J Clin Periodontol 2005; 32: 659–664 doi: 10.1111/j.1600-051X.2005.00733.x

Journal of Clinical Periodontology

A method for the validation of a new calculus detection system

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Meissner G, Oehme B, Strackeljan J, Kuhr A, Kocher T. A method for the validation of a new calculus detection system. J Clin Periodontol 2005; 32: 659–664. doi: 10.1111/j.1600-051X.2005.00733.x. © Blackwell Munksgaard, 2005.

Abstract

Background: Recently, pilot studies from our laboratory have shown that dental surfaces may be discriminated by the analysis of tip oscillations of an ultrasonic instrument, which possesses computerized calculus-detection features. For the evaluation of this smart detection system, its surface recognition qualities are of crucial importance. For in vivo studies, however, it proved to be difficult to verify the subgingival detection results. Therefore, it was necessary to develop a method, which allowed a reliable validation of surface recognition results of this new device. This evaluation method is described here.

Materials and Methods: Thirty extracted human teeth with subgingival calculus were embedded with plaster in a tray. To simulate subgingival pockets, dissected mucoperiostal porcine gingiva was sutured on the teeth. The thus-constructed dentition was mounted into a phantom head. A CCD-cam was attached with an intra-oral X-ray mount to the teeth. The dentist scanned the pockets with the ultrasonic instrument, simultaneously videotaping the scanning path of the supragingival portion of the insert. At the same time, the signals of the modified ultrasound scaler were recorded. After the tooth was removed from the phantom head, the tip of the ultrasound scaler could be repositioned using the video sequences. The actual insert location on calculus or cementum was assessed and compared with the computer signals. The whole procedure was repeated a second time and the reproducibility of the evaluation method was estimated.

Results: A κ value of 0.95 was attained for the evaluation method.

Conclusion: The present experimental design allows the in vitro repositioning of an automated dental instrument for the detection of subgingival surfaces on the tooth following an in vitro phantom-head video recording of its intra-oral scanning movements. This method will be used for the verification of in vivo results of a new ultrasound-based surface detection system.

Key words: experimental design; in vitro; in vivo; repositioning; subgingival scaling; ultrasonic scaler; video camera

Accepted for publication 26 October 2004

The authors are currently developing an ultrasound-based device for in-office use which is automatically able to detect subgingival calculus. In continuation of work by Strackeljan et al. (1997) and Kocher et al. (2000), this device has been tested and revised in pre-clinical studies (Meissner et al. 2005). Recent studies have demonstrated the system's smart surface detection ability under laboratory conditions (sensitivity 79%, specificity 77% for calculus discrimination), which was not affected by relevant handling parameters such as lateral application force or tip angle (Meissner et al. 2005). For the validation of in vivo results, it was necessary to develop a method which would allow the comparison of the in vivo subgingival root surface detection results and the objective in vitro results after extraction of the tooth. This proved to be rather difficult, since the subgingival surfaces to be classified were not directly visible. The subsequent surface classification by a dental expert was not an option, because not only is there a lack of sensitivity for tactile control (Sherman et al. 1990), but a substantial repositioning error also occurs if one changes from one instrument to another. It was therefore the aim of the present study to develop an objective method which allows the comparison of the in vivo detection with the objective in vitro results after tooth extraction.

Materials and Methods

Principle

A phantom head was used to simulate the clinical situation, in which subgingival root surfaces (''periodontal pocket'') were screened for calculus by an automated surface detection system, the efficiency of which was being tested. During ongoing subgingival screening movements with the ultrasonic insert, all positions of the supragingival (''visible'') portion of the insert as well as the results of the detection system were recorded in separate files on a computer hard disk. Both files were then synchronized and subsequently screened for situations in which the detection system had found calculus. By repositioning the instrument tip onto the then-extracted tooth, the efficiency of the surface detection system could be evaluated.

Experimental set-up

Following the approval of the local ethics committee, caries-free teeth with subgingival calculus, which were extracted for periodontal reasons, were debrided of large plaque and soft tissue residues. Between extraction and experimental use, teeth were stored in saline solution at 4°C for up to 3 weeks. Teeth were embedded in dental plaster up to their apical third, and the coronal part of the root surface was covered with porcine gingiva. The gingiva was fixed to the teeth with single sutures. This resulted in accessible and stable artificial gingival pockets. The selected teeth were embedded in a tray to mimic a close-to-nature situation for both jaws. These dentitions were then mounted into a phantom head (Kavo EWL, Biberach, Germany). The heads can be placed in an ordinary dental unit and possess a jointed jaw, which can be fixed in both the open and the closed position (Fig. 1).

A camera (ToUcam, Phillips, Hamburg, Germany) was attached to a modified intra-oral X-ray film mount (RWT Standard Filmhaltersystem, Kentzler-Kaschner Dental, Ellwangen, Germany). This set-up enabled standardized video recording of the supragingival (''visible'') path of the ultrasonic insert during the subgingival calculus detection movement. The clenched part of the film mount was covered with impression putty (Panasil, Kettenbach-Dental, Eschenburg, Germany), which fixes the tooth in a reproducible position and thereby allows the subsequent relocation of the insert's exact position on the ''extracted'' tooth. The distance between camera and tooth (and thus the picture size) could be adjusted and was marked on the X-ray mount. For each experiment, a new mount was used. To facilitate the exact reproduction of the insert's subgingival position on the root surface from the video sequences, reference rings were marked on the supragingival part of the tip. This marking corresponded to the pattern of a periodontal probe. In addition, a thin wire (referred to as ''3D needle'') was bent three times at 90° angles and fixed to the ultrasonic scaler 2 mm from the tip base. This wire could be positioned on both sides of the tip as needed (Fig. 2).

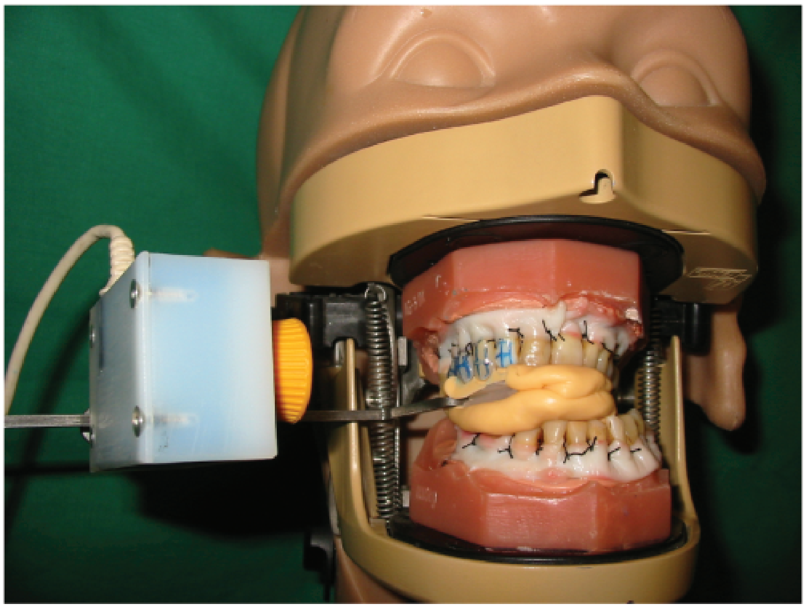

Fig. 1. Experimental set-up: phantom head and dentition preparation. Human teeth are embedded in dental plaster up to their apical third, and the coronal part of the root surface is covered with porcine gingiva. They are mounted in a phantom head and marked with vertical and horizontal lines. A video camera is attached onto an X-ray holder. Camera mount is fixed intra-orally with impression material.

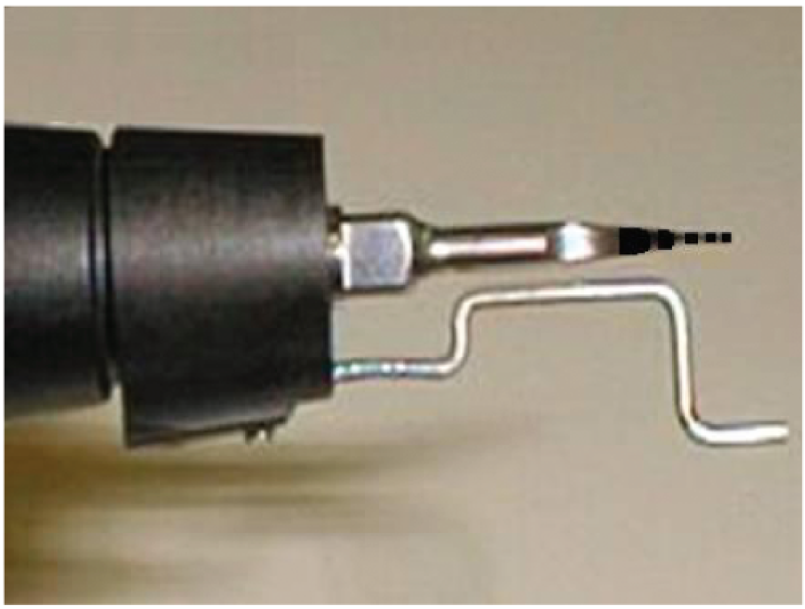

Fig. 2. Reference points for 3D reproduction. Instrument tip and 3D needle bearing millimetre markings.

Measuring

The principle of dental surface discrimination dates back to work by Strackeljan (1993), Strackeljan et al. (1997) and Kocher et al. (2000). The tip of a conventional dental ultrasound scaler

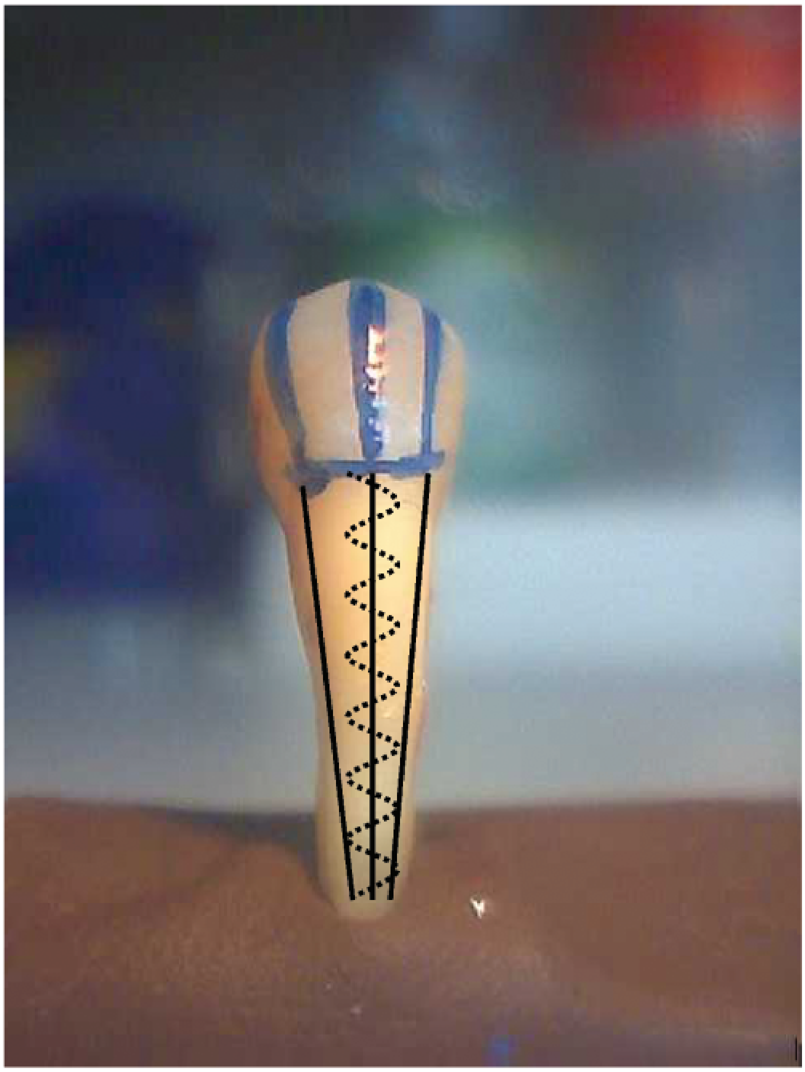

Fig. 3. Scanning path for root evaluation. Ideally, the instrument tip is moved along the lines marked on the enamel with an amplitude of 1 mm in a coronal to apical direction.

receives short, weak impulses, which transform into oscillations of the instruments tip of about 5 μm at the dental surface. The dental substrate itself is thereby stimulated to oscillate, the frequency being dependent on the substrate's topology, density, elasticity, and crystalline structure. These oscillations are transferred back to the piezoceramic disks, which transform the oscillations into voltages. This signal is evaluated with a computerized system, which contains a learning curve generated by a dental expert and uses fuzzy-logic algorithms. In this manner, the system generates information about substrate characteristics at the tip of the instrument and distinguishes between cementum, enamel, and calculus (Strackeljan 1993, Strackeljan et al. 1997, Meissner et al. 2005).

After fixation of camera, X-ray mount, and dentition in the closed jaw position within the phantom head, the camera was placed to face the sagittal axis of the interdental embrasure in a close-up view. The impression material was then removed from the phantom head and material covering the buccal site was removed. The course of the gingival margin, the vertical and the horizontal medians of the dental crown and, depending on the crown size, additional verticals within the mesial or distal part of the crown were marked using a waterproof pen (Fig. 1).

Characteristic signal patterns were elucidated after the start of the recordings for subsequent synchronization of video sequence and data stream. The buccal root surface was systematically scanned in a coronal to apical direction, including the mesiobuccal and distobuccal approximal sites, with an amplitude of about 1 mm (Fig. 3). Subsequently, the scanned teeth were ''extracted'' from the phantom head and adhesively fixed in their position in the impression material, thus exactly mirroring their intra-oral position (Fig. 4). The described procedure was repeated on all teeth in the study.

Data analysis

For surface discrimination, the data pool was first scanned for signals recorded for calculus by the evaluation algorithm. The video sequences corresponding to these signals, containing information about the exact tip and instrument positions, were extracted from the video file. After the camera was exactly positioned onto the extra-oral impression, its resulting live image was coupled to the extracted sequences from the video file using video software. Thus, using the reference points on the tip as well as on the 3D needle, the intra-oral position of both the instrument and the tip could be exactly matched extra-orally with the entire root exposed. The final position of the instrument and the tip for each situation was documented on single digital photographs (Fig. 5a, b). The position of the distal tip on the root surface was evaluated using magnifying eyeglasses (2.5 ×, Carl Zeiss, Jena, Germany). After repositioning, if the given spot of calculus was found again within an area of 1 mm diameter, the measurement was classified as correct for the following reasons. The video stream recorded 15 frames per second, and the estimated speed of tip movement for several common situations was 6 mm/s (0.4 mm between two pictures, which are 66 ms apart). Since the software of the surface detection system was able to record data only every 300 ms, the tip could have moved 1.8 mm between individual measuring points given the data above, which justifies a distance of 0.9 mm between the tip position and the closest calculus spot to be taken as a correct identification.

Data were separately evaluated for mesiobuccal, midbuccal, and distobuccal sites. Even if there were several signals from the same spot (because the insert was moved over it more than once), this spot was counted only once. The sequence given above quantifies all correctly classified calculus as well as

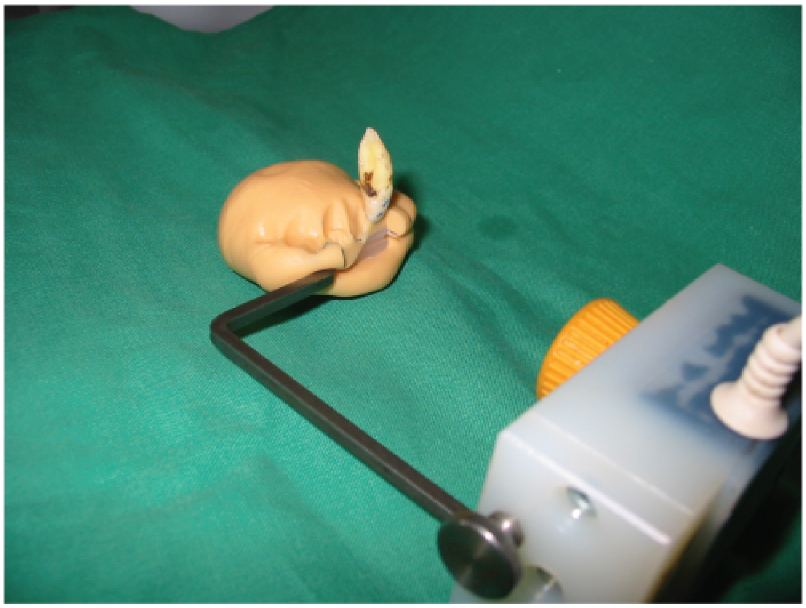

Fig. 4. Video camera and tooth impression. The impression is prepared for the repositioning of the teeth after ''extraction''.

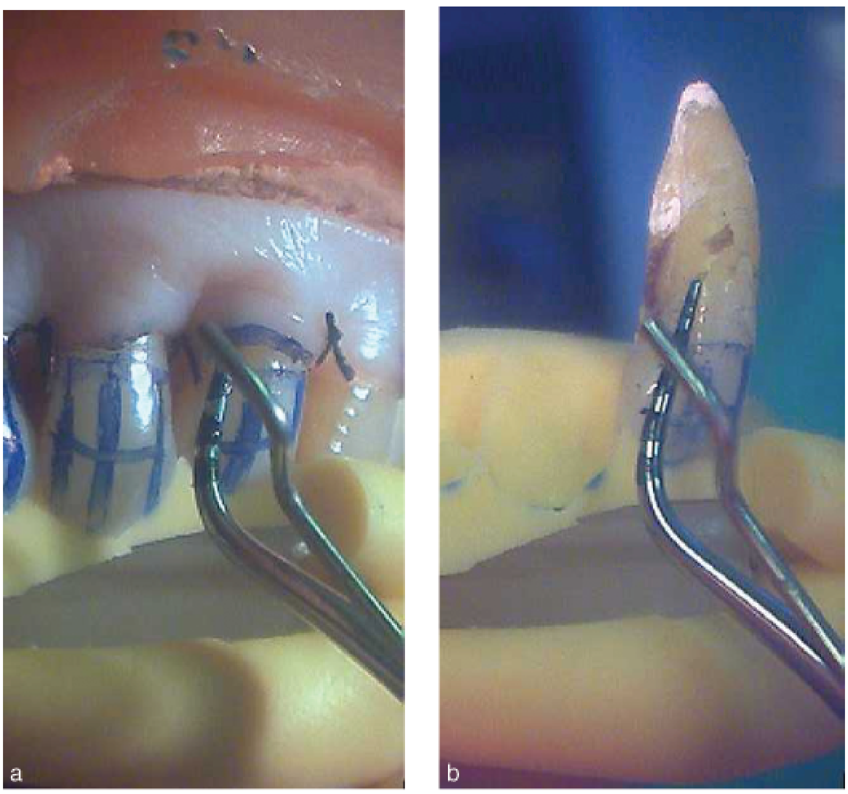

Fig. 5. Simultaneous display of intra-oral situation and extra-oral reproduction. The ''intra-oral'' position of the insert during the surface scan (a) is reproduced under direct visual control after the ''extraction'' of the tooth and its fixation in the impression (b).

all incorrectly classified root surfaces. In the case of rather small spots of calculus, it was not possible to tell whether or not the tip had touched it. These regions were referred to as neutral, and thus did not contribute to the final evaluation. Areas with large pieces of calculus definitely had to be assigned to the calculus group. Surfaces devoid of calculus had to appear as calculus-free during continuous scanning, in which case it was classified correctly as negative. A schematic flow chart of the complete analysis is given in Fig. 6.

Results

The matching procedure of 30 teeth was evaluated twice. A κ value of 0.95 was found for twofold comparison of the ''in vivo'' detection results with the ''objective in vitro'' results after tooth ''extraction''.

Discussion

In this paper, we describe a method to evaluate the in vivo effectiveness of a newly developed smart surface detection system. Experimental design and analysis methodology are presented.

There is a variety of calculus detection systems on the market, such as Detectar® (Ultradent Products, South Jordan, UT, USA), Keylaser II® (KaVo Dental GmbH & Co. KG, Biberach, Germany), and Dental Endoscope (Stambaugh et al. 2002, Dentalview Co., Irvine, CA, USA). However, to our knowledge, all devices lack published studies regarding their effectiveness for subgingival calculus detection. Therefore, our system cannot be compared with any of them. An alternative procedure to establish the system's efficiency could have been the comparison of signals before and during a flap operation. However, the technical problems inherent to relocating an instrument are even greater during surgery than in our selected approach.

Because of its classical instrument–tip combination, the chosen design of the detection system implies scanning accuracy similar to that of manual scaling. Debridement may be incomplete at the bottom of the pocket, in invaginations, along the line angle, and in furcations (Waerhaug 1978, 1980). Incomplete surface scanning may be due either to limited access space or problematic guidance of the instrument. Thus, the ideal scanning movement (given in Fig. 3) is in fact rarely applied to an entire root. As a result, calculus might be overlooked without blaming the detection method. This systematic error cannot be ruled out for upcoming clinical applications and studies.

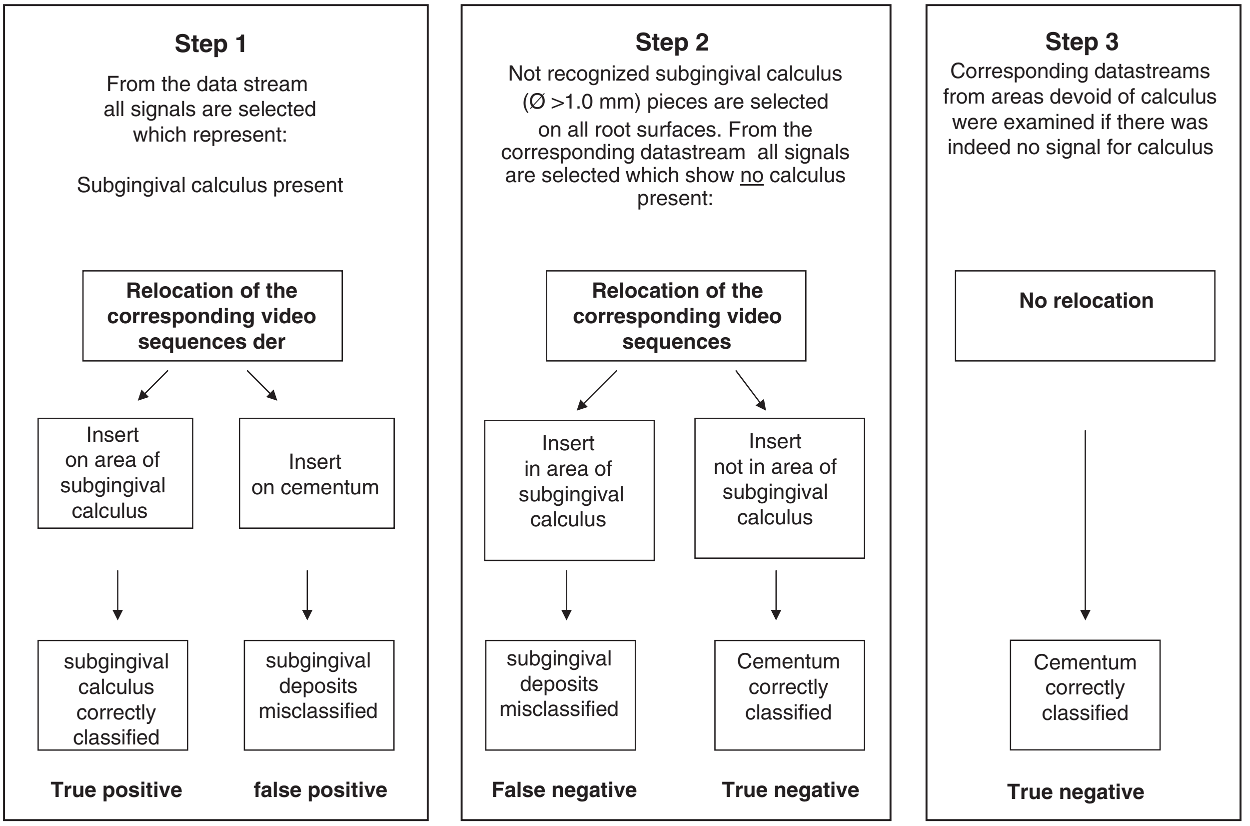

Fig. 6. Flow chart of decision process for presence or absence of calculus on root surface.

The ideal reproduction of the exact position of an object in space would require video sequences from two different cameras rather than only one and the 3D needle. We chose the latter option for practical reasons: a second camera would have called for a second camera-mount perpendicular to the first one, thereby substantially reducing working room while adding weight and potential error sources to the set-up. While technical and software problems might have been solvable, the evaluation system might have dominated and thus influenced the actual scaling process. An automated analysis of the video sequences is currently being realized for the set-up.

The 3D-repositioning problem was addressed by Kinuta et al. (2003) for the evaluation of jaw movements by adding an extra-oral mirror to a single camera, which was not appropriate for our set-up for the same reasons a second camera was not.

The calculation of sensitivity and specificity proved to be rather difficult for scanning dental surfaces, because it cannot be stated how often the surface was touched; each time the instrument touches the surface the probability of calculus detection is increased. Thus, the calculated data may only estimate the accuracy of the test system based on the observed calculus.

In summary, this paper presents a method for the evaluation of the intra-oral effectiveness of an ultrasound-based dental surface discrimination system. This is substantially different from in vitro studies under visual control conducted previously, i.e., by Folwaczny et al. (2002) as well as our own group (Meissner et al. 2005). The method described is not only applicable to our own system but may also help to judge other systems in vivo.

Acknowledgements

The authors are indebted to Konrad Meissner, Department of Pharmacology, Greifswald, for helpful discussions during the preparation of the manuscript. This work was supported by grants from the German Federal Ministry of Education and Research to T. K. and to J. S. (BMBF 01 EZ 0025, 01 EZ 0026).

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