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A new system to detect residual subgingival calculus: *in vitro* detection limits

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Abstract

Aim: We recently introduced an experimental surface detection system based on a conventional dental ultrasonic scaler. This device automatically discriminates cementum and dental calculus, which is the prerequisite for complete and thorough calculus removal. In the present study, the detection limits of this device were tested in vitro.

Material and Methods: From 50 extracted teeth, subgingival calculus was gradually removed using a Gracey curette. During this stepwise procedure, detection properties of the surface detection system were continuously monitored and systematically verified until the system stopped discriminating calculus from the root surface. By measuring the diameter, circumference and area of the smallest, yet recognizable deposit, and of the no longer recognizable deposit, the cut-off point of the discriminative capability of the detection device was determined.

Results: The cut-off points for the correct classification of residual deposits averaged on a diameter of 219 μm, an area of 21,600 μm^2, and a circumference of 748 μm. This means a sensitivity of 73% and a specificity of 80% in this critical area.

Conclusions: This calculus detection system was able to detect small deposits. In clinical practice, this device may support dentists in deciding whether to stop or to continue the debridement.

Key words: detection limits; extracted tooth; fuzzy logic; residual calculus; ultrasonic instrument

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A successful periodontal therapy requires the complete debridement of plaque and calculus, leaving healthy tooth structures intact at a time (Pihlstrom & Ammons 1997). However, it is very difficult to detect calculus in subgingival root areas without visible access and to remove the deposits properly without harming the calcified tooth structure. Using a probe for the detection of residual calculus results in a very low sensitivity (Kepic et al. 1990, Sherman et al. 1990b, Pippin & Feil 1992). A lack of objectivity in the deciding about the presence of calculus demonstrates that the quality of the rendered treatment depends on the expertise and on the professional training of the operator (Brayer et al. 1989, Fleischer et al. 1989, Kocher et al. 1997). Within the last few years, different systems have been developed to discriminate calculus and cementum (Strackeljan et al. 1997, Kocher et al. 2000, Folwaczny et al. 2002, Stambaugh et al. 2002, Buchalla et al. 2004, Krause et al. 2005). The studies of Strackeljan et al. (1997) and Kocher et al. (2000) described a sensor-based method to detect calculus, where the piezoceramic of a conventional ultrasonic device causes oscillations of the working tip . The oscillations at the surfaces touched were reflected and analysed mathematically. Our team further developed and tested this system focusing on a calculus detection and removal device, which provides feedback. At the moment, this device offers the possibility to switch from a detection mode, discriminating calculus deposits, and clean roots to a treatment mode allowing a conventional ultrasonic treatment with different power levels. Under laboratory conditions, it achieved clinically acceptable results in the discrimination of the calculus and cementum surfaces in static tests (sensitivity: 87%, specificity: 76%) (Meissner et al. 2005a) as well as under probing movements of the working tip (sensitivity: 76%, specificity: 86%) (Meissner et al. 2005b). We made sure that in these tests, the working tip was always positioned on either one of the surfaces under investigation, and that the diameter of the calculus area to be examined significantly exceeded the diameter of the distal end of the working tip (0.5 mm).

In a real root surface treatment, the calculus areas are reduced, and the working tip moves back and forth from cementum to calculus. The smaller a calculus deposit becomes during treatment, the shorter the period the tip gets in touch with the deposit during the probing movement. This increases the difficulty to spot the residual deposit.

Utmost accuracy is an important prerequisite of a modern detection device, because a non-mineralized plaque layer of variable thickness may also cover very small calculus flecks (Tan et al. 2004), which in turn expand the plaque radius (Garant & Cho 1979), and thus may impede the healing process.

The aim of our study was to evaluate the minimal size of a calculus deposit that still is recognizable with the detection device used in our tests. For this purpose, we made in vitro examinations on successively reduced calculus deposits and determined the detection limits of the modified ultrasonic instrument.

Material and Methods

Principle of the recognition process

Strackeljan et al. (1997) and Kocher et al. (2000) were the first to describe and further develop the principle of sensor-based surface detection on teeth. The construction as well as the exact function and the analyzing algorithm of the detection device were recently described (Meissner et al. 2005).

The detection principle is based on the assessment of oscillation signals. Via a working tip of a conventional, commercially available ultrasonic handpiece, low-power square pulses with a wattage of 0.002 W are applied onto the root surface. A piezoceramic oscillation stimulator causes these impulses with a frequency of 100 Hz. These impulses result in tiny movements of approximately 5 μm at the working tip. When the oscillating working tip touches different tooth surfaces, these also react with characteristic oscillatory movements, which are reflected and then recognized by the system via the working tip and the piezoceramic. The measuring system detects voltage changes and analyses them on the basis of fuzzy logic. Random samples can be recorded in intervals of 50 ms, which corresponds to a measuring frequency of 20 Hz. The different surface types cementums and calculus can be distinguished by reflected voltage patterns, which were then analysed to discriminate calculus and root surfaces.

Samples

A total of 50 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 before instrumentation. After the extraction, the teeth were placed in 0.9% saline solution and stored at 4°C for up to 3 weeks before being used in our tests.

Measurements

The teeth were embedded in a soft modelling clay mass. The ultrasonic tip was moved over the surface with an application pressure of about 0.3–0.5 N at an angle of 10–30°. The device used was the Siroson L (Sirona Dental Systems, Bensheim, Germany) with tip SI 11 (Fig. 1).

A dental operator wearing magnifying eyeglasses (× 2.5 magnification; Carl Zeiss Jena GmbH, Jena, Germany) moved the detection tip with a slow scanning motion (5 mm/sec) over an arbitrarily chosen root surface covered with calculus. The distal end of the working tip was repeatedly moved back and forth over the calculus deposit onto the surrounding clean root surface. An independent observer watched the detection results of the system and took notes. At first, the applicability of the device for the respective tooth was confirmed on non-treated calculus as well as surrounding cementum. This control ensured that only properly classifiable surfaces were evaluated.

Now the dental operator carefully treated the calculus deposit under visual control using magnifying eyeglasses (× 2.5 magnification; Carl Zeiss Jena GmbH) by means of sharp curettes (Gracey 1/2, 3/4, 5/6). After one to two strokes on or at the margin of the calculus deposit, this area was examined again with the detection tip, as described above. Subsequently images of the properly classified calculus area were taken using an incidental light microscope with 35-time magnification (Fig. 2a–d) (OLYMPUS Optical Co, Hamburg, Germany) connected to a video camera (SONY POWER HAD, Model 950 P,

Fig. 1. General test procedure: the working tip touches a calculus area.

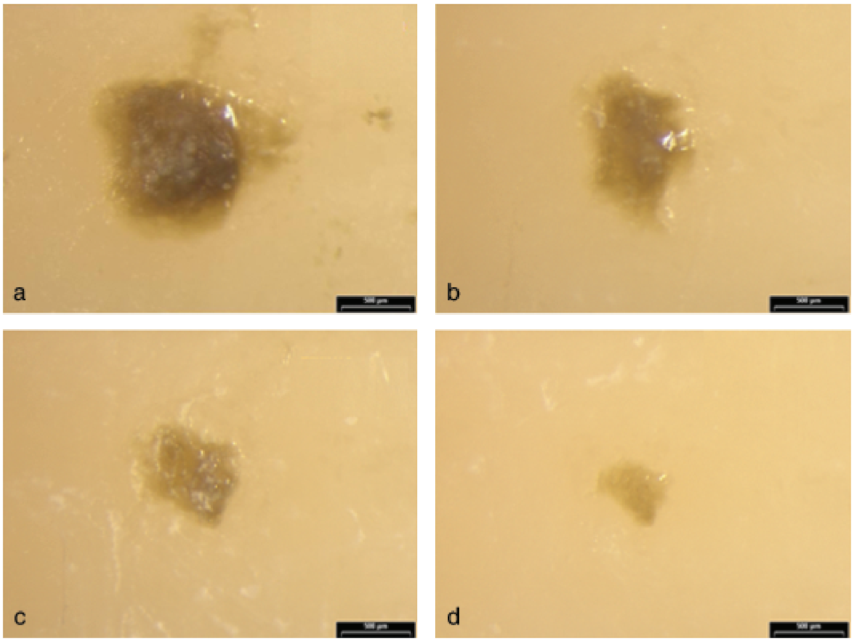

Fig. 2. (A—D) Calculus reduction: example of the successive reduction of a calculus deposit on a specified root area. The smallest calculus area shown in (D) was not recognized by the detection device.

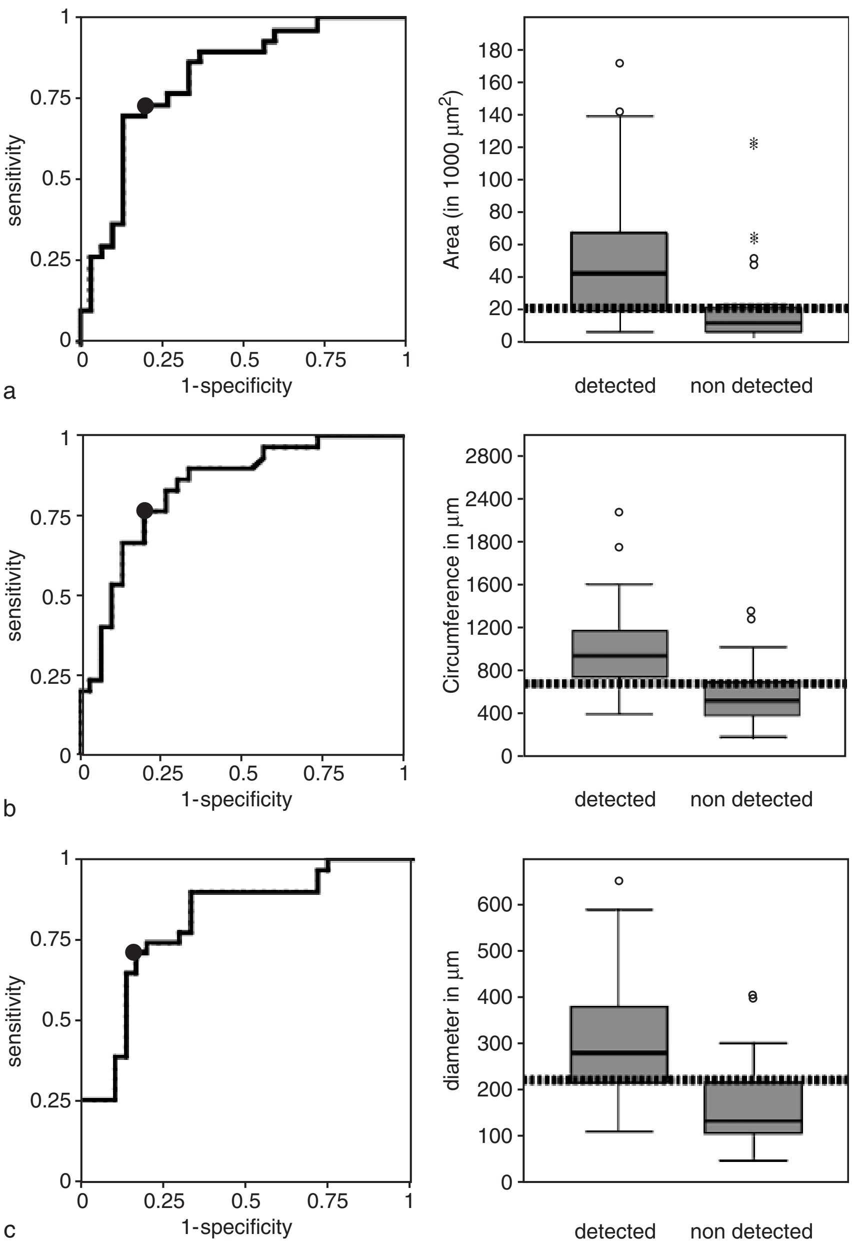

Fig. 3. (A—C) Receiver operating characteristic (ROC) curves and boxplots: ROC curves (left panel) of the detection result in relation to the size of the calculus deposits, constructed to determine the cut-off point for sensitivity and specificity. The cut-off points chosen were marked. Boxplots (right panel) (10%, 25% 50% 75%, 90% percentiles and outliers) of the deposits recognized and not recognized. The dashed lines represent sensitivity based on the ROC curve. There were always one to two strokes between the still recognized and the no longer recognized calculus deposit. (a) Values determined for the area of the calculus. (b) Values determined for the circumference of the calculus. (c) Values determined for the diameter of the calculus.

Tokyo, Japan) and were analysed with analySIS 2.1 (Soft Imaging System, Münster, Germany). This process of successively reducing, detecting and photographing the calculus area was repeated until the detection system recognized only cementum but no calculus anymore. The final status of the studied surface was documented with the imaging system as well (Fig. 2a–d).

Analysis

For the calculation of a size-dependent cut-off point between recognizable and no longer recognizable calculus areas, the diameter, circumference and area of each smallest and of the no longer recognizable calculus area were measured by means of the stored images (analySIS 2.1 Soft Imaging System).

The Mann–Whitney test was used to evaluate significant differences between the circumference, the diameter and the area of the smallest still recognizable and the no longer recognizable calculus deposit. The data were shown with median and with inter-quartile ranges (IQR). Then, the receiver operating characteristic (ROC) curves were constructed to determine the cut-off point for sensitivity and for specificity, which were both expected to be above 70%. The cut-off points chosen were marked in the ROC curves and in the boxplots (Fig. 3a–c). The data were statistically evaluated with the SPSS for Windows 11.0.

Results

The median of the area of recognizable deposits was 41,995 μm^2 (IQR: 53,950) and that of the not recognizable deposits, 11,633 μm^2 (IQR: 14,577). The median of the diameter of the recognized deposits was 276 µm (IQR: 214) and that of the no longer recognized deposits, 130 µm (IQR: 115); the median of the circumference of the recognized deposits measured was 942 µm (IQR: 492) and that of the no longer recognizable deposits measured 516 µm (IQR: 324). Thus, the recognized and no longer recognized deposits showed significant differences (Mann–Whitney test, $p < 0.001$).

The cut-off point for the area was 21,598 μm^2 (sensitivity: 73.3%, specificity: 80%), the cut-off point for the widest diameter was 219.4 µm (sensitivity: 74.2%, specificity: 80%) and the cut-off point for the circumference reached 748 µm (sensitivity: 73.3%, specificity: 80%) (Fig. 3a–c).

Discussion

The aim of this study was to evaluate an ultrasonic calculus detection device under in vitro conditions and to determine its detection limits on successively reduced calculus deposits. This detection device proved to be able to detect even very small residual calculus deposits on the root surface under optimal conditions. As continued treatment after removal of the calculus may result in destruction of the intact root surface, the determination of the right end point is a prerequisite for a successful periodontal treatment.

Different authors claim that periodontal destruction is accompanied by the presence of calculus, which is virtually always covered with dental plaque (Mandel & Gaffar 1986, Roberts-Harry & Clerehugh 2000). Therefore, the goal of periodontal therapy is to remove the smallest calculus residuals from the root surface.

The present study demonstrates that calculus deposits of 0.2 mm in diameter can still be recognized under optimal conditions by our surface detection system. The ultrasonic SI-11 working tip has a diameter of 0.5 mm at its distal end. At an estimated probing speed of 5 mm/sec, a tooth surface of 1 mm is traversed in 200 ms. During this time, measurements are carried out every 50 ms (resulting in a total of 4). When touching a calculus deposit, the oscillations projected onto the tooth are still correctly classified if there is a 1:2.5 relation between the area of the calculus and the size of the working tip. We did not find published results for other calculus detection methods, which compare with our data (DetekTar; (Ultradent Products, South Jordan, UT, USA), DentalView (Irvine, CA, USA), Key-Laser (Kaltenbach & Voigt, Biberach, Germany).

Although the optimal detection limit of the system remains under the size of the distal end of a conventional working tip if tested in vitro, we assume that the size of calculus deposits detected in vivo exceeds this detection limit. We do not know yet how big the chances are that the operator scans every single spot of the root surface while moving the working tip over the root surface. This could only be guaranteed if the operator was able to completely ''scan'' the tooth with overlapping movements. But we suppose that some areas are touched several times while other areas are never contacted (Kocher et al. 1997). Thus, in vivo results reported until now consider the technical detection limits of a system as well as the diligence and the skill of the operator to run the instrument over the tooth surface in accurate courses (Sherman et al. 1990a).

In two clinical situations, the detection device used determines a more exact end point of the periodontal treatment. The first indication is to check the root surface during or immediately after deep scaling. Sherman et al. 1990 aproved very impressively how difficult it is to detect residual calculus on the root surface by manual probing. They compared the clinical results after probing with an explorer with the microscopic evaluation after the extraction and showed that microscopically 58% of all surfaces had residual calculus, while clinically only 19% of such deposits were detected. Thus, many flecks of calculus are not recognized, potentially resulting in under-treatment at these sites. Furthermore, the explorer might detect nicks or troughs indicating calculus deposits in the respective area. We know that the treatment with ultrasonic devices or hand instruments might cause the above-mentioned alterations on the root surface as well (Rees et al. 1999, Schmidlin et al. 2001, Busslinger et al. 2001, Folwaczny et al. 2004). The dentist may feel a roughness without knowing whether it is because of nicks or calculus (Jacobson et al. 1994). If the operator makes a wrong decision, he removes even more healthy tooth structure. Teeth, which were treated by unskilled operators, showed a significantly higher amount of calculus than teeth treated by experienced dentists. This problem may increase when pockets with a depth of more than 5 mm bearing more residual calculus than shallow or moderately deep pockets are treated (Brayer et al. 1989, Fleischer et al. 1989). This finding was confirmed by other authors who also found problems of access and less efficiency in deeper pockets and in molars with furcation involvement (Rabbani et al. 1981, Caffesse et al. 1986, Buchanan & Robertson 1987, Leon & Vogel 1987). Therefore, the unskilled as well as the experienced operator may benefit from the introduced detection device already in the first treatment session.

The second clinical indication is secondary therapy, such as the recurrent disease during the maintenance therapy or the re-evaluation after the conventional quadrant deep scaling and after the debridement in a full-mouth scaling (Kinane 2005, Koshy et al. 2005, Wennström et al. 2005). Calculus, which had been treated before, has a relatively smooth or burnished surface, which might be interpreted as smooth root surface and therefore is just ''overlooked''. This implies additional difficulty for the treatment of inflamed deep pockets during maintenance therapy. Another risk in this situation is unnecessary harm or removal of healthy tooth structure. In a confined area with increased probing depth and signs of inflammation, the operator supported by this detection device may scan the respective area more systematically. Therefore, the influence of the operator on the detection results mentioned above could be minimized by concentrating on a confined area. If the operator knows the location of the residual calculus, he can apply a high power of ultrasonic instrument there while applying lower power in the other areas to remove the biofilm without damaging the surrounding root surface.

In our in vitro tests, this detection device achieved a higher detection limit than the actual size of a conventional ultrasonic tip. We assume that neither probing with hand instruments nor the scanning of the root surface with an ultrasonic instrument reaches such a high level of accuracy in clinical use. The operator is helped by our detection system in his decision whether the optimal endpoint of debridement is reached or whether nicks, troughs and roughness falsely indicate an untreated root surface. Subsequent in vivo studies have to evaluate clinical results of this detection device.

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Clinical Relevance

Scientific rationale for study: We developed a calculus detection system based on established dental ultrasonic technology, which automatically classifies dental calculus. AS even the smallest calculus deposits may become a mineralization nucleus and increase the plaque radius, such a calculus detection device should be able to discriminate calculus and cementum with the utmost accuracy.

Principal findings: The detection limits of this calculus detection device have been determined by subsequently reducing the calculus deposits in vitro.

Practical implications: The present device may help to find the optimal time point to stop the treatment during a systematic treatment procedure.