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# Influence of handling-relevant factors on the behaviour of a novel calculus-detection device

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***Abstract***

**Objectives:** The aim of periodontal therapy is always the complete debridement of root surfaces with the removal of calculus and without damaging cementum. We have recently demonstrated the feasibility of a surface recognition device that discriminates dental surfaces by mathematical analysis of reflected ultrasound waves. This principle should enable the construction of calculus detecting ultrasonic device. Pre-clinical test results are presented here.

**Material and Methods:** An impulse generator, coupled to a conventional piezo-driven ultrasonic scaler, sends signals to the cementum via the tip of an ultrasound device. The oscillation signal reflected from the surface contains the information necessary to analyse its characteristics. In order to discriminate different surfaces, learning sets were generated from 70 extracted teeth using standardized tip angle/lateral force combinations. The complete device was then used to classify root surfaces unknown to the system.

**Results:** About 80% of enamel and cementum was correctly identified in vivo (sensitivity: 75%, specificity: 82%). The surface discrimination method was not influenced by the application conditions examined. A new set of 200 tests on 10 teeth was correctly recognized in 82% of the cases (sensitivity: 87%, specificity: 76%).

**Conclusions:** It was shown in vitro that the tooth surface recognition system is able to function correctly, independent of the lateral forces and the tip angle of the instrument.

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

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Root surfaces with intact cementum but devoid of plaque and calculus is one of the major goals of modern periodontal therapy. Earlier assumptions that endotoxins were located within cementum, justifying cementum removal, did not prove correct (Moore et al. 1986, Cheetham et al. 1988, Smart et al. 1990). Moreover, a potential contribution to periodontal attachment regeneration is attributed to cementum (Blomlöf et al. 1987, Bernstein et al. 1990). Clinically, cementum removal from root surfaces may lead to exposure of dentine tubules to the oral cavity and may thus result in hypersensitivity (Haugen & Johansen 1988, Grant et al. 1993, Tammaro et al. 2000).

It is difficult to selectively remove calculus using a conventional scaler and leave the cementum intact (Kocher & Plagmann 1997, Kocher et al. 1997). Since the specificity of the instrument's tactile sensitivity is low, areas of residual calculus may remain unidentified (Sherman et al. 1990, Kocher et al. 2001). In addition to the equipment used, the skills and experience of the dentist markedly influence the final outcome. Trained operators treat root surfaces in a more systematic way and may therefore remove a larger portion of both subgingival calculus and plaque (Brayer et al. 1989, Dragoo & Wheeler 1996, Kocher et al. 1997). Using power-driven instruments for calculus removal even further impairs tactility (Rühling et al. 2002), resulting in potential overtreatment of cementum. In conclusion, root surface debridement using conventional or ultrasonic instruments for calculus removal leads to unintended loss of dental tissue (Ritz et al. 1991, Jacobson et al. 1994, McGuire & Nunn 1996, Flemmig et al. 1998a, b).

Concepts for selective calculus removal include 655-nm-wavelength laser-based technology, which allows identification of subgingival calculus via induced fluorescence emission (Folwaczny et al. 2002). In vitro, this method was able to discriminate between calculus and cementum in saline, blood, and air (sensitivity:100%, specificity:100%). In addition, the recently introduced endoscopy-based device DentalView® (DV2 Perioscopy System, Dental View, Irvine, CA, USA) (Stambaugh et al.

2002) improves surface recognition compared with classical systems. Reich and co-workers, however, developed an Er:Yag-laser-based surface detection device, which incorporates a feedback-driven treatment mode and thus may serve as an alternative to previous subgingival scaling methods (Schwarz et al. 2001). However, there are no data on sensitivity or specificity available for this device. It thus remains to be seen whether any system is able to not only reliably identify subgingival calculus but also remove it at the same time.

Based on laboratory investigations by Strackeljan and Kocher (Strackeljan et al. 1997, Kocher et al. 2000), our goal is to develop an instrument based on a conventional piezoceramic ultrasound scaler for reliable enamel, cementum, and subgingival calculus identification, which also incorporates sensitive calculus removal capacities by feedback-driven power-throughput to the tip of the instrument. The final ultrasound instrument should be able to regulate its power automatically, thereby enabling complete calculus removal while simultaneously preserving cementum.

Since variations in tip angle and lateral force due to the individual operator are known to influence ultrasound-scaling results (Kocher 1992, Flemmig et al. 1998a, b), the influence of these parameters on ultrasound-based surface recognition was also examined.

## Material and Methods

### Detection method

The surface detection method described by Strackeljan and Kocher (Strackeljan 1993, Strackeljan et al. 1997, Kocher et al. 2000) is in principle comparable to the way in which one might test the integrity of a wine glass by slightly tapping on its rim with a hard artefact, thereby acoustically identifying cracks.

The insert of a conventional dental ultrasound scaler receives short, weak impulses with a frequency of about 50 Hz, which make the insert's distal tip oscillate with an amplitude of about 5 μm on the dental surface. The dental surface itself is thus stimulated to oscillate at a frequency dependent upon its surface characteristics. These oscillations are conducted from the tip back into the instrument and into the piezoceramic discs, which are able to transform oscillations into voltages. The intensity of the respective voltage represents the intensity of the tip oscillation, whereas the frequency stays the same. The overall signal, consisting of both the impulse stimulus and the impulse response, is measured and evaluated simultaneously using a computerized system, thereby generating information about given surface characteristics (Fig. 1a).

### Data evaluation – the feature level used as evaluation method

Initially, the impulse response of the system is present as a time scale of a fading oscillation, comparable to that of a bell curve (Fig. 1b). Using a mathematical operation, this signal is split into a virtually infinite number of sinus oscillations with different frequencies. By using this procedure, also called fourier transformation, it is possible to depict fading oscillations as a collection of frequency signals (Fig. 1c).

The resolution of our system was 250 Hz, which allowed only steps of this size to be analysed, hence reducing the number of frequencies. For better orientation, all frequencies used were consecutively numbered from 0 to 400. The resulting numbers were then called features (Fig. 1d). Each feature on the *x*-axis was correlated to its voltage amplitude on the *y*-axis, representing the strength of the respective oscillation. In the example cited above, the feature 200 stands for a frequency of 50 kHz and is correlated to an amplitude of 11.5 mV. It is now possible to plot voltage amplitudes of two arbitrary features, which results in a graphic level referred to as feature level (Fig. 2). If an experiment which tests one surface consists of several samples, the result is a variety of scattered voltage amplitudes and thus a number of spots within the same feature level, in other words, a scatter (or feature) diagram.

### Distinction of surfaces

How can the method described above distinguish between different dental surfaces? Different dental surfaces display voltage amplitude deviations at certain characteristic frequencies. By appropriately choosing two characteristic frequencies or features (determination of optimal or "appropriate" frequencies is explained below), we

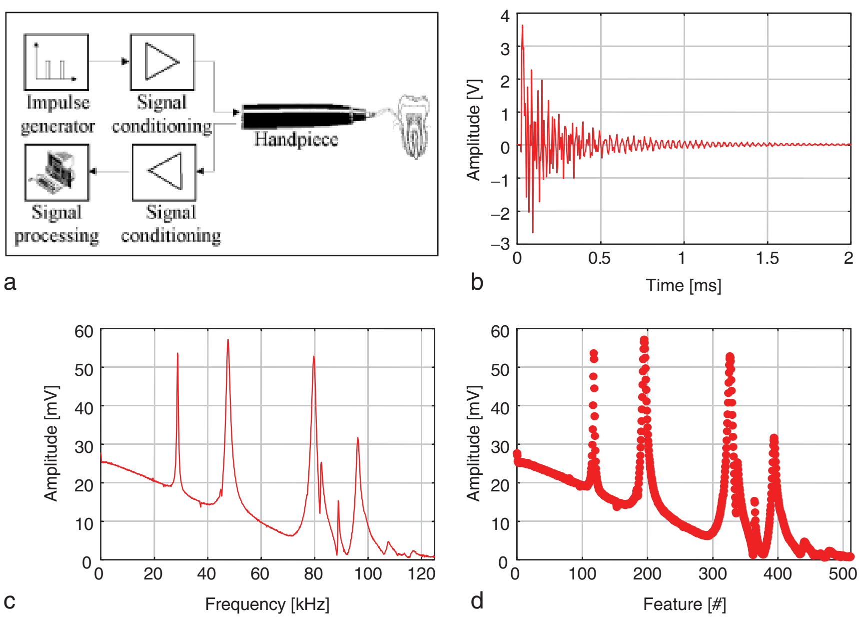


*Fig. 1.* Data acquisition and processing pathway in the ultrasound-based surface recognition system. (a) The tip of a dental ultrasound scaler receives impulses, which transform into oscillations of the instrument's tip at the dental surface. The tip is thus stimulated to oscillate. The signal of the reflected impulse is analysed with a computerized system. (b) Original impulse and resulting oscillation of the system, consisting of both the tooth and the scaler. The voltage amplitude represents an oscillation, which consists of different frequencies. These fade over time. (c) Spectral display of the resulting oscillation from (b). The peaks represent the frequencies within the sum oscillation with the highest intensity (or amplitude). (d) Spectral display from (c) after sequential analysis of defined stepwise frequencies. By dividing the respective frequency by 2501 Hz, "features" are generated, ranging from 0 to 400.

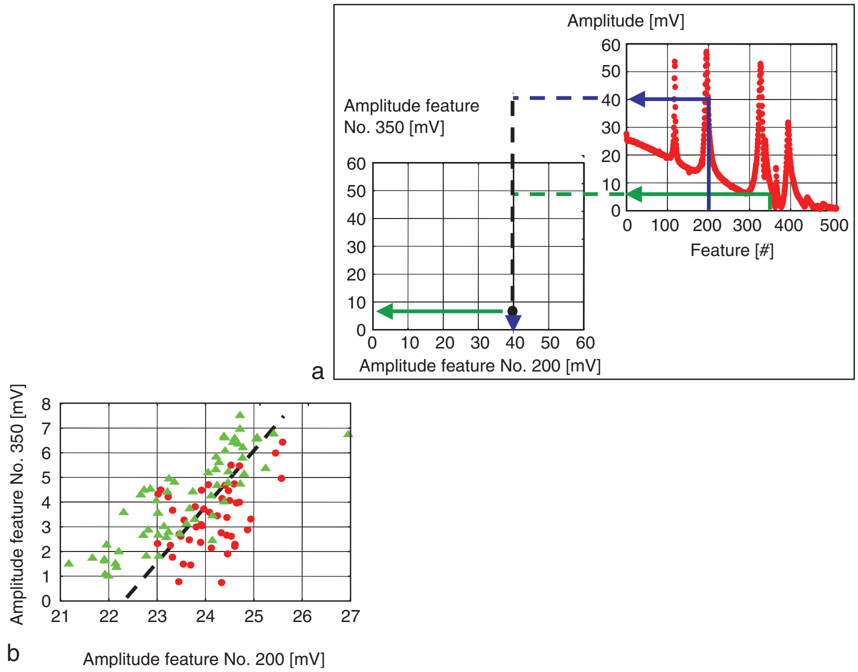


*Fig. 2.* Origin of the feature level. (a) The voltages (intensities) of two features of the same sum oscillation are plotted against each other: feature 200 on the *x*- and feature 350 on the *y*-axis. (b) Plot of voltage amplitudes of the two features described in (a) for a number of point-checks, which belong to one of two different surfaces (surface 1: triangles; surface 2: circles). The resulting scatter clouds can be separated from each other in case the chosen features are able ("appropriate") to properly distinguish between the two surfaces.

are able to display feature levels, which results in a surface-dependent formation of scatter clusters within the feature diagram. If one were to plot voltage amplitudes of two different surfaces at the "frequencies" of, for instance, 200 and 350 within the feature level, the surfaces can be classified if an optimal line between the two scattered clusters can be drawn (Fig. 2).

#### Feature level and learning set

Each combination of features within the measured range of frequencies is feasible for use as distinction criteria within the feature level. The optimal ("appropriate") combinations of features are not arbitrarily chosen but generated using a computer-assisted algorithm based on the rules of fuzzy logic. The difference from classical logic rules is the assumption that any unit of information is not necessarily either true or false but might just as well represent graded information between the two extremes. Both root and calculus substrates are measured to generate learning curves from known dental surfaces. The larger the learning set becomes, the sharper are the distinction features and thus the smaller the error.

In addition to different surfaces to be classified, different modes of instrument use (angles and lateral forces) were also integrated into the learning set. These attributes were classified using selected features as described above for the surfaces. The best results are achieved if the features used for surface recognition do not interact with working parameters (angles and lateral forces) of the ultrasonic scaling device.

#### Feature decision

After constructing the learning curve and subsequently generating the two scatter clusters that now represent two different surfaces, the mean within the feature level is separately calculated for each cluster. Depending on the distance of each sample point from one of the means, the sample can now be defined as true (closer to the mean of its own cluster) or false (closer to the opposite mean).

#### Teeth

A total of 80 caries-free teeth removed for periodontal reasons were gently cleaned of soft tissue and plaque, and stored at 4°C in saline solution for up to 3 weeks after removal. The study was approved by the local ethics committee.

#### Implementation

A learning set was generated by an experienced operator on a total of 560 points on the surfaces of 70 teeth (cementum or calculus), with each surface point being measured up to five times, resulting in 2600 unrelated point-checks. The tip was placed solely on either cementum or calculus using magnifying eye glasses (× 2.5, Carl Zeiss, Jena, Germany). The ultrasound instrument was mounted on a device which enabled standardized weights to be placed on the tip. The teeth were embedded in rubber cement, which was placed on a balance (Maul, Odenwald, Germany), and different tip angle/lateral force combinations were applied.

#### Influence of lateral forces

In case the dentist unknowingly applies more lateral force while detecting a rather small area of calculus, the obtained result may depend not only on surface characteristics but also on the particular lateral force applied in that situation. Therefore, the potential influence of the lateral forces 0.2, 0.45, and 0.9 N was examined while the angle combination was set to 15°/15° by definition (Kocher 1992, Flemmig et al. 1998a, b). Each one of the three lateral forces was tested on 20 teeth with eight points on each tooth being tested (four sites with calculus and four with cementum). The discrimination results of these three forces were compared with the data obtained using the standardized feature level as described above. At first, discrimination results were studied using the optimal (separate) feature level for each force tested. Thereafter, the standardized feature level was applied to the data regardless of the force applied, to determine whether it would still be possible to distinguish the surfaces.

#### Influence of tip angle

Similarly, the influence of different tip angles was examined. Two different angles were used to describe the tip–surface relationship, the first being the instrument handle's deviation from the longitudinal axis of the tooth (15–45°), and the second being the rotation of the instrument along the distal tip axis (15–

90°, Fig. 3). Tip angles were examined using either 0.2 or 0.45 N as clinically relevant lateral forces. Each of the four possible tip angle settings was tested on 10 teeth with eight points on each tooth tested (four calculus and four cementum). Similar to the method described above for analysis of the influence of application force, the angle combination data were initially analysed using the applicable optimal features for the respective angle, followed by an evaluation of the potential surface discrimination using the features defined according to the learning set results.

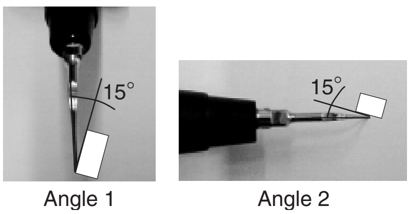


*Fig. 3.* Schematic drawing of the two angles tested for potential influence on surface recognition results. Angle 1 depicts the instrument's deviation from the longitudinal axis of the tooth (varied between 15° and 45°), whereas angle 2 stands for the rotation of the instrument along the distal tip axis (varied between 15° and 90°).

#### Test of unknown teeth

A total of 10 teeth unknown to the system were analysed to test the system's ability to correctly discriminate surfaces. Therefore, tip angles orientated in space between 15° and 30° and a lateral force of 0.45 N were used. On each tooth, two cementum and two calculus points were identified and repeatedly analysed, resulting in a total of 40 points and 200 samples.

## Results

For all 2600 samples, cementum or calculus were correctly identified in 78% of the cases (all tip angles and lateral forces used, sensitivity:75%, specificity:82%) (Fig. 4a; Table 1).

#### Influence of lateral force

Within the same feature level, representing voltage differences for two fixed frequencies, the feature "lateral force" (0.2, 0.45, or 0.9 N) could be correctly discriminated in 62% of the experiments (Fig. 4b). Since certain forces (Fig. 4b) could not be attributed to certain surfaces (Fig. 4a), it can be concluded, that lateral force does not influence detection results of the presented method within the clinically relevant limits.

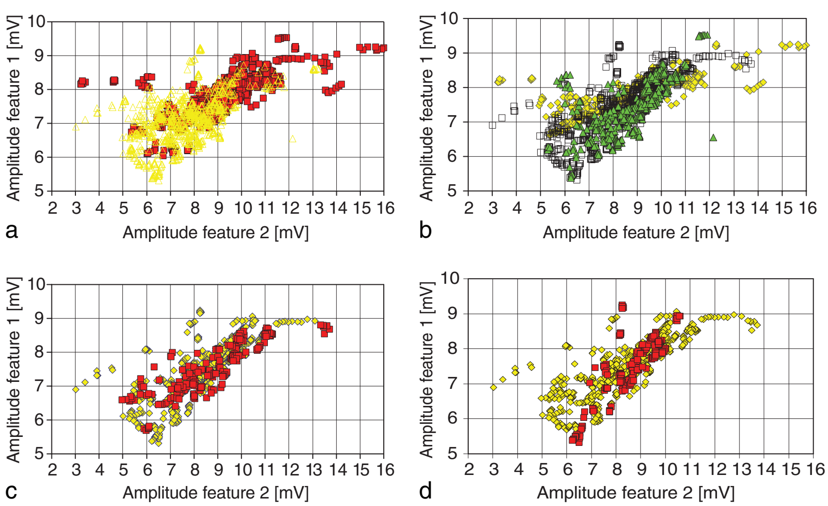


*Fig. 4.* Scatter plots of surface recognition results. (a) Display of an optimal discrimination of two surfaces of the learning set: the scatter clouds of calculus (yellow triangle) can be discriminated from cementum (red square). About 80% of the point-checks were properly assorted by the algorithm. (b) Distribution of the three lateral forces, which are included in the shown subset of the learning set. The influence of these working parameters is tested within the same feature level used for surface discrimination in (a) (yellow diamond: 0.2 N; white square: 0.45 N; green triangle: 0.9 N). Uniformly distributed scatter clouds demonstrate lack of influence of lateral forces on surface recognition results. (c) Distribution of the two tested extents of angle 1 under the same conditions as described in (b) (yellow diamond: 15°; red square: 45°) with a subset of the learning set (uniformly distributed scatter clouds). (d) Distribution of the two tested extents of angle 2 under the same conditions as described in (b) (yellow diamond: 15°; red square: 45°) with a subset of the learning set (uniformly distributed scatter clouds).

#### Influence of tip angles

The influence of different tip angles on surface discrimination results within the same feature level was tested and evaluated (Fig. 4a). The tested angle settings were equally distributed within the scatter and could not be attributed to a specific surface. The discrimination results of two different surfaces were 63% for the first (15–45°) and 57% for the second orientation of the angle (15–90°), and thus again slightly greater than if results were randomly distributed (Fig. 4c, d). It can be concluded that the system is able to distinguish the dental surfaces' cementum and calculus regardless of the tip angle within the demonstrated limits.

#### Unknown sample investigation

Having shown the system's ability to readily classify dental surfaces without the bias of parameters such as lateral force and tip angle, a total of 10 unknown teeth were studied under the influence of these parameters in vitro (angles: between 15° and 30° in both orientations, lateral forces 0.45 N). A total of 200 samples were tested (four defined calculus and cementum points per tooth, multiple testing), revealing a correct surface discrimination in 82% of the samples (sensitivity:88%; specificity:76%, Table 2).

## Discussion

In the present paper, we describe tests conducted with a modified piezoceramic ultrasonic scaler, which enables the discrimination of the dental surfaces' and substrates' "cementum" and "subgingival calculus".

Because of conclusions drawn from the work by Kocher and Flemmig regarding the relevance of tip angle and lateral force for the amount of tooth substance removal by an ultrasonic scaler (Kocher 1992, Flemmig et al. 1998a, b), the influence of these working parameters was investigated on the described discrimination method. Neither angle nor lateral force were shown to interfere with discrimination results within clinically relevant limits.

*Table 1*. Surface recognition using an ultrasound-based detection device (learning set results)

| | Test | | Sum |
|---|---|---|---|
| | positive | negative | |
| Calculus | 946 | 326 | 1272 |
| Cementum | 241 | 1087 | 1328 |
| Sum | | | 2600 |

*Table 2*. Surface recognition using an ultrasound-based detection device (results from unknown teeth)

| | Test | | Sum |
|---|---|---|---|
| | positive | negative | |
| Calculus | 85 | 11 | 96 |
| Cementum | 25 | 79 | 101 |
| Sum | | | 200 |

The method used for surface discrimination is based on fuzzy logic. Following the excitatory signals delivered by the ultrasonic scaler on the tooth surface, the system chooses certain oscillation signal frequencies out of all reflected oscillations based on a classification algorithm. These two frequencies (or features) may characteristically classify scatter clusters of their respective signal intensities (voltage amplitudes) and thereby discriminate the specific dental surfaces. According to Strackeljan, the scatter clusters of a variety of oscillation analyses often form a convex, elliptically coherent formation, which may be arbitrarily oriented within the level (Strackeljan 1993).

The principle of using a learning set to obtain the appropriate feature level is a standard method in smart pattern recognition technology (Worden & Staszewski 2003). We intentionally chose this procedure in order to test the system's ability to discriminate surfaces despite the interference of working parameters. Since the focus was on optimal sensitivity and specificity, the system was allowed to choose both features necessary for the learning set itself. Although the number of teeth tested as learning set was rather large, this does not predict the system's surface discrimination abilities on unknown teeth. The discrimination results were within the same magnitude for both sensitivity and specificity in unknown teeth.

The current precision of the present system is expressed as sensitivity of 74% and specificity of 82%. Sherman et al. (1990) identified a sensitivity of 24% and specificity of 88% for the tactile identification of subgingival calculus after subgingival scaling. However, the numbers are not easy to compare as there was no scaling before we tested our samples. Nevertheless, the low sensitivity associated with comparable specificity demonstrates the potential of ultrasonic-assisted calculus identification for root substance conservation compared with tactile testing, which obviously often fails to correctly identify calculus-free subgingival regions.

A study addressing direct comparisons of the surface discrimination properties of the new system and conventional hand-guided scaling is in progress. The advantage and aim of our ultrasonic-based system is the addition of an identification tool to the calculus-removing instrumentarium, which may eliminate information losses between identification and removal of calculus. Through more accurate calculus identification, a larger proportion of the remaining root may be preserved while areas of residual calculus should be decreased.

The only available system that currently combines calculus identification and feedback-driven removal is based on an Er:Yag laser, but to date, there is a lack of studies on its sensitivity and specificity (Schwarz et al. 2001).

Our system must now be tested regarding its stability over time in vitro as well as in vivo. Pre-clinical and clinical trials will be necessary to show the possible influence of non-standardized working parameters. Moreover, its resolution must be addressed in order to properly describe the system's discrimination properties.

In summary, we describe an ultrasound-based subgingival calculus identification system, which successfully implements fuzzy-logic-based algorithms for reliable dental surface discrimination. The system was shown to function within the range of standardized clinical working parameters. If subsequent tests are able to demonstrate these capabilities within clinical studies, the principle of ultrasound-based subgingival calculus identification could be integrated into calculus removal tools, which may thus become promising instruments for dentists and auxiliary personnel providing periodontal care.

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