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Calculus removal and the prevention of its formation

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Periodontitis is strongly associated with the presence of dental calculus on root surfaces. Although the rough calculus surface may not in itself induce inflammation in the adjacent periodontal tissues, dental calculus serves as an ideal substrate for subgingival microbial colonization. Therefore, cause-related anti-infective therapy aims to eliminate the microbial biofilm and calcified deposits from the diseased root surfaces by means of root surface debridement.

Over the past 50 years, a large number of clinical and laboratory studies have been performed to determine the efficacy of calculus removal from diseased root surfaces by various methods. These studies aimed to determine whether complete removal of subgingival calculus by root surface debridement is possible. They also evaluated the importance of operator experience in the effectiveness of calculus removal. Possible differences in efficacy between hand tools and power-driven instruments or lasers have been investigated. The impact of tooth and site characteristics, such as probing depths, tooth type, tooth surfaces and furcation areas, has also been evaluated. In addition, side-effects such as unintentional root substance removal and patient discomfort have been assessed.

This review focuses on the composition and formation of calculus, its significance for the disease process, the methods available for calculus removal, and prevention of its formation.

Calculus composition

Dental calculus is calcified mineralized plaque composed primarily of calcium phosphate mineral salts covered by an unmineralized bacterial layer (121). Calculus can be classified as supragingival calculus, which is located coronal to the gingiva and is easily visible, or subgingival calculus, which is found apical to the gingival margin and is therefore not visible on routine clinical examination. Subgingival calcified deposits, i.e. calculus, are dark brown or greenish black in color, hard and dense, and adhere firmly to the tooth root. Subgingival calculus is affected by hemorrhagic components from the gingival crevicular fluid and its black pigmentation is derived from mineralized anaerobic microorganisms, while supragingival calculus is influenced by saliva, food pigments and tobacco and has a rather claylike consistency. Subgingival calculus usually extends from the cement–enamel junction to close to the bottom of the pocket, but does not reach the junctional epithelium. A zone free of calculus is observed at the base of the pocket due to the fact that plaque growth is inhibited by the gingival crevicular fluid (86). Supragingival calculus is mainly observed on the buccal surfaces of the maxillary molars and the lingual surfaces of the mandibular anterior teeth, and this is explained by flow from the salivary gland in these areas. By contrast, subgingival calculus is mainly found on the interproximal and lingual tooth surfaces, and is usually randomly distributed on the teeth around the mouth (121).

A number of studies of the crystal types in subgingival deposits and their elemental composition as well as their morphology have been performed. Calculus is a highly calcified deposit with an inorganic content that is similar to bone, dentine and cementum (96, 121). The inorganic part of both supragingival and subgingival dental calculus consists mainly of calcium phosphate salts, including dicalcium phosphate dehydrate, octacalcium phosphate, substituted hydroxyapatite and magnesium-substituted tricalcium phosphate (whitlockite). The majority of the inorganic components, i.e. the inorganic salts, are in crystalline

form (63, 68, 88). The main crystal forms found in calculus are hydroxapatite, magnesium whitlockite, octacalcim phosphate and brushite (68). In addition to the mineral part, dental calculus includes an organic matrix (72). Studies on the ultrastructure of calculus revealed that supragingival calculus is heterogeneous, with islets of mineralized material within the covering plaque and non-mineralized areas within the calculus. Subgingival calculus appeared to be somewhat more homogeneously calcified, with the covering plaque containing no mineralized material and only mineralized material seen within the calculus itself (48, 51). The organic matrix of calculus is less extensive in subgingival calculus, and consists of proteins, lipids and carbohydrates. Protein–polysaccharide complexes, desquamated epithelial cells, leukocytes and various types of microorganisms make up the organic component of calculus (68, 97). With regard to their morphology, both types of calculus have a heterogeneous core covered by a soft, loose layer of bacteria (50).

Calculus formation

The formation of calculus is always preceded by the development of a bacterial biofilm, which constitutes the organic matrix for subsequent plaque calcification. Dental calculus is bacterial plaque that has undergone mineralization due to the precipitation of mineral salts, although not all the plaque becomes calcified. Saliva is the mineral source for calcification of supragingival calculus, while the gingival crevicular fluid provides minerals for the mineralization of subgingival deposits. Although microorganisms are not necessarily essential in the formation of calculus, as indicated by studies in germ-free rodents (65, 145), they are involved in and facilitate the formation of calculus in humans. Lactate dehydrogenase, alkaline phosphatase and acid phosphatase activities have been detected in plaque, suggesting that calcification of the dental plaque is not simply passive mineralization of non-viable microorganisms, but also an active process supported by enzymes derived from the bacterial layers (49). Bacterial plaque absorbs and concentrates calcium and phosphate derived from saliva and the gingival crevicular fluid (91). Mineral salts in subgingival calculus are also derived from blood and pus entering the pocket from the surrounding soft tissues (153). Calcium phosphate supersaturation, membrane-associated components and the degradation of nucleation inhibitors are critical factors for the initial calcification of plaque and microorganisms (72). Supersaturation of saliva and plaque fluid with respect to calcium phosphates is critical for mineralization of partially soluble calcium phosphate minerals and hence plaque calcification. Mineralization is characterized by binding of calcium ions to the carbohydrate–protein complexes of the organic matrix and the precipitation of crystalline calcium phosphate salts (98). The crystals develop initially in the intercellular matrix and on the bacterial surfaces and finally within the bacteria (57, 68, 165). Studies suggest that the calcification of calculus begins with deposition of precursor phases of calcium phosphate, such as octacalcium phosphate and dicalcium phosphate dehydrate. Deposition of the less soluble hydroxapatite and whitlockite minerals follows during maturation (122, 158). The surface of calculus always remains covered by a layer of non-calcified dental plaque (Figs 1–4).

Calculus adheres firmly to tooth surfaces as a result of the fact the pellicle beneath the bacterial plaque also undergoes calcification, such that firm attachment to the enamel, cementum and/or dentin crystals is established (83, 86, 135). Furthermore, calculus crystals fill the pits and irregularities of the tooth surface, causing even firmer attachment. In

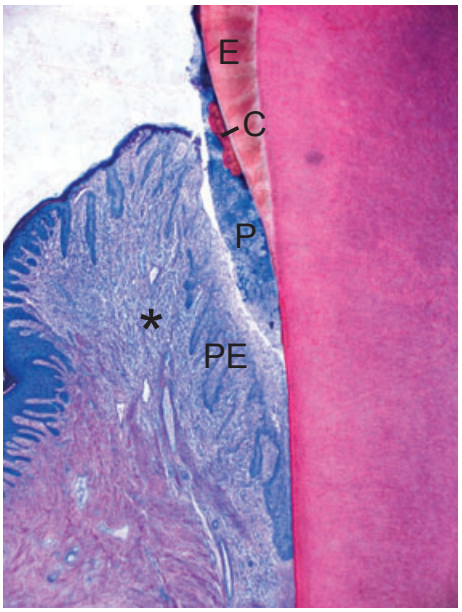

Fig. 1. Histological view of the cervical region of a tooth with a periodontal pocket. The enamel (E) is covered with a layer of calculus (C) and plaque (P), which extends subgingivally. Due to pocket formation, the junctional epithelium has developed into pocket epithelium (PE). The pocket space is clearly recognizable and separates the pocket epithelium from the biofilm. The soft connective tissue adjacent to the pocket epithelium is infiltrated by inflammatory cells (indicated by an asterisk). Undecalcified ground section stained with toluidine blue and fuchsin. Courtesy of Dr D. Bosshardt, Bern, Switzerland.

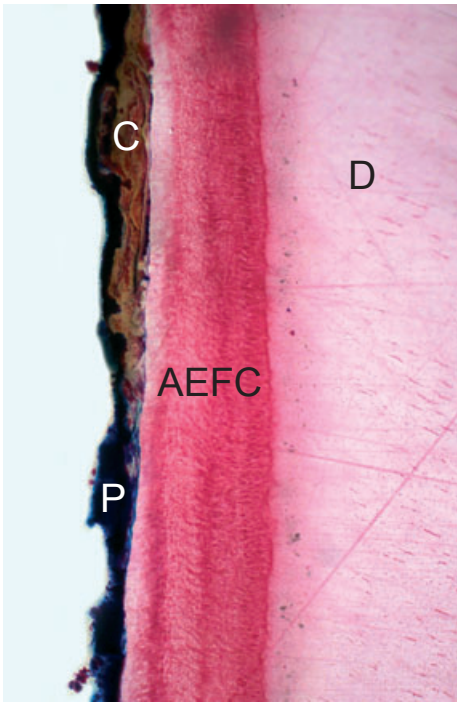

Fig. 2. Histological view of a human tooth root with calculus (C) and plaque (P) deposited on a layer of acellular extrinsic fiber cementum (AEFC). Undecalcified ground section stained with toluidine blue and fuchsin. D, dentin. Courtesy of Dr D. Bosshardt, Bern, Switzerland.

addition, calculus follows the contours of the cementum (68).

The development, amount and composition of calculus vary from person to person (heavy, moderate and slight calculus formers and non-calculus formers), and also from site to site and over time (34, 35, 67, 68, 105, 150). The amount of calculus is influenced by numerous variables, such as age, gender, ethnic background, diet, location in the oral cavity, oral hygiene, bacterial composition, host response differences, access to professional cleaning, mental or physical handicaps, systemic diseases and prescribed medications (158). Moreover, radiographic investigations showed a significant association between smoking and subgingival calculus load, which increased with smoking exposure, suggesting a strong and independent impact of tobacco smoking on subgingival calculus deposition (13, 116).

Significance of calculus for the disease process

The significance of calculus in the initiation and progression of periodontitis has been determined by cross-sectional and longitudinal epidemiological

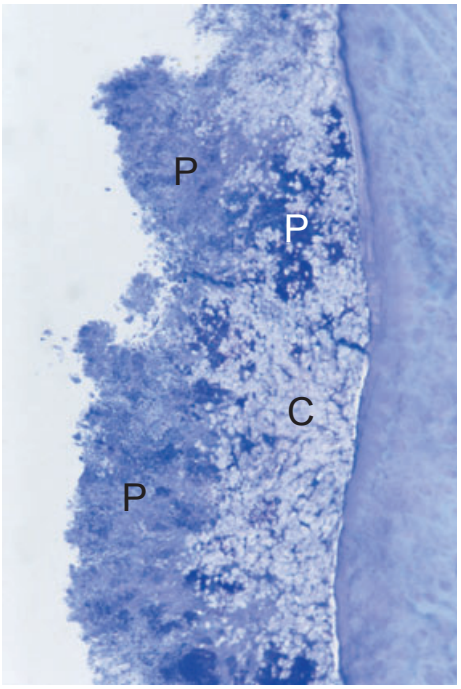

Fig. 3. Histological section of a human tooth root covered with calculus (C) and plaque (P). The light-coloured inner portion of the biofilm is mineralized, whereas the outer and more intensely stained regions correspond to uncalcified plaque. Decalcified thin section stained with toluidine blue. Reproduced with permission from *Periodontal Regenerative Therapy*, A. Sculean (ed.), Quintessenz, Berlin, 2010.

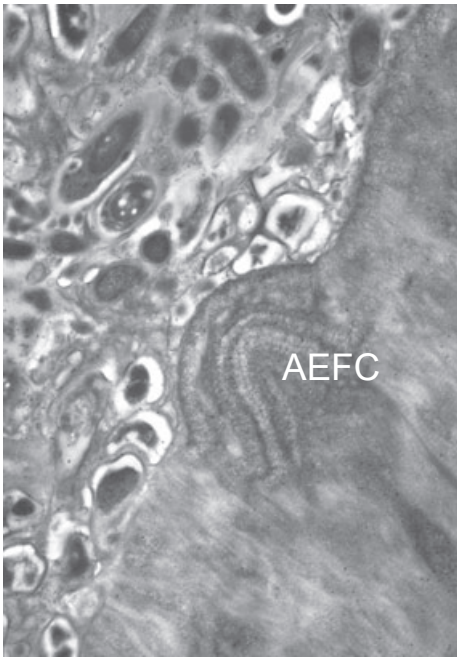

Fig. 4. Transmission electron micrograph showing a human tooth root with a mature biofilm deposited on a layer of acellular extrinsic fiber cementum (AEFC). In thick biofilm layers such as the one seen here, bacteria in the innermost portion are frequently dead. Courtesy of Dr D. Bosshardt, Bern, Switzerland.

studies that demonstrated clear associations between the presence of calculus and periodontitis (2, 3, 4, 5, 8, 27, 29–31, 62, 64, 74, 94, 100, 112, 121, 139, 146, 154). However, the design of these studies did not allow conclusions to be drawn regarding cause and effect. Calculus may be considered the result rather than the cause of periodontal inflammation as calcification of subgingival plaque requires a high flow of gingival crevicular fluid, which is strongly induced by inflammation and provides the minerals that are required for plaque mineralization (99).

Studies of periodontal healing have provided further insight. If calculus is associated with progressive periodontal attachment loss and has a causal effect on disease progression, healing after periodontal treatment should be reduced/jeopardized in the presence of calculus. When the influence of retained subgingival calculus on periodontal healing following flap surgery was investigated, inflammation was more intense when calculus was present (52). However, as calculus is always covered with viable bacterial plaque, it is difficult to distinguish between the effects of calculus or plaque on the periodontium (158). In fact, early studies in experimental animals showed that autoclaved calculus does not cause pronounced inflammation or abscess formation in connective tissues (6), and provided evidence that a normal epithelial attachment can be formed on calculus if its surface has been treated with chlorhexidine (90).

Viable aerobic and anaerobic bacteria were found in supragingival calculus harvested from patients with moderate to severe chronic periodontitis, specifically in the internal channels and lacunae (144). Subgingival calculus provides an ideal environment for bacterial adhesion (86, 129, 165), and the periodontal pathogens *Aggregatibacter actinomycetemcomitans*, *Porphyromonas gingivalis* and *Treponema denticola* are found within the deep recesses of its structural lacunae and channels (25). Complex lipids produced by *P. gingivalis* have been found in lipid extracts from subgingival calculus (107, 108). Further evidence indicating the lack of a primary etiological role of calculus is provided by several pre-clinical and clinical studies. These studies demonstrated that removal of subgingival plaque covering the subgingival calculus resulted in periodontal healing (86, 102, 109, 110). The clinical outcomes for locally delivered controlled-release doxycycline or scaling and root planing in adult periodontitis patients were equivalent, regardless of the extent of subgingival calculus present at baseline, suggesting that positive clinical changes depend on altering the subgingival biofilm rather than the removal of calculus (73).

In conclusion, periodontal healing occurs even in the presence of calculus as long as the bacterial plaque is removed or bacteria are controlled by antimicrobial agents. Therefore, it can be assumed that calculus plays an indirect role in the etiopathogenesis of periodontal diseases. The above-mentioned studies suggest a secondary role of calculus in the development and progression of periodontitis, by providing an ideal porous vehicle for bacterial plaque retention and growth as well as a reservoir for toxic bacterial products and antigens. Hence, subgingival calculus represents a secondary product of infection, and should be regarded a secondary etiological factor rather than a primary cause of periodontitis.

Once formed, the presence of calculus may jeopardize oral hygiene procedures and thereby promote the growth of pathogenic plaque. As a prominent plaque retentive factor, it must be removed for adequate periodontal therapy and prophylaxis (28, 86).

Calculus removal methods and their efficacy

A large number of clinical and laboratory studies have been performed to determine the efficacy of calculus removal from diseased root surfaces by various methods. The most appropriate approach appears to involve *in situ* studies, in which root debridement is performed immediately before extraction of the teeth involved, as this offers a variety of options for subsequent analysis, i.e. planimetric, scanning electron microscopic or histological evaluations. A shortcoming of this study design is that it is not possible to match teeth with regard to the amount of calculus present before treatment. Consequently, the total amount of calculus removed cannot be determined, and results are usually displayed as areas of residual calculus and/or surfaces devoid of calculus. A number of excellent review articles on cause-related periodontal therapy have summarized the findings of these studies (2, 33, 37, 149). The results of a number of more recent *in situ* studies that evaluated calculus removal under clinical conditions or simulated clinical conditions using a phantom head are presented in Table 1. Research has also been performed to determine factors that influence the effectiveness of calculus removal from diseased root surfaces.

Table 1. *In situ* studies evaluating calculus removal under (simulated) clinical conditions

Reference	Model	Number of teeth	Initial PPD	Methods of evaluation	Instrument (number of teeth)	Treatment time (min)	Efficiency (mm^2/s)	Percentage of surfaces without residual calculus	Percentage of calculusfree area	% of residual deposits
Kocher et al., 1997 (82)	Phantom head	560	6.8 ± 1.4 mm (buccal/oral)	Planimetric evaluation	Curettes (140)	45.9 (exp.), 41.0 (unexp.)				13.0 (exp.), 23.9 (unexp.)
			7.3 ± 1.1 mm (approximately)		Perioplaner (140)	49.3 (exp.), 43.7 (unexp.)				18.6 (exp.), 26.7 (unexp.)
					Sonic scaler (140)	38.8 (exp.), 35.2 (unexp.)				21.4 (exp.), 28.3 (unexp.)
					Ultrasonic (140)	39.8 (exp.), 34.0 (unexp.)				20.4 (exp.), 28.1 (unexp.)
Rühling et al., 2002 (123)	Phantom head	1220	4–11 mm	Planimetric evaluation	Curettes (660)	3.4 (day 1), 3.3 (week 10)			63.1 (day 1), 84.7 (week 10)	
					Periopolisher (660)	3.9 (day 1), 3.2 (week 10)			52.3 (day 1), 81.6 (week 10)	
Eberhard et al., 2003 (38)	*In vivo*	30	5.6 ± 1.1 to 6.4 ± 1.5 mm (hopeless teeth)	Histology, scanning electron microscopy	Er:YAG laser (15)	2:15 ± 1:00			68.4 ± 14.4	
						4:24 ± 0:56			83.3 ± 5.7	
					Curettes (15)	2:15 ± 1:00			93.9 ± 3.7	
						2:12 ± 0:28			96.3 ± 3.5	
Schwarz et al., 2003 (133)	*In vitro/in vivo*	24	> 8 mm at two aspects (hopeless teeth)	Histology	Er:YAG laser (8)	*In vitro:* 2		81/76		
					GaAsAl diode laser (8)	*In vivo*: not reported		21/15		
					Curettes (8)			95/78		
Braun et al., 2006 (17)	*In vivo*	8	> 4 mm	Planimetric evaluation	Curettes (8)		4.8		96 (84–99)	
					Vector system (8)		9.7		97 (86–99)	

Table 1. (Continued)

Reference	Model	Number of teeth	Initial PPD	Methods of evaluation	Instrument (number of teeth)	Treatment time (min)	Efficiency (mm^2/s)	Percentage of surfaces without residual calculus	Percentage of calculusfree area	% of residual deposits
Schwarz et al., 2006 (132)	*In vivo*	12	5.8 ± 0.1 mm	Histology	Er:YAG laser (3 x 12)	4:37 ± 0:14				7.5 ± 4.7
			5.8 ± 0.3 mm		Vector system (12)	6:43 ± 0:08				2.4 ± 1.8
			5.9 ± 0.3 mm		Curettes (12)	4:52 ± 0:09				12.5 ± 6.9

Exp., experienced; unexp., unexperienced; PPD, probing pocket depth.

Mechanical debridement (hand tools or power-driven instrumentation)

Pocket depth

Studies have demonstrated that subgingival scaling using curettes is an effective procedure for the removal of bacterial deposits from the root surface, leaving residual calculus deposits on 4.6–30% of all treated surfaces in single-rooted teeth (20, 70, 164), indicating that complete removal of calculus may be impossible. The effectiveness is correlated with the initial probing pocket depth. In pockets with an initial probing pocket depth <5 mm, 90% of the subgingival calculus was removed, vs. 77% in pockets with a probing pocket depth of 5–6 mm, and 65% in pockets >6 mm (119). These results are in agreement with those of another study, which reported that 19% of the surfaces had residual calculus for teeth with an initial probing depth <4 mm, vs. 38% for pockets of 4–5 mm and 43% for pockets >5 mm after hand instrumentation (55). This correlation between the initial pocket depth and the effectiveness of calculus removal was also observed for power-driven instruments. Using a sonic scaler, 14% of all surfaces showed residual calculus after treatment of pockets with an initial probing depth <4 mm, vs. 33% for a probing depth of 4–5 mm and 59% for an initial probing depth >5 mm (55). Studies using a combination of hand tools and motor-driven instruments confirmed this correlation (22).

Tooth type and surface

In addition to pocket depth, tooth type and surface determine the efficacy of hand instrumentation. Single-rooted teeth showed 10% residual deposits, vs. 30% for multi-rooted teeth (55). For approximal surfaces with an initial probing pocket depth of 0–3 mm, 16% of the surfaces were still covered with residual calculus, vs. 40% in deep pockets with an initial probing pocket depth of 4–12 mm. In contrast, the effectiveness of calculus removal from buccal or oral surfaces was not influenced by pocket depth, and approximately 22% residual calculus deposits were measured on buccal surfaces after hand instrumentation. These data indicate that the root surfaces of multi-rooted teeth and approximal surfaces are difficult to clean using hand instruments even if specially designed Gracey curettes are used. In studies on molars, 68% of molar surfaces that had been treated with curettes showed residual deposits (42). Removal of deposits in the furcation area of teeth in phantom heads using hand instruments resulted in

61.1% of treated surfaces having residual deposits in maxillary molar furcations vs. 39.5% in mandibular molar furcations, indicating more effective treatment of molars in the lower jaw (111). These data are similar to the 54% residual deposits found in molar furcations of grades I–II reported in a clinical situation (163), but are in contrast to the results of another clinical study that observed approximately 30% residual deposits after hand instrumentation for both non-molar and molar teeth (20).

Similar observations were reported for ultrasonic instruments. An ultrasonic straight-tip device left 50.3% of surfaces in maxillary molars and 44.1% of surfaces in mandibular molars covered with residual calculus (111). In another study, 34% of the surfaces of single-rooted teeth and 23.5% of the surfaces of molar teeth showed residual calculus after ultrasonic instrumentation (20).

Overall, use of power-driven instrumentation provides similar outcomes to hand instrumentation; however, the difficulty in combining the results of the various studies makes definite conclusions impossible.

Repeated instrumentation and access

It could be speculated that repeated instrumentation of root surfaces might increase the efficacy of treatment; however, it has been demonstrated that a single episode of 10 min non-surgical debridement using curettes was as effective as two episodes of 10 min each within a 24 h interval (7).

In contrast, the ability to remove calculus was improved by use of open flap procedures in deep pockets, enabling the visual control of the cleaned root surfaces. In pockets <3 mm deep, 86% of the root surfaces were completely free of calculus after closed or open root debridement procedures, vs. 43% of all surfaces after closed scaling and 76% of all surfaces after open scaling in pockets of 4–6 mm. After closed scaling of pockets >6 mm deep, 32% of the surfaces were free of residual calculus, vs. 48% after an open flap procedure and scaling (24). These results were less favorable for hand instrumentation compared to other studies, possibly due to the difficulties in detecting deposits on root surfaces in a clinical situation compared with teeth that were extracted after instrumentation (136). The advantages of an open approach are even more apparent in the furcation area of molar teeth. Open procedures with hand instruments were more effective compared to closed procedures for calculus removal in mandibular furcation areas (101, 114). More recently, the use of dental endoscopes was advocated to facilitate calculus removal during closed subgingival scaling, and pilot studies have shown encouraging results (161, 162).

Use of a combination of curettes and ultrasonic scalers by trained periodontists increased the effectiveness of calculus removal in pockets of 4–6 mm from 21% residual calculus using a closed approach, compared to 4% residual calculus when using open flap access. After instrumentation of teeth with initial pockets >6 mm deep, 19% residual calculus was found without a flap procedure vs. 5% residual calculus after instrumentation in combination with a flap procedure (19).

Instrument design and operator experience

Specially designed Gracey curettes were more effective in penetrating deep pockets compared to standard Gracey curettes (38 and 42% of surfaces with residual deposits, respectively) (106). For motor-driven instruments used in a phantom head, specially designed ultrasonic scaler tips for molars were more effective than standard tips for removal of deposits in maxillary molars (50.3 vs. 15.1% of surfaces with residual calculus) and mandibular molars (44.1 vs. 16.7% of surfaces with residual calculus) (111). Instrumentation of teeth with initial pocket depth of 5–12 mm using three ultrasonic inserts (standard, fine diamond and medium diamond) showed the high effectiveness of all instruments in terms of the fraction of surfaces with residual calculus; however, 40% of the teeth debrided using the standard tip or the fine diamond showed some residual calculus compared to 25% of the teeth instrumented using the medium diamond tip (164). The superior effectiveness of ultrasonic instrumentation of deep pockets using a slimline insert compared with a standard ultrasonic insert has been reported. After instrumentation with a standard ultrasonic tip, 42% of the surfaces in pockets >6 mm were covered with residual calculus, compared to 34% after instrumentation using the slimline insert (32).

Training of the operator is a further parameter that affects the efficacy of root debridement, especially when using hand instruments. Studies demonstrated that less experienced periodontal residents or dental hygienists were not as effective at producing calculus-free surfaces in periodontal pockets as experienced periodontists (19, 42). The effect of operator experience was demonstrated for both closed and open procedures, with trained periodontists removing significantly more calculus (19% of surfaces with residual calculus) than residents (66% surfaces with residual calculus) during a closed procedure on

pockets >6 mm using a combination of curettes and ultrasonic instruments (19). Subsequent studies in phantom heads that showed that approximately 15–24% of all surfaces still had deposits after treatment by an inexperienced operator, compared with 13% residual deposits after root instrumentation by an experienced operator (82, 123) (Table 2).

Newer instruments for power-driven root debridement

During recent years, studies of newer designs of power instruments have mainly focussed on a linear oscillating device, the Vector™ system (Duerr Dental, Bietigheim-Bissingen, Germany), in which ultrasonic oscillations are generated at a frequency of 25 kHz and then converted by a resonating ring, which deflects the horizontal oscillation vertically. As a consequence, the instrument tip moves parallel to the tooth surface. It is recommended that the device be used in conjunction with either a hydroxyl-apatite-containing polishing fluid or a silicon carbide-containing abrasive fluid. In a series of *in vitro* and *in vivo* studies, the Vector system has been evaluated in terms of calculus removal and effects on the root surface compared to hand scaling and conventional ultrasonics (15–17, 75, 124, 131) (Figs 5–7 and Table 2). Recent reviews have concluded that, overall, the Vector system showed comparable efficacy to conventional ultrasonic methods of root debridement (66, 155). Furthermore, new *in vitro* research shows that there is a variation in the performance of various tip designs and generators, but the clinical relevance of these results remains unknown (126, 155).

Laser ablation

The lasers most commonly used for periodontal therapy commonly include semiconductor diode lasers (gallium / aluminum / arsenide and indium / gallium / arsenide / phosphide), solid-state lasers such as Nd:YAG (neodymium-doped: yttrium, aluminum and garnet), Er:YAG (erbium-doped: yttrium, aluminum and garnet) and Er,Cr:YSGG (erbium, chromium-doped yttrium, scandium, gallium and garnet), and carbon dioxide lasers. Their wavelengths range from 635 to 10,600 nm (11). According to the cause-related concept of periodontal treatment, thorough removal of any bacterial deposits from the root surface without causing major damage to the adjacent tissues is required in order to support healing at diseased sites. For this therapeutic purpose, thorough knowledge on the potential interaction of a specific emission wavelength with biological tissue is fundamental in order to determine both the efficacy and safety of laser radiation. The impact of laser application on periodontal wound healing has recently been comprehensively reviewed (131).

One drawback of diode, Nd:YAG and CO_2 lasers is that they are not effective in removing mineralized bacterial deposits from periodontally diseased root surfaces (103, 133). Accordingly, application of these specific laser devices for periodontal treatment appears to be very limited (11).

It is the absorption of laser radiation by water molecules that mainly determines its tissue penetration and the risk of causing thermal damage in biological tissues. This physico-chemical requirement is potentially fulfilled by the emission wavelengths of both Er:YAG and Er,Cr:YSGG lasers. The Er:YAG laser radiation (2,940 nm) has a high absorption in water, resulting in vaporization of water molecules within the irradiated tissues, which physically contributes to the ablation process (i.e. a thermo-mechanical or photo-mechanical effect). Aoki et al. (9) demonstrated that a pulsed Er:YAG laser may be suitable for effective removal of subgingival calculus from periodontally diseased root surfaces using a glass-fiber tip in contact mode under water irrigation (energy density 10.6 J / cm^2). The emission wavelength of the Er,Cr:YSGG laser (2780 nm) is absorbed to a greater extent by hydroxyapatite than by water molecules (40), and these lasers were introduced in order to improve hard tissue ablation (77, 78, 156). Preliminary data suggest that a 1.0 W output setting (600 μm fiber) may be appropriate for calculus removal without causing any conspicuous morphological alterations to the root surface (147).

At present, experimental and clinical studies evaluating the efficacy and safety of emission wavelengths in the 3,000 nm range for potential use in periodontal therapy are only available for the Er:YAG laser.

A study was performed to evaluate the efficacy of and histological changes in response to Er:YAG laser scaling in comparison with ultrasonic scaling on periodontally diseased human extracted teeth *in vitro*. Laser irradiation was performed at 40 mJ / pulse using an 80° curved 600 μm tip in contact mode (14.2 J / cm^2) under water spray. Both treatment procedures resulted in comparable subgingival calculus removal without resulting in major thermal changes at the histological level. However, the efficiency of laser scaling, defined as the time required for calculus removal, was significantly

Table 2. *In vitro* studies evaluating various methods for root debridement (removal of calculus and/or root substance)

Reference	Title	Model/patients	Groups	Study design	Conclusions
Busslinger et al., 2001 (23)	A comparative *in vitro* study of a magnetostrictive and a piezoelectric ulrasonic scaling instrument	*In vitro*: 30 extracted human teeth with subgingival calculus	(1) Curette (n = 10) (2) Ultrasonic device (Cavitron) with slimline insert (n = 10) (3) Piezoelectric ultrasonic device (Sonosoft) with prototype insert (n = 10)	Standardized contact pressures were used; planimetric evaluation determined residual calculus and profilometric measurements determined surface roughness.	The piezoelectric scaler was more effective than the magnetostrictive device, but left the surface rougher.
Petersilka et al., 2003 (115)	Safety and efficiency of novel sonic scaler tips *in vitro*	*In vitro*: 52 extracted teeth	(1) Sonic device with novel paddle-like working tip (n = 26) (2) Sonic device with usual scaler tip (n = 26)	A metal sonic scaler tip with a paddle-like working end covered with spheroid convexities of 0.8 mm diameter and 0.3 mm height was designed on the basis of optimized adaptation to the root anatomy. Instrument efficiency was quantified by measuring the time required to completely remove calculus. Subsequent laser-optical determination of resulting root substance loss.	The novel scaler tip appears to be significantly more efficient in calculus removal and less damaging to the root surface than the conventional tip.
Jepsen et al., 2004 (71)	Significant influence of scaler tip design on root substance loss resulting from ultrasonic scaling: a laserprofilometric *in vitro* study	*In vitro*: 20 teeth that had been extracted for orthodontic reasons	(1) Magnetostrictive ultrasonic device with regular insert (n = 5) (2) Magnetostrictive ultrasonic device with narrow insert (n = 5) (3) Piezoelectric ultrasonic device with universal insert (n = 5) (4) Piezoelectric ultrasonic device with narrow insert (n = 5) Separate test areas for lateral forces of 0.3 and 0.7 N	Loss of root dentin was determined on the basis of defect width, defect depth and defect volume resulting from standardized instrumentation using laser profilometry.	The aggressiveness of the magnetostrictive and piezoelectric ultrasonic devices on root substance was significantly influenced by the scaler tip design, increasing for wider scaler tips compared with narrow, probe-shaped inserts.

Table 2. (Continued)

Reference	Title	Model / patients	Groups	Study design	Conclusions
Braun et al., 2005a (15)	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) Ultrasonic device (Vector), metal probe and polish (n = 10) (2) Ultrasonic device (Vector), metal curette and polish (n = 10) (3) Ultrasonic device (Vector), metal probe and abrasive (n = 10) (4) Ultrasonic device (Vector), metal curette and abrasive (n = 10) (5) Ultrasonic device (EMS 400), P-tip at high-power setting (n = 10) (6) SRP (n = 10)	During instrumentation, photographs of the root surface were taken at intervals of 10 s.	The efficiency of calculus removal with the ultrasonic Vector device is significantly dependent on the selection of inserts and irrigation fluids.
Braun et al., 2005b (16)	Removal of root substance with the VectorTM-system compared with conventional debridement *in vitro*	*In vitro*: 40 periodontally involved human teeth	(1) Ultrasonic device (Vector), metal curette and polish (n = 10) (2) Ultrasonic device(Vector), metal curette and abrasive (n = 10) (3) Ultrasonic device (EMS 400), P-tip at high-power setting (n = 10) (4) SRP (n = 10)	Calculus removal was assessed in mm^2/s until the root surfaces were cleaned completely. 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 ultrasonic Vector device in combination with polishing fluid or the ultrasonic EMS device may be used for root debridement without extensive root substance removal.
Rupf et al., 2005 (124)	*In vitro*, clinical, and microbiological evaluation of a linear oscillating device for scaling and root planing	*In vitro*: 32 extracted human teeth with visible calculus	(1) Ultrasonic device (Vector), metal tip (n = 8) (2) Ultrasonic device (Satelec-ProphyMax) (n = 8) (3) Curettes (n = 16)	The end-point of calculus removal was visible cleanliness of the root surface and a smooth surface appearance. Scanning electron microscopy analysis assessed remaining calculus and loss of cementum.	Linear oscillation was not as effective as the two other instruments in removing calculus, but preserved more tooth substance.

Table 2. (Continued)

Reference	Title	Model / patients	Groups	Study design	Conclusions
Braun et al., 2006 (17)	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	(1) Ultrasonic device (Vector-system), metal curette and polish (n = 10) (2) Ultrasonic device (Vector), metal curette and abrasive (n = 10) (3) Ultrasonic device (EMS 400), P-tip at high-power setting (n = 10) (4) SRP (n = 10)	The end-point 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).	Root surfaces can be debrided as thoroughly with the ultrasonic Vector device as with the ultrasonic EMS device or SRP. However, the Vector treatment is more time-consuming than conventional debridement.
Krause et al., 2007 (84)	Evaluation of selective calculus removal by a fluorescence feedback-controlled Er:YAG laser	*In vitro*: 20 extracted human teeth with calculus	Fluorescence-controlled Er:YAG laser (n = 20)	The end-point of calculus removal was determined by the laser. Residual calculus was assessed by planetric evaluation and loss of tooth substances by histomorphometric analysis.	A mean of 11% residual calculus was calculated. The level of remaining calculus was determined by the laser fluorescence feedback system.
De Mendonça et al., 2008 (36)	Er:YAG laser, ultrasonic system, and curette produce different profiles on dentine root surfaces: an *in vitro* study	*In vitro:* 36 flattened bovine roots	(1) Er:YAG laser (2,940 nm), 120 mJ / pulse, 10 Hz, 8.4 J/cm^2 (n = 12) (2) Ultrasonic system (n = 12) (3) Manual curette (n = 12)	The mean surface roughness of each sample was measured using a profilometer before and after the treatments. The micro-morphology of the treated and untreated (control) root surfaces was evaluated by scanning electron microscopy at 50× and 1,000× magnification.	All instruments increased the roughness of the dentine root surface after treatment; however, the curette produced rougher surfaces than the other devices. Scanning electron microscopy analysis revealed distinct root surface profiles produced by the three devices.
Casarin et al., 2009 (26)	Root surface defect produced by hand instruments and ultrasonic scaler with different power settings: an *in vitro* study	*In vitro*: 40 root surfaces	(1) Gracey curettes (n = 10) (2) Ultrasonic scaler at 10% power (n = 10) (3) ultrasonic scaler at 50% power (n = 10) (4) ultrasonic scaler at 100% power (n = 10)	After instrumentation with 15 strokes each specimen was divided in the middle to evaluate the defect depth produced by the instrumentation and the contact area of the instrument tips, as analyzed by scanning electron microscopy.	Ultrasonic instrumentation produced a similar defect depth to that of hand instrumentation, independently of the power setting used for scaling.

SRP, scaling and root planing.
Cavitron, Dentsply, New York, NY; Sonosoft, KaVo, Biberach, Germany; Vector, Duerr, Bietigheim-Bissingen, Germany; EMS, Nyon, Switzerland; Satelec, Acteon, Mettmann, Germany.

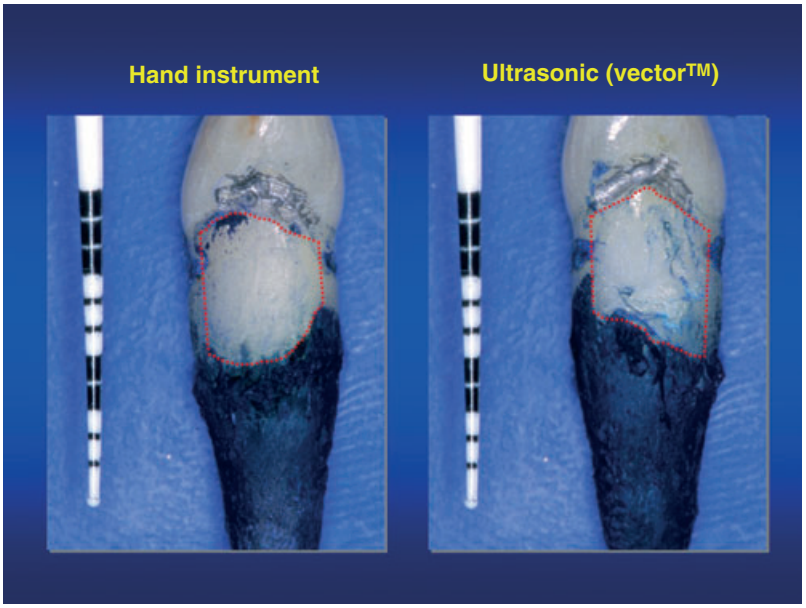

Fig. 5. Representative specimens for teeth treated with hand instruments or an ultrasonic device (Vector) *in situ* before extraction. The red lines indicate the area of interest, determined by the coronal groove, lateral margins 1 mm away from the line angle of the tooth, and the border of connective tissue attachment.

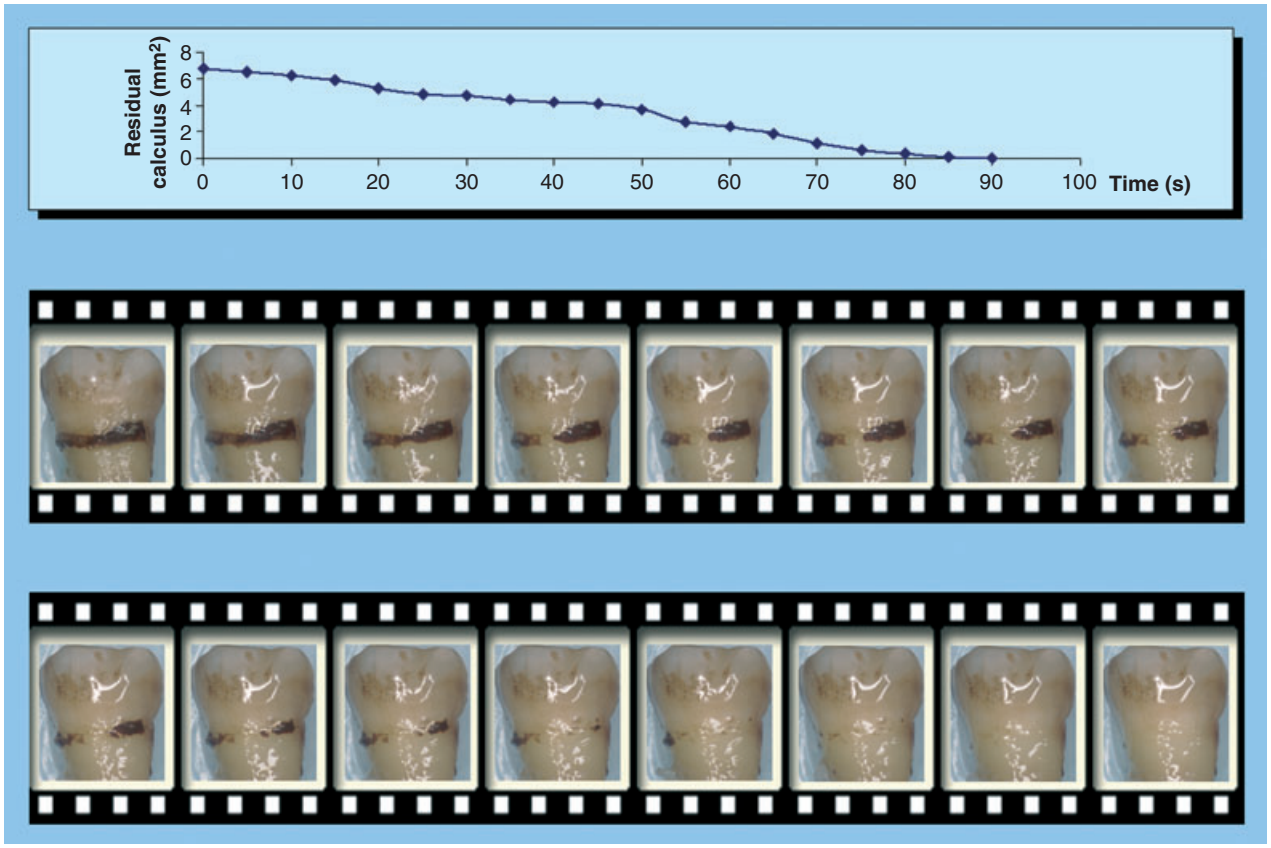

Fig. 6. *In vitro* effectiveness of calculus removal using an ultrasonic system (EMS ultrasonic system, Nyon, Switzerland). Photographs taken at intervals show the amount of remaining calculus. The chart shows the amount of residual calculus on the tooth at intervals of 10 s.

lower in the laser group compared with the ultrasonic group, ranging from 0.06 to 0.25 mm^2/s in the Er:YAG laser group and from 0.08 to 0.42 mm^2/s in the ultrasonic group. The authors concluded that the Er:YAG laser may provide a level of calculus removal similar to that provided by ultrasonic scaling (10).

The efficacy of subgingival calculus removal with an Er:YAG laser was compared to that of manual scaling in an *in situ* study (Table 2) (38). Single-

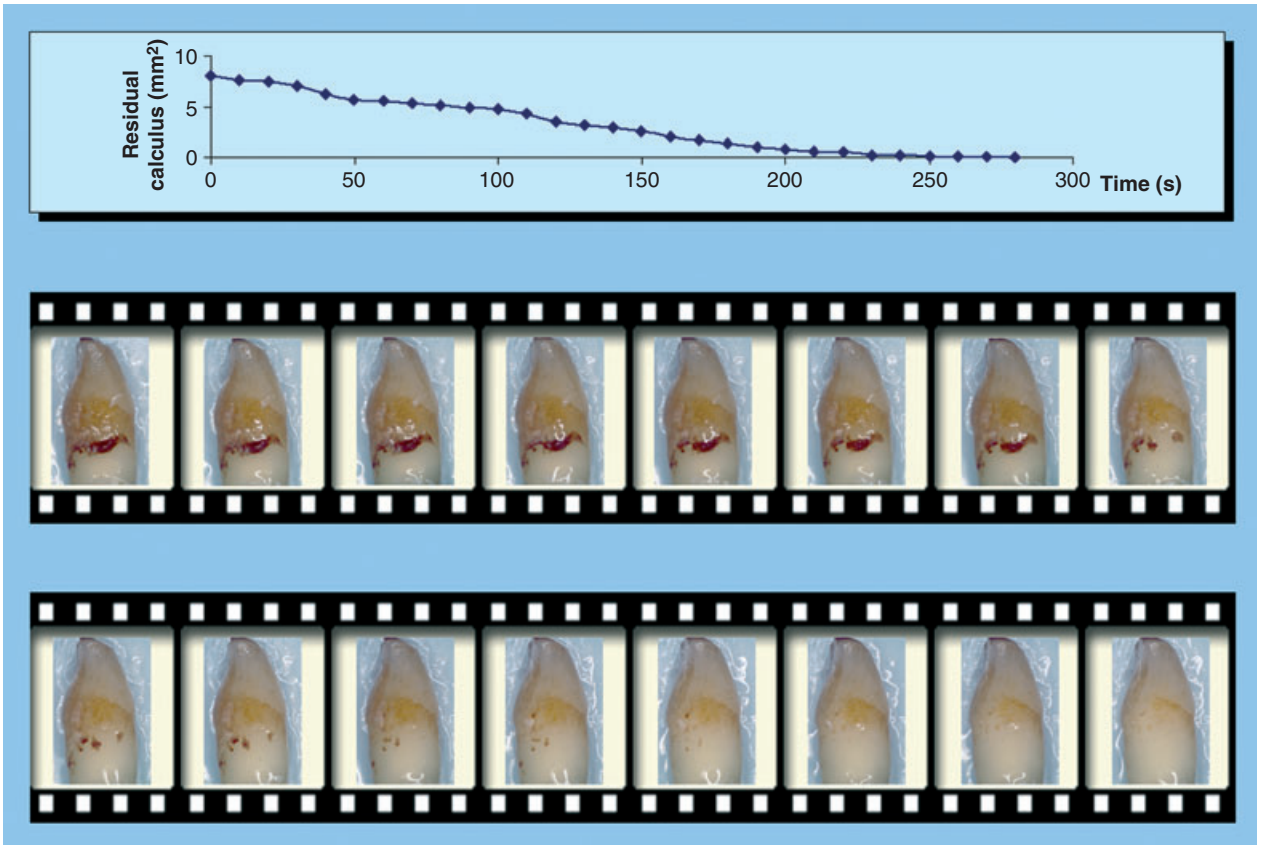

Fig. 7. ***In vitro*** **effectiveness of calculus removal using the Vector system with a metal probe insert and polishing fluid containing hydroxylapatite. Photographs taken at intervals show the amount of remaining calculus. The chart shows the amount of residual calculus on the tooth at intervals of 10 s.**

rooted teeth with untreated severe chronic periodontitis were randomly allocated to Er:YAG laser application (chisel-shaped fiber tip 0.5 × 1.65 mm, 136 mJ / pulse, 10–15 Hz, 20.4 J / cm^2) or scaling and root planing using hand instruments. The residual calculus and root surface changes were assessed planimetrically and histologically immediately after tooth extraction. The evaluation revealed a mean calculus-free surface area of 93.9 ± 3.7% in the scaling and root planing group and 68.4 ± 14.4% in the laser group when both treatment procedures were performed for the same period of time (2 min 15 s ± 1 min). These values increased to 83.3 ± 5.7% when the duration of laser irradiation was extended to twice that used for hand instrumentation (96.3 ± 3.5%). However, the differences between both groups were statistically significant for both time periods. In addition, efficacy did not seem to be influenced by initial probing depth. Laser application was associated with minimal root surface alterations, but scaling and root planing resulted in nearly complete cementum removal. Based on these findings, the authors concluded that the Er:YAG laser shows *in vivo* capability to remove calculus from periodontally involved root surfaces. Although its efficiency appeared to be lower than that of scaling and root planing, its application was associated with preservation of root cementum (38).

Recently, use of an Er:YAG laser device was combined with 655 nm InGaAsP (indium gallium arsenide phosphate) diode laser radiation to induce a fluorescence signal in subgingival bacterial deposits (41, 46, 85). Once an adjustable fluorescence threshold level is reached, the therapeutic Er:YAG laser radiation is activated. The efficacy of this modified Er:YAG laser device has been evaluated in three experimental studies (84, 132, 133). In the first study, the *in vivo* and *in vitro* efficiency of the feedback-controlled Er:YAG laser device and scaling and root planing using hand instruments were compared on periodontally diseased root surfaces of teeth that were scheduled for extraction due to severe disease progression (133). The mesial root surfaces were randomly instrumented (Er:YAG laser or scaling and root planing) *in vivo* under local anesthesia until adequately debrided and planed. Immediately after tooth extraction, the corresponding distal root sur-

faces were treated with the same instruments under standardized conditions. The parameters for the Er:YAG laser were 160 mJ / pulse and 10 Hz, and the pulse energy at the chisel-shaped fiber tip (size 0.5 × 1.65 mm) was approximately 136 mJ / pulse (20.4 J / cm^2). Laser treatment was performed in a coronal to apical direction in parallel paths, with an inclination of the fiber tip of 15–20° to the root surface under copious water irrigation. Histologically, Er:YAG laser radiation both *in vitro* and *in vivo* resulted in subgingival calculus removal at a level equivalent to that provided by scaling and root planing. The remaining debris as percentage of the mesial and distal root surface varied from 9% (*in vitro*) to 24% (*in vivo*) in the Er:YAG laser group, and from 5% (*in vitro*) to 22% (*in vivo*) in the scaling and root planing group. Unfortunately, the time required for root surface debridement *in vivo* was not recorded. The end point of debridement *in vitro* was judged as the inability to detect subgingival calculus visually. The mean amount of time required in all groups was 2 min per surface. The mean depth of surface alterations at the mesial and distal root surface varied from 36.8 μm (*in vitro*) to 0.0 μm (*in vivo*) in the Er:YAG laser group, and from 24.3 μm (*in vitro*) to 26.4 μm (*in vivo*) in the scaling and root planing group. Accordingly, it was concluded that a feedback-controlled Er:YAG laser may provide selective subgingival calculus removal at a level equivalent to that provided by scaling and root planing (133).

In the second study, the efficiency of fluorescence-controlled Er:YAG laser radiation for calculus removal was evaluated *in vivo* using various energy settings (132). Single-rooted teeth were randomly treated by a single course of subgingival instrumentation using laser application (chisel-shaped fiber tip 0.4 × 1.65 mm) at either 100 mJ (85 mJ / pulse; 12.8 J / cm^2), 120 mJ (102 mJ / pulse; 15.4 J / cm^2) or 140 mJ (119 mJ / pulse; 18.0 J / cm^2) (10 Hz), an ultrasonic system (linear oscillation pattern employing hydroxylapatite particles) or hand instruments. Untreated teeth served as a control. After tooth extraction, areas of residual subgingival calculus and depth of root surface alterations were assessed histologically and morphometrically. The highest percentages of residual subgingival calculus areas on mesial and distal root surfaces were observed in the scaling and root planing (12.5 ± 6.9%) group, significantly higher than those for the Er:YAG laser (7.8 ± 5.8, 8.6 ± 4.5 and 6.2 ± 3.9%, respectively, for the three energy settings). Use of the ultrasonic device resulted in a mean residual subgingival calculus value (2.4 ± 1.8%) that was significantly lower that those for the laser groups. The extent of residual calculus correlated directly with initial pocket depth at all laser-treated sites as well as in the scaling and root planing group (i.e. the greater the pocket depth, the higher the amount of residual calculus). The mean time required for root surface instrumentation was significantly longer in the ultrasonic group compared with the Er:YAG laser and scaling and root planing groups. While scaling and root planing was associated with conspicuous root surface alterations, use of the Er:YAG laser or ultrasonic device resulted in a homogeneous and smooth root surface morphology (Fig. 8 and Table 2). Accordingly, it was concluded that both the Er:YAG laser and ultrasonic devices enabled more effective removal of subgingival calculus and enabled root surface preservation in comparison to scaling and root planing (132).

The third study demonstrated that the effectiveness of a feedback-controlled Er:YAG laser device *in vitro* (i.e. the amount of residual calculus) could be improved by adjusting the threshold level for the fluorescence signal. Lowering the threshold level was associated with a significant decrease in the amount of residual calculus (5[U]: 0–78% to 1[U]: 0–26%) (84). However, determining the clinical relevance of these data requires further investigations.

The results of a recent systematic review have also indicated that, among all laser devices investigated the Er:YAG laser is most suitable for the non-surgical treatment of chronic periodontitis. Research performed so far has confirmed its safety and shown effects that are within the range reported for conventional mechanical debridement (130). However, stronger evidence is required before a clinical recommendation can be made (126).

Adverse effects

Root substance loss

In an attempt to completely remove the bacterial deposits and calculus attached to the root surface, considerable amounts of cementum and dentin may be removed. A large number of laboratory *in vitro* studies have investigated the effects of hand and powered instruments or lasers on root surfaces. Such studies, which are typically performed on extracted teeth using standardized conditions to control relevant parameters, such as working angle, applied pressure, number of strokes, time etc., have evaluated the amount of root substance loss by 2D or 3D laser profilometry, scanning electron microscopy or histological evaluation (15–17, 23, 26, 36, 43–45, 47,

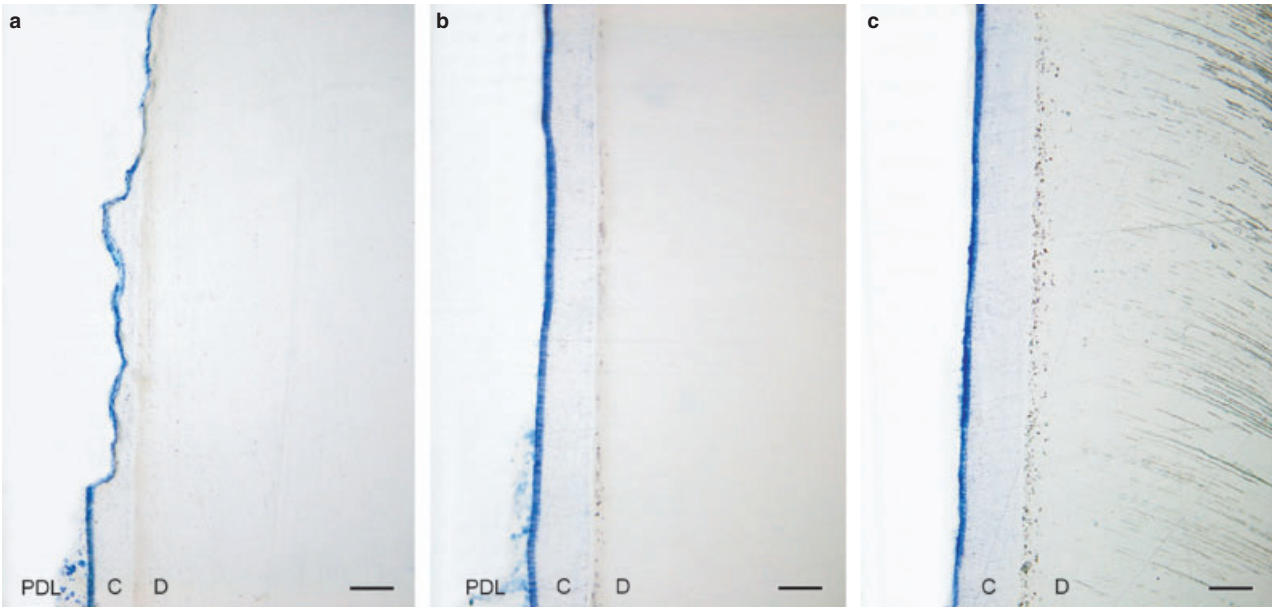

Fig. 8. Longitudinal toluidine blue-stained sections of root surfaces indicating surface alterations subsequent to a single treatment procedure by (a) hand instruments (scaling and root planing), (b) Er:YAG laser irradiation at 120 mJ (15.4 J/cm^2) or (c) Er:YAG laser irradiation at 140 mJ (18 J/cm^2). Following hand instrumentation, crater-like defects with sharply edged borders were frequently observed. Laser irradiation at settings of 120 and 140 mJ resulted in a smooth root surface morphology irrespective of the energy density. C, cementum; D, dentin; PDL, periodontal ligament. Scale bar = 200 μm.

71, 79, 84, 115, 124, 128) (Table 2). Important information with regard to safety can be derived from such studies; however, care should be exercised when extrapolating these *in vitro* results to the *in vivo* situation.

Patient discomfort

Patient comfort is an important aspect of periodontal therapy. However, only a few studies have addressed patient discomfort and pain during calculus removal. A linear oscillating device (Vector™ system) moves parallel to the tooth and avoids application of vibrations horizontally to the root surface. As a result, treatment has been shown to be less painful than conventional methods for periodontal therapy (18). These results were confirmed during supportive periodontal therapy (69). When the power settings of a conventional ultrasonic device were reduced, comparable pain sensations were recorded for both the linear oscillating Vector™ system and the conventional device for maintenance therapy (80). When comparing an ultrasonic and a sonic device for calculus removal during prophylaxis, the type of power-driven instrument did not appear to have an impact on perceived pain (81). Thus, the oscillation pattern did not influence the pain experience. A randomized controlled trial to explore attitudes to routine scaling and polishing and to compare manual vs. ultrasonic scaling showed that the majority of patients experienced some degree of discomfort regardless of the treatment method (21). Using the technique of an intermodal intensity comparison, the impact of the design of the scaler tip on painful sensations was assessed. It was shown that less painful sensations occurred with slimline ultrasonic scaler tips compared with conventional ultrasonic devices for supragingival calculus removal (14) (Table 3). Clearly more studies are needed that include patient-centred outcomes.

Prevention of calculus formation

As calculus is highly prevalent and its removal is labor- and time-consuming, much effort has been spent on developing chemical approaches for calculus prevention and/or elimination. Strategies to accomplish these goals may include measures to solubilize calculus and the organic matrix, or to inhibit plaque adhesion, formation and mineralization (72, 95, 158). The use of decalcifying, complexing or chelating substances to dissolve or soften the mineralized deposits is compromised by the risk that these agents will damage enamel, dentin or cementum (95). Therefore, research has focused on the inhibition of plaque attachment and alteration of its metabolic and chemical characteristics, i.e. development of early mineralized plaque, using antiseptics, antibiotics, enzymes and matrix-disrupting agents.

Table 3. Clinical studies assessing patient discomfort during calculus removal

Reference	Model	Number of teeth / number of patients	Initial PPD	Methods of evaluation	Instruments (number of patients)	Treatment time	Pain score during treatment (U)	Pain score assessed after treatment (U)
Braun et al., 2003 (18)	*In vivo*, subgingival	60 / 20	≥3 mm	Hand pressure, VAS	Curettes (20)	80 ± 32 min	30 ± 11	4.2 ± 2.7
					Siroson ultrasonic device(20)	60 ± 18 min	30 ± 12	3.7 ± 1.8
					Vector ultrasonic device (20)	127 ± 44 min	5 ± 3	1.1 ± 1.2
Kocher et al., 2005 (81)	*In vivo*, supra-gingival	444 / 74	≤4 mm	VAS	Ultrasonic device (74)	2 min	–	3.5 ± 0.26
					Sonic device (74)	2 min	–	3.7 ± 0.24
Bonner et al., 2005 (21)	*In vivo*	– / 420	Not specified	Question-naire	Ultrasonic device (185)	–	69% felt 'a little uncomfort-able'	
					Curettes (166)	–	60% felt 'a little uncom-fortable'	
					Ultrasonic device and curettes (69)	–	–	–
Braun et al., 2007 (14)	*In vivo*, supragingi-val	120 / 20	≤4 mm	Hand pressure, VAS	Conventional ultrasonic device (20)	77.5 (54–127) s*	7.8 (0–14.7)*	5 (2.5–8)*
					Slimline ultrasonic device (20)	95.5 (64–164) s*	1.4 (0–3.5)*	1 (0–3.5)*

*Values are medians, with minimum and maximum values in parentheses. PPD, probing pocket depth; U, units; VAS, visual analog scale.
Siroson, Siemens, Bensheim, Germany; Vector, Duerr, Bietigheim-Bissingen, Germany.

However, because of concerns regarding the effectiveness and / or safety of these substances, e.g. development of resistance to antibiotics, the focus of the research changed to inhibition of crystal growth by pyrosphosphate and bisphosphonate, as well as the use of zinc salts, such as zinc chloride and zinc citrate, as anti-calculus substances (72, 95, 158). At present, the anti-calculus strategy is still largely based on inhibition of crystal growth to reduce the development of calcified plaque. As crystallization inhibitors are partially degraded in the oral cavity, the concentration of these inhibitors in dentifrices, mouthrinses and chewing gums must be high. Although these crystallization inhibitors have been shown to reduce calculus formation, they are not capable of dissolving existing deposits (158).

Use of anti-calculus agents in toothpastes, mouthrinses and chewing gums can reduce the quantity and quality of calculus (72, 95, 158). However, as the effects of mouthrinses, toothpaste and chewing gum are mostly less limited to the supragingival area, such anti-tartar agents have only been proven effective for the control of supragingival calculus. In order to have an inhibitory effect on the formation of subgingival calculus, the anti-calculus agents must be applied topically in gingival pockets. The efficacy of these agents for the control of subgingival calculus is largely unknown (72, 95, 158).

Anti-calculus agents currently used include triclosan, in combination with polyvinyl methyl ether (PVM) and maleic acid (MA) co-polymer, and crystal growth inhibitors such as pyrophosphate with

PVM/MA co-polymer, zinc citrate and zinc chloride (72, 95, 158). As a broad-spectrum antimicrobial agent, triclosan can prevent bacterial uptake of essential amino acids, and, at higher concentrations, destroy the integrity of the cytoplasmic membrane (120). Triclosan also exerts both direct and indirect anti-inflammatory effects (54, 72). A number of clinical studies have confirmed the anti-calculus efficacy of triclosan (72). Pyrophosphate has been shown to reduce crystal growth by binding to the crystal surface. Moreover, pyrophosphate can impede the conversion to hydroxyapatite and reduce pellicle formation (72). Pyrophosphate is susceptible to rapid breakdown by phosphatases and pyrophosphatases in the mouth, but this breakdown appears to be inhibited by the PVM/MA co-polymer (95). The co-polymer also appears to have a weak effect on the crystal growth (53). Pyrophosphate at various concentrations in dentifrices, mouthrinses, chewing gums and whitening strips has been shown to work as an anti-calculus agent (1, 40, 72, 95, 117, 141, 143, 151, 158). Bisphosphonates, which are stable synthetic analogs of pyrophosphate with resistance to hydrolysis, have also been shown to act as anti-calculus agents (104, 137, 138, 142). Significant reductions in calculus formation were also achieved by use of polypyrophosphates, such as hexametaphosphate, as advanced mineralization inhibitors (92, 159, 160). Phytate, which has structural similarities to pyrophosphate, is capable of inhibiting the formation of brushite and hydroxyapatite crystals *in vitro* and *in vivo* (58, 60, 61). In a randomized, double-blind, three-period crossover clinical study, the anti-calculus efficacy of a phytate-containing mouthwash was examined. The levels of calcium, magnesium and phosphorus present in the residues obtained by dental cleaning were significantly reduced in the phytate treatment group compared with controls, demonstrating that phytate is an effective substance for prevention of calculus formation (59).

Zinc ions are effective in inhibiting crystal growth by binding to the surfaces of solid calcium phosphates (56). In addition, zinc ions also affect the types and amounts of calcium phosphate crystals (87). Zinc salts have also been reported to reduce plaque acidogenicity and plaque growth (113). Dentifrices containing zinc salts such as zinc citrate and zinc chloride have been shown to be effective in reducing calculus (39, 93, 118, 125, 140). A significant reduction in supragingival calculus formation was also found after chewing gum containing vitamin C, which could be due to the acidic properties of ascorbic acid (89).

Anti-calculus agents have been used at various concentrations alone or in dentifrices. In addition, their effects have been evaluated in varying study populations, after various periods of time, and by using various study designs and controls. Therefore, it is difficult to quantify the true clinical effect of anti-calculus agents. A large number of studies on anti-calculus dentrifices have been published. Only a few studies presented data on sites or subjects free of calculus (127). The differences in calculus scores compared to control dentrifices are usually expressed as a percentage reduction of these scores. For example, it was found that a dentifrice containing pyrophosphate and a PVM/MA co-polymer, a dentifrice containing triclosan and a PVM/MA co-polymer, and a dentifrice containing triclosan and zinc citrate caused significant reductions in supragingival calculus formation ranging from 39 to 55% in comparison to a placebo dentifrice, after 12 weeks of use. No significant differences were found among the three dentifrices (12). After 1 year, subjects using an anti-calculus dentifrice containing pyrophosphate and a PVM/MA co-polymer had 37% less supragingival calculus than subjects using a placebo dentifrice (148). After 6 months of use, use of a zinc citrate/silica product had reduced calculus formation by 32% (76). When a dentifrice containing zinc citrate was used, the mean calculus scores were 13% lower compared to the control dentifrice after 3 months (134). A reduction in calculus scores was also found in other studies (39, 151, 157). Collectively, the results of studies on anti-calculus dentrifices indicate that formation of supragingival calculus can be affected by the use of such toothpastes. Typical differences compared to control dentrifices varied between 15 and 50%, and commonly amount to 30–40% in trials of 3–6 months duration (152).

Taken together, although some agents have been proven to reduce calculus formation, their anti-tartar effect appears to be limited to supragingival calculus. In addition, total suppression of calculus formation was not achieved. Future studies should continue to search for even more effective anti-calculus substances or formulations and for application modes that make it possible to affect subgingival calcification processes.

Summary and conclusions

Calculus is always covered with viable bacterial plaque. It provides an ideal porous vehicle for bacterial plaque retention and growth, and is

therefore regarded a secondary etiological factor in periodontitis. It must be removed for adequate periodontal therapy and prophylaxis. None of the currently available methods or devices used for root debridement are effective in completely eliminating all calculus from diseased root surfaces. Anatomical factors, probing depth, instrument design and operator experience have an influence on the efficacy of subgingval calculus removal. Similar results can be achieved using hand as opposed to power-driven instruments or lasers. Among the laser systems that are available, the Er:YAG laser appears to be most suitable for calculus removal. Newer designs of powered instruments have not shown any benefit compared with conventional ultrasonic devices. Although recent *in vitro* research has shown variation in the performance of various designs of power-driven tip, the clinical relevance of these findings remains unknown. The introduction of new instruments or devices should include *in vitro* evaluation of their performance under various standardized working conditions. Unintentional removal of root substance can occur during root debridement, and this depends on the design and angulation of the working tip, the force applied and the duration of treatment. Only a few studies have addressed patient-centred treatment outcomes such as discomfort and treatment duration. Some anti-calculus agents have been shown to reduce the formation of supragingival calculus; however, total prevention of calculus formation could not be achieved. Future studies are required to search for even more effective anti-calculus substances, and for application modes that can affect subgingival calculus formation.

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