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In vitro calculus detection with a moved smart ultrasonic device

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Abstract

Study objective: The objective of subgingival instrumentation of periodontally diseased root surfaces is to remove the adhering microbial biofilm and calcified deposits. Recently, we have described an automated calculus detection system under static conditions. Clinically however, the tip of the system has to be moved over tooth surfaces. It was thus necessary to study the entire system in motion.

Methods: The detection device is based on a conventional dental piezoelectric ultrasonic handpiece with a conventional scaler insert. The impulse response of the mechanical oscillation system is analysed by a fuzzy logic-based computerized algorithm, which classifies various surfaces. The present study investigates dental surface recognition properties of the new system with the tip being moved over teeth surfaces in vitro. Following a training set of 7977 measurements (3960 calculus, 4017 cement) on 200 extracted teeth, 1363 measurements were conducted on 34 teeth unknown to the system.

Results: The surfaces cementum and calculus were correctly classified in 78% within the training set and in 81% within the set unknown, with a κ value of 0.68.

Conclusion: It was shown that this method of automatic recognition of tooth surfaces is able to distinguish between different tooth surfaces in vitro independently from tip movements.

Key words: calculus detection; fuzzy logic; in vitro; pattern recognition; subgingival scaling; ultrasonic scaler

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An essential component of periodontal therapy is the effective removal of bacterial plaque from the diseased root surface. The aim of the treatment is to create a biologically acceptable root surface by eliminating calculus and the bacterial biofilm (Cobb 1996, Van der Weijden & Timmerman 2002), which can be accomplished either with hand instruments or with power-driven devices (Tunkel et al. 2002, Khosravi et al. 2004, Obeid et al. 2004). However, both ways of root surface treatment may result in unintended substance loss (Schmidlin et al. 2001, Gagnot et al. 2004, Jepsen et al. 2004).

The rationale for the complete elimination of calcified deposits is based on the aetiology of chronic destructive periodontal disease. The beneficial effects of subgingival calculus removal on resolution of inflammation have been documented in numerous clinical studies (Drisko et al. 2000). Operators should selectively remove the subgingival calculus and the biofilm without extensively removing the underlying cementum (Nyman et al. 1986, Blomlöf et al. 1987). Currently, the thoroughness of subgingival instrumentation is determined by the degree of smoothness and hardness of the root surface. Following debridement, the clinician traditionally evaluates the endpoint of root surface instrumentation with a probe and has to rely on tactile sense (Low 1995, Clerehugh et al. 1996). Sherman et al. (1990a, b) compared the clinical results after probing with an explorer with the microscopic evaluation after extraction, and showed that microscopically 58% of all surfaces had residual calculus, while clinically only 19% of such surfaces were detected. Thus, many flecks of calculus are not recognized, potentially resulting in undertreatment at these sites. Distinguishing between the existence of calculus and nicks or troughs may be difficult or impossible (Rabbani et al. 1981, Sherman et al. 1990b). These authors questioned the usefulness of this subjective method of root surface evaluation and called for other methods to detect residual subgingival calculus.

Therefore, there is a need for the development of alternative methods to assist in the detection of residual calculus (Pippin & Feil 1992). The goal of further technological development of mechanical root-surface instrumentation should be a working instrument with a feedback function to recognize calculus. In this way, technological progress should result in (a) less aggressive instrumentation without unnecessary cementum removal, (b) more effective retreatment in complex anatomical situations by experienced operators during re-evaluation after the initial scaling phase, and (c) an improved effectiveness for inexperienced operators during the initial scaling phase.

We recently described the development of a conventional piezoceramic ultrasonic device, which can distinguish between the hard tooth substances enamel and cementum as well as subgingival calculus (Strackeljan et al. 1997, Kocher et al. 2000). Furthermore, we reported that under standardized conditions, the detection ability of the new device is not influenced by the marginal parameters ''application force'' or ''instrumentation angle'' (Meissner et al. 2005). In the studies cited, the instrument was successfully tested under static conditions with an immobile tip. However, the operator is accustomed to performing scanning movements when working with both periodontal probes and ultrasonic scalers. For this reason, it was necessary to test the potential of the system under this realistic condition as well.

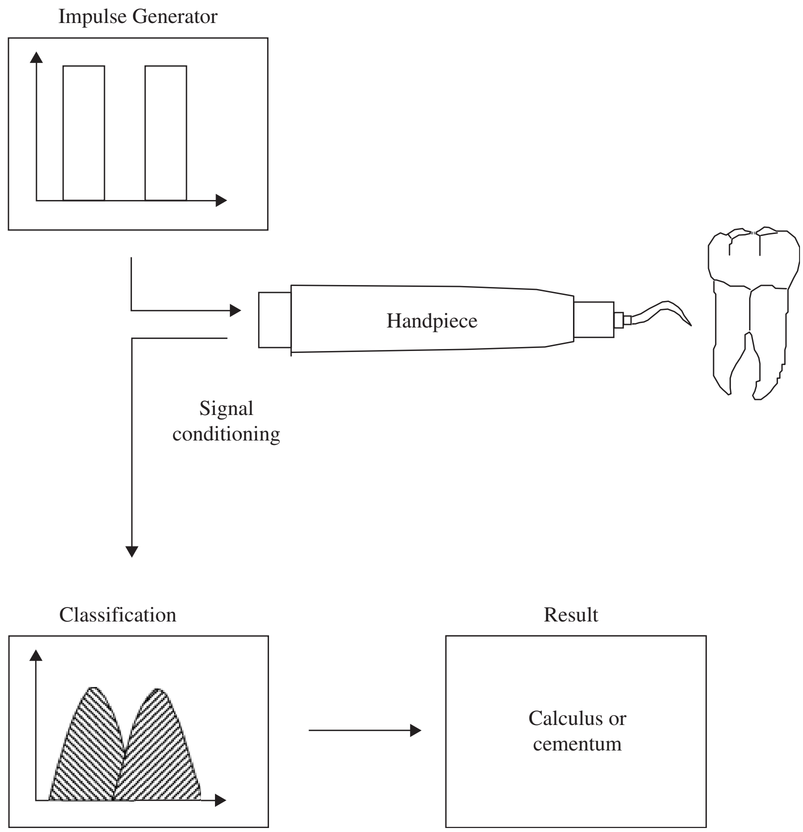

Fig. 1. Principle of the recognition method. An impulse generator sends signals to the piezoceramics and further to the tip of a usual dental ultrasonic scaler. The shift of the signals coming back from the tip contains the information necessary to analyze surface characteristics. Based on these, the differentiation between calculus and cementum is possible.

Materials and Methods

Principle of the recognition process

The principle is based on a method described by Strackeljan and Kocher (Strackeljan et al. 1997, Kocher et al. 2000). The working tip of a conventional, commercially available ultrasonic handpiece bearing a piezoceramic oscillation stimulator is excited by short, low-power impulses to perform about 50 oscillations/s. Excursions of less than 5 μm arise at the working tip. When this oscillating working tip touches different tooth surfaces, the latter also react with characteristic oscillatory movements. As a response, they induce – via the working tip – a mechanical deformation of the piezoceramic, which in turn leads to changes in voltage in the electrodes of the ceramic elements. The total signal consisting of impulse stimulation and impulse response is measured and evaluated by a data collection system. Because different materials possess characteristic signals, different tooth surfaces can be distinguished from one another (Fig. 1).

Feature level and learning set

In a learning phase, a dental operator trained the system with data generated by conclusively touching known root and calculus surfaces with the working tip. From the resulting response, signals were unambiguously assigned to each surface type, and mathematical properties and the extent of their expression (characteristics) were determined for all samples. With these characteristics, it was possible to optimally classify signals as calculus or root surfaces (see Fig. 2, *x*–*y* axis). Algorithms of fuzzy logic were used for this process of classification (Strackeljan et al. 1997, Kocher et al. 2000, Meissner et al. 2005). Because of the statistical principles upon which the classification algorithm of fuzzy logic is based, a probability from 0 to 1 can be determined for data from the learning set and for those from unknown surfaces, by which each sample can be classified as either root or calculus, given its characteristics. Figure 2 displays the probability (*z*-axis) for all samples of the training set. This value is dependent on the expression of the two characteristics the learning algorithm identified as optimal; for each sample, these two characteristics are represented on the *x* and *y* axes.

Samples

After informed consent and approval by the local ethics committee, a total of 234 human teeth were used, which had been extracted for periodontal reasons. The teeth were caries free and exhibited subgingival calculus on their root surfaces. Massive plaque deposits and soft tissue were carefully removed prior to instrumentation. Following extraction, the teeth were placed in 0.9% saline solution and stored at 4°C for up to 3 weeks before use in the trials.

Conducting measurements

An expert ''taught'' the system to recognize subgingival calculus and cementum on 200 teeth. The purpose of this training set was to adjust the parameters of the mathematic classifier employed. A dental operator wearing magnifying eyeglasses (2.5 × magnification; Carl Zeiss Jena, Jena, Germany) moved the detection tip with a slow scanning motion exclusively on the sur-

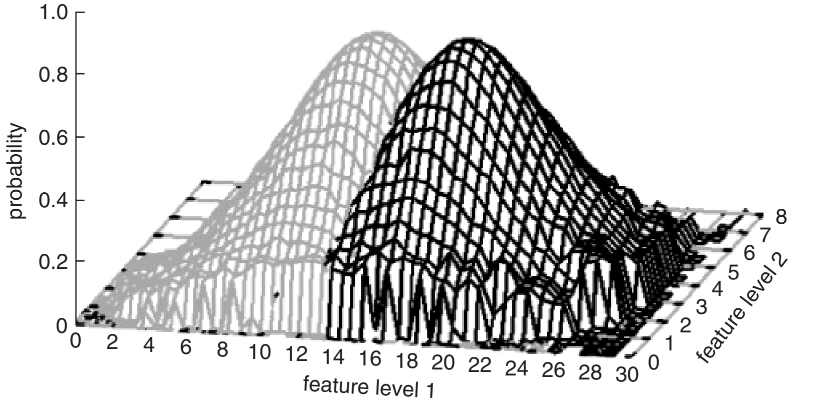

Fig. 2. Result of visualization and classification of the training set. Based on the expression of the two optimal characteristics (see above, *x*- and *y*-axis) and according to the probability (*z*-axis) for their classification as one of the two surfaces taught to the system by the dental operator, the individual samples of the training set are aligned.

face to be identified. On each tooth, both cementum and calculus were scanned at four locations. On each of these locations, about five consecutive measurements were recorded, resulting in about 40 measurements per tooth and a total of 7977 measurements. The teeth were embedded in a soft modelling clay mass during examination. The ultrasonic device Siroson L (Sirona Dental Systems, Bensheim, Germany) with the tip SI 11 (Sirona Dental Systems) was moved over the surface with an application pressure of ca. 3–5 N (balance: Maul, Odenwald, Germany). To mimic the clinical situation, the tip was moved at an angle of 10–30°. The lack of influence of the angle on the detection process was recently described (Meissner et al. 2005).

After data acquisition, the recorded training set was again presented to the classifier – which is based on the fuzzy logic principle. Finally, the system was tested on 34 unknown teeth, which were not part of the training set.

Statistical analysis

Sensitivity, specificity and κ values were calculated using SPSS 11.5 software (SPSS Inc. Chicago, IL, USA).

Results

Training set

Within the training set, the differentiation of the two surfaces – subgingival calculus and cementum – was correct in 78% of the cases. We found a sensitivity of 77% and a specificity of 79% with a κ value of 0.67 for this procedure (Table 1, Fig. 2).

Table 1. Overall results in the training set

	Positive	Negative	Sum
Calculus	3041	919	3960
Cementum	840	3177	4017
Sum			7977

Figure 2 graphically depicts the classification results.

Test set

After it was shown that the system could achieve a correct classification rate of 78% on teeth known to it, unknown teeth not contained in the training set were tested. Within the test set, the differentiation of the two surfaces – subgingival calculus and cementum – was correct in 81% of the cases. In the test set, we found a sensitivity of 76%, a specificity of 86%, and a κ value of 0.68 for this procedure (Table 2).

Table 2. Overall results in the test set

	Positive	Negative	Sum
Calculus	513	166	679
Cementum	98	586	684
Sum			1363

Discussion

In this study, a recently described prototype piezoceramic ultrasonic device with a fuzzy-logic based detection mode was tested, which can distinguish between the hard tooth substances enamel, cementum and subgingival calculus. In addition to its reported capability to classify surfaces with an immobilized tip under laboratory conditions, the present study confirms the applicability of the system to the clinical setting with a moved instrument tip in vitro. The classification algorithm selects certain frequencies from the oscillation measurements and applies the corresponding voltage amplitudes in a mathematical plane, in order to distinguish surface differences through fuzzy separation. In many experiments involving oscillation, Strackeljan et al. (1997). observed that the sets of points formed often fill one convex, elliptical area, which can possess any arbitrary orientation in a plane. The quality of the classifier is tested as follows: after training, a test set is applied to the algorithm, thus determining an error rate, sensitivity, and specificity. Although these results do not allow definitive statements on the response of the system to unknown teeth, the measured parameters do provide an indication of the future behaviour of the system. The viability of this method is shown by the comparison of our training set and test set results (error rate in both cases ca. 20%).

In previous studies (Strackeljan et al. 1997, Kocher et al. 2000), the ultrasonic scaler was tested contacting just one point at a time, without moving it during measurement. Although this contact mode between instrument and tooth surface is easier to implement in an experiment than an instrument operated freehand, it does not correspond to periodontal reality: in practice, periodontal treatment and diagnostic instruments are applied with a scanning movement. For instance, a periodontist runs a probe over the root surface in order to determine whether all calculus has been removed. Thus, this in vitro study examined whether the recognition rate of the system was dependent on the movement of the instrument and whether results comparable with those of our first trials (recognition with immobile tip) were possible. This new experimental condition yielded a decisive change of the previously considered procedure. In order to obtain a certain classification of the given surface, the evaluation algorithm requires at least four consecutive measurements on one surface, taking the average to obtain the result. This means that the measurement time and frequency must be selected so that the tip remains and recognizes one small subgingival calculus during this time. The previously used measurement speed was too slow for the scanning movement, so that it soon became obvious in the course of setting up the experiment that a second marginal condition – the speed of data acquisition – also had to be increased. Thus, our results cover two major changes relative to our previous experimental design. Every 350 ms, a result was obtained which, at an assumed scanning speed of 5 mm/s, is sufficient to record subgingival calculus with an extent of about 1.5 mm in the direction of the current movement. For the clinical routine, of course, the resolution limit must be increased further. The influence of the pocket wall was studied in experiments using extracted teeth and removed gingiva from pigs adjacent to the root surface (data not shown). Influence of gingival tension on the detection could be found, but proved to be rather limited.

The current precision of the method is expressed by a sensitivity of 76% and a specificity of 86%. The results of this study are comparable with the values obtained from the study using static trials. For manual scanning of residual calculus after subgingival scaling, Sherman et al. (1990b) determined a sensitivity of 24% and a specificity of 88%. As far as these two examination methods are comparable at all, the dramatic difference in sensitivities with similar specificity results indicates that a smart ultrasonic device provides the operator with more information about the scaled root surface than a manual probe. Ultrasonic detection recognized a greater percentage of calculus-covered tooth surfaces than did manual scanning.

When comparing the present method with another diagnostic procedure, the receiver operating characteristic curve (ROC) is suitable. In this, corresponding values for specificity and sensitivity are calculated for different threshold values and compared. In the system developed by the present authors, different specificities and sensitivities and thus the ROC curve are produced functionally, as the classifier, which makes the decision whether an acquired sample unknown to the system should be assigned to the one or the other surface, is fuzzy. Depending on weighting, the decision can be influenced in one direction or the other. In the extreme case, the acquired sample is assigned 100% to one of the two surfaces. In this manner, this method makes it possible to adjust the threshold for different sensitivity and specificity requirements. In future experiments whether different sensitivity and specificity values should be applied for different phases of periodontal therapy must be investigated (Fig. 3).

The great potential and goal of developmental work on these ultrasonic recognition methods lies in the possibility of uniting detection and removal modes in one feedback system. Following the recognition of subgingival calculus, it can be removed immediately. This largely eliminates the information loss in terms of calculus location, which occurs in manual scanning and subsequent scaling. Moreover, the issue of debridement in a single visit (full-mouth scaling) *versus* quadrant scaling draws much attention in the periodontal community. From all these studies it can be learnt that full-mouth scaling needs less time and is more patient friendly (Kinane 2005, Koshy et al. 2005, Wennström et al. 2005). Our device may facilitate the single visit treatment sequence as outlined by Wennström et al. 2005, because in the re-evaluation period the decision process of the operator is supported and the operator can work with less or full power setting depending on the presence of calculus.

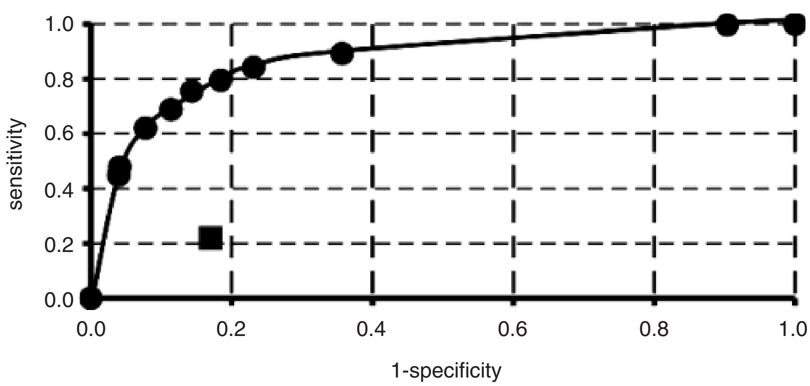

Fig. 3. Receiver operating characteristic curve (ROC) curve: Representation of sensitivity over specificity with the ROC curve of the test set (●). The square represents the sensitivity and specificity of a clinician using a manual explorer (after Sherman et al. 1990a).

The ultrasonic-based system must now be tested in clinical trials on patients: the functionality must be examined under realistic conditions. Such a trial is now in preparation in our laboratory. A further focus of future work will be the examination of resolution limits in vivo.

The present system (based on a conventional, commercially available ultrasonic device) for automatic recognition of surfaces is able to reliably distinguish between the surfaces cementum and subgingival calculus. It was demonstrated that in a large number of teeth under realistic instrumentation conditions, the two surfaces cementum and subgingival calculus were correctly classified. Combined with a power-controlled ultrasonic mode, it should be possible to remove subgingival calculus in a manner, that is both precise and gentle on teeth.

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Clinical Relevance

Scientific rationale for study: Root surface debridement with concomitant calculus removal is the cornerstone of periodontal therapy. To facilitate residual calculus removal, we developed a piezoceramic ultrasonic scaler with an additional mode for calculus spotting, which automatically classifies calculus deposits.

Principal findings: The automatic surface classification system works not only in a static environment but also with a moving tip in a scanning mode in vitro.

Practical implications: If used as a combined detection/removal instrument, our device allows for improved calculus removal with conserved cementum compared with current instruments.

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