/RP) by

Table 5. ***In vivo* effect of the VUS for calculus removal (CR), time of instrumentation (T), efficiency $mm^{2\ or\ 3}/s$ (E), root surface removal (RSR), cell attachment (A), patients' perception (P), bleeding on probing (BOP), probing pocket dept (PPD), clinical attachment loss (CAL) and microbiological (M) effect compared to the different treatment approaches**

Study #	Tip	Fluid	CR	T	E	R	A	P	BOP	PPD	CAL	M	Comparison
I	C	Po	**0**	□	**–**	□	□	□	□	□	□	**0**	S/RP
IV	P	?	□	□	□	□	□	**+**	□	□	□	□	S/RP
	P	?	□	□	□	□	□	**+**	□	□	□	□	CUS
V	P + C	Po	□	**0**	□	□	□	□	0	**0**	**0**	**0**	S/RP
VI	?	?	□	□	□	□	□	□	**0**	**+**	**0**	**0**	S/RP
VII	P	?	□	□	□	□	□	**+**	□	□	□	□	CUS
VIII	P	Po	□	□	□	□	□	□	**0**	**0**	**0**	□	S/RP
IX	P	Po	**0**	□	□	**+**	□	□	□	□	□	□	S/RP
XI	P + C	Po	□	**–**	□	□	□	**0**	**0**	**0**	**0**	□	CUS
XII	P	?	□	□	□	□	□	□	**0**	**0**	**0**	**0**	S/RP
	P	?	□	□	□	□	□	□	**0**	**0**	**0**	**0**	CUS
XIII	P + C	Po	**+**	**–**	□	**+**	□	□	□	□	□	□	S/RP
XIV	C	Po	**0**	?	□	**0**	**+**	□	□	□	□	□	S/RP
XV	P + C	Po	□	□	□	□	□	□	**0**	**0**	**0**	□	S/RP

For abbreviation see Table 4.

Table 6. **Microbiological differences for the various periodontal pathogens and total bacterial load (TBL) reduction between the base line and end of treatment measurements**

Study #	Aa	Pg	Tf	Td	Pi	Cr	Fn	Ec	TBL
I	□	**0**	**0**	**0**	**0**	□	□	□	□
V	**0**	**0**	**0**	**0**	□	□	□	□	**0**
VI	**0**	**–**	**+**	**+**	**0**	**–**	**0**	**+**	**+**
XII	**0**	**0**	**0**	**0**	**0**	□	□	0	**0**

Aa, Aggregatibacter actinomycetemcomitans; Pg, Porphyromonas gingivalis; TF, Tannerella forsythia; Td, Treponema denticola; Pi, Prevotella intermedia; Cr, Campylobacter rectus; Fn, Fusobacterium nucleatum; EC, Eikenella corrodens. For abbreviation see Table 4.

baseline–end measurements on BOP, PPD and CAL after initial treatment (#V, VI, VIII, XI, XII, XV). No significant differences were presented between VUS and CUS or S/RP treatments on these clinical parameters (#V, VI, VIII, XI, XII, XV). Only #VI showed that 6 months after instrumentation, the reduction in PPD after use of the VUS was more extensive than with S/RP ($P < 0.05$).

(ii) *Microbiological findings*. Similar reductions in total number of periodontal pathogenic bacteria between baseline and end of the treatment were observed comparing the VUS, S/RP, or CUS (#I, V, VI, XII) (Table 6).

(iii) *Effect on patient' perception*. Three studies (#IV, VII, XI) describe the perception of patient comfort after treatment. In patients with periodontal lesions, the VUS caused significant less pain during subgingival cleaning than S/RP or the CUS ($P < 0.05$) (#IV). During supportive periodontal treatment, the VUS caused less discomfort than the CUS when assessed for pain, vibration, noise and volume of coolant (#VII). However, #XI showed that during supportive periodontal treatment with the VUS or the Cavitron (at reduced power setting) the patients neither perceived the treatment as unpleasant nor was their perception of pain intensity different.

Time and efficiency: When the time was assessed to perform the subgingival treatment the VUS took significantly longer as compared to CUS or S/RP (#XI, XIII). Treatment time needed to obtain a smooth root surface free of bacterial plaque and calculus (verified by a dental explorer), was not different between VUS and S/RP (#V). Study #XIV states that the amount of time needed in the S/RP group was on average 4 min per tooth longer than VUS. Following extraction of the tooth and planimetric evaluation of the treated surface relative to treatment time, the efficiency of the VUS appeared to be significantly lower than S/RP (#I).

Discussion

The primary objective of cause-related periodontal therapy is the effective reduction of subgingival plaque and calculus and the prevention of a re-colonization of the pockets by periodontal pathogens (#II). Periodontal healing following instrumentation with ultrasonic scalers systems versus hand instruments was found to be similar in many studies (5). Comparing the VUS with CUS, one has to consider the different working mechanism of the VUS. That is vertical oscillations, parallel to the root surface, with a minor mechanical effect of the working tip, which is supposed to be compensated by the addition of an abrasive medium to the irrigation fluid. In patients with moderate to advanced chronic periodontitis, non-surgical periodontal therapy with the VUS resulted in a clinical and microbiological treatment response that was similar to those obtained by S/RP (#V, XI, XII, XV). However, while in moderate pockets no differences were found between the VUS and S/RP, in deep pockets (≥7 mm) the VUS was less effective in resolving gingival inflammation. The authors of #VI were unable to provide definite data about an improved clinical effectiveness of the VUS compared to S/RP in patients with deep periodontal pockets (≥6 mm).

The VUS unit is intended to be used for non-surgical periodontal therapy and should therefore remove a maximum amount of subgingival calculus and a minimum amount of root substance. As the VUS 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 (#I, III). In study #XII, the VUS required as much as four times longer to remove all calculus compared to the CUS.

Another possible explanation of the lower efficiency of the VUS with the metal probe tip might be the comparatively smaller surface area of the insert resulting in less hydrodynamic forces acting on the root surface or less interaction of the tip with the calculus. Accordingly, the metal curette insert with a larger surface demonstrated higher efficiency, comparable to a CUS (#III). Overall, the effectiveness in relation to treatment time with respect to calculus removal was the smallest with the VUS, as compared to a CUS or S/RP. Calculus remnants provide niches for retention and re-colonization of

periodontal pathogens. In line with the *in vitro* findings of #II, possibly a less effective root surface debridement with the VUS, especially in deep pockets, might explain the greater residual BOP score and the tendency towards a reduced CAL gain in these sites compared with S/RP after any mechanical treatment (#V).

Few studies have reported the effect of ultrasonic instruments on the subgingival microflora. They are in agreement when demonstrating that the manual, sonic and ultrasonic treatments cannot effect the complete removal of subgingival bacteria and achieve similar clinical and microbiological results (32, 33). The studies carried out with the VUS (#V, XII) showed reduction in total bacterial load comparable to S/RP and the CUS. The reduction of the levels of the putative periodontal pathogens points out the effectiveness of the VUS treatment. The incomplete elimination of periodontal pathogens can in particular be explained by the ability of these bacteria to invade periodontal tissues, and their capacity in evading the host defence, thus causing tissue breakdown. Also remnants of calculus and biofilm may provide a niche form which bacteria may recolonize the periodontal pocket.

In the past, it was deemed necessary to remove extensively the cementum of the root surface by S/RP and to remove root-associated endotoxins for successful periodontal therapy (34). However, endotoxins are only superficially associated with cementum and calculus. As it is easily removed by washing, brushing, light scaling or polishing the tooth surface (11, 35, 36), periodontal healing can be achieved without extensive cementum removal. A significant increase in fibroblast attachment was observed when root surfaces were treated with the VUS system as compared to the SRP group. The fact that the polishing fluid used with the VUS contains hydroxyapatite particles may provide an explanation. These particles may produce surface pH changes more favourable to cellular attachment (#XIV).

Compliance with supportive periodontal therapy is generally poor (37) with rates approximating 30%. The reasons for this are multifactorial and remain largely speculative, but experience or fear of discomforting stimuli during SPT appointments may be a significant factor. Also as subgingival instrumentation is carried out repeatedly during supportive periodontal therapy, it is crucial to prevent root damage (38, 39, #XI). Various clinical findings (#V, VII, XI, XIII), indicate that the VUS may be preferably used as a gentle root debridement device for supportive periodontal therapy, as an alternative to CUS.

As the VUS seems to be gentler to the root surface, it may also be sufficiently gentle for instrumentation of the rather delicate implant surface (40). The peri-implant area seems to be more susceptible than the periodontium to bacteria (41), indicating that early plaque removal is essential in patients with dental implants. The main problem in removing plaque from implants relates to the danger of damaging the implant surface. Although treatment of peri-implant pockets with the VUS tended to be more efficient than mechanical cleaning with hand instruments in reducing BOP, the VUS did not consistently eliminate the inflammatory lesion (42). This indicates that in the situation with exposed threads, resolution of the peri-implant inflammatory lesion by means of only mechanical means is extremely difficult (43). Sato *et al.* (40) observed that the VUS and the CUS used with non-metal tips are useful for removing artificial debris without *in vitro* significant damage to titanium surfaces. However, Schwarz *et al.* (44) concluded that all surfaces treated with VUS showed conspicuous surface damages (scratches) and deposits of the used carbon fibre.

Two papers (#XIII, XIV) additionally compared the VUS with an Er:YAG laser (KaVo, Biberach, Germany). They concluded that the laser and the VUS obtained similar effects with respect to calculus removal and root surface preservation. The laser appeared to be more suitable for instrumentation of titanium surfaces than the VUS used with a carbon fibre tip (44).

Conclusions

- The VUS provided comparable clinical and microbiological periodontal healing results as S/RP and CUS in moderately deep pockets.
- The VUS may be used as a gentle root debridement device for supportive periodontal therapy, as an alternative to other CUS.
- The operator should however consider the extra time needed for instrumentation.

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