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Abstract. Detecting dental calculus is clinically challenging in dentistry. This study used typodonts with extracted premolar and molar teeth and simulated gingival tissue to compare the performance of differential reflectometry and periodontal probing. A total of 30 extracted teeth were set in an anatomical configuration in stone to create three typodonts. Clear polyvinyl siloxane impression material was placed to replicate the periodontal soft tissues. Pocket depths ranged from 10 to 15 mm. The three models were placed in a phantom head, and an experienced dentist assessed the presence of subgingival calculus first using the DetecTar (differential reflectometry) and then a periodontal probe. Scores from these two different methods were compared to the gold standard (direct examination of the root surface using 20× magnification) to determine the accuracy and reproducibility. Differential reflectometry was more accurate than tactile assessment (79% versus 60%), and its reproducibility was also higher (Cohen kappa 0.54 versus 0.39). Both methods performed better on single rooted premolar teeth than on multi-rooted teeth. These laboratory results indicate that differential reflectometry allows more accurate and reproducible detection of subgingival calculus than conventional probing, and supports its use for supplementing traditional periodontal examination methods in dental practice. © 2012 Society of Photo-Optical Instrumentation Engineers (SPIE). [DOI: 10.1117/1.JBO.17.10.106017]

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1 Introduction

Correct identification of subgingival deposits is important for assessing the periodontal status and for quality control during periodontal debridement. Calculus deposits on the root surface are both porous and rough,¹ with variable numbers of microorganisms and calcium phosphate compounds. Although certain species of gram negative anaerobic bacteria are recognized as the primary cause of periodontitis, calculus contributes to the disease process by enhancing the subgingival biofilm and by retaining and releasing microbial products such as endotoxins.^{2,3} Hence, effective removal of subgingival calculus is a cornerstone of periodontal therapy.^{4,5} Whereas supragingival calculus can be easily removed without great difficulty, deposits of subgingival calculus are difficult to detect.^{6,7}

The conventional method for detecting subgingival calculus relies on the tactile feedback gained from periodontal probing.^{7,8} This method is prone to false negatives (from burnished calculus, which is smooth to touch) and false positives (from instrument-induced irregularities on the root surface).⁷ To augment periodontal probing, a range of other methods for calculus detection have been suggested, including ultrasound,⁹ intra-oral endoscopy,¹⁰ and radiography.¹¹ Sonic systems have been introduced only recently but they show promising performance in laboratory trials, with an accuracy of 80%⁹ and a high inter-examiner reliability.¹² Direct imaging using solid lenses attached to intra-oral endoscopic cameras is difficult as the optical components are fragile, delicate, and expensive.¹⁰ Intra-oral radiography is of value only for identifying large deposits of

subgingival calculus. For approximal surfaces, this technique lacks sensitivity. Radiography cannot be used to find deposits with small surface areas or low thickness areas such as those burnished onto the root surface by blunt hand instruments. A further disadvantage is the attendant risk of ionizing radiation.¹¹

Differential reflectometry is a promising technology for discriminating between two materials, such as between subgingival calculus and cementum. The device directs light onto the root surface. The spectra of intensity of reflected light is compared with the previously stored spectra using a processing algorithm. The DetecTar device (Ultradent, Salt Lake City, Utah) uses a 635 nm visible red light emitting diode (LED) to deliver light into a probe tip, which has similar dimensions to a conventional periodontal probe. Following collection of reflected light, a green flashing indicator lamp and an audible tone indicate the presence of subgingival deposits as a binary result, either yes or no. It is claimed that the performance of the device is unaffected by ambient fluids (blood, saliva, and water), and the system is able to detect deposits as small as 0.1 mm in size.¹³ Results of one *in vitro* evaluation have been published;¹³ however, the examination method used neither involved mounted teeth with replication of soft tissues nor there was a comparison with a conventional periodontal probe undertaken.¹³ One small clinical study involving the examination of teeth from a total of eight patients has been undertaken;¹⁴ however, this neither reported sensitivity or specificity values nor were data presented on the types of teeth examined and the extent of pocketing present at the time of the examination. A recent review of calculus detection methods¹⁵ concluded that the utility of this spectro-optical approach had yet to be examined thoroughly.

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In light of the above, the present study was undertaken to compare the performance of differential reflectometry and periodontal probing for the detection of subgingival calculus in a laboratory replication using extracted human posterior teeth set up in a phantom head with soft-tissue replication to simulate the clinical setting.

2 Materials and Methods

2.1 Typodont Model Preparation

A total of 30 extracted teeth (18 molars and 12 premolars), which had been stored in saturated thymol solution, were selected from a large collection so that there would be an equal distribution of sites on the roots with and without subgingival calculus. No carious lesions or restorations were present on the root surfaces. The teeth had been collected by forceps extraction from patients with periodontitis, with the approval of the institutional ethics committee. Root surfaces were washed and cleaned with a toothbrush under tap water. The most apical 2 mm region, which would later be used to mount the teeth, was scaled with a Vector ultrasonic scaler to eliminate any traces of subgingival calculus. The apical 2 mm of each root was mounted into one of three stone blocks, which were formed using a mold to allow the typodont to be later inserted into a Frasco phantom head. Each model had 10 teeth (4 premolars and 6 molars) with 10 to 15 mm of the coronal and middle thirds of the roots exposed. After application of artificial saliva (Oralube) as a separating medium, the exposed root surfaces were covered with a clear medium body polyvinyl siloxane impression material (Monet Clearbite2). Once set, a No. 15 surgical blade was used to trim the set impression material to replicate the anatomical contours of gingival tissue.

2.2 Scoring of Calculus

The typodont models were hydrated in water, covered with a thin layer of Oralube, and then inserted into a phantom head, which was positioned to be at the level of the operator's elbow. A conventional halogen dental operating light was used. Each tooth was scored at 8 sites per tooth (the four line angles and the four intervening middle region), giving a total of 240 sites per model. All teeth were first examined using the DetecTar, immediately after calibration of the unit. According to the manufacturer's instructions, water was sprayed into the gingival crevice immediately before inserting the tip of the instrument, which was moved slowly across the root surface. A continuous beeping tone signified a positive score for subgingival calculus. After recording the scores for all 240 sites, the teeth were then reexamined using a number 14 William's periodontal probe and the scores were recorded on a separate sheet so that there was no access to the initial recordings. To assess reproducibility, each cast was rescored on the following day and again after 14 days.

2.3 Gold Standard

The impression material was removed from each model, and the root surfaces photographed and viewed at a final magnification of 20 \times using a digital camera (Coolpix 995, Nikon, Tokyo, Japan) fitted to an Olympus U-PMTVC stereoscopic microscope which was in turn connected to a video monitor.

2.4 Data Analysis

For both the DetecTar and periodontal probe examinations, the scores for each of the 240 surfaces were characterized as either calculus present or calculus absent. Using a grid showing the data from the gold standard (which had calculus at 118 sites), each score was then assigned to being a true or false positive or a true or false negative. The sensitivity, specificity, and accuracy for each method were then calculated. Differences in performance between the DetecTar and probe were assessed using two-tailed paired *T* tests.

The Cohen kappa statistic was used to evaluate intra-examiner reproducibility by comparing the data from day 1, day 2, and day 14 assessments. The kappa scores were designated as fair agreement (0.21 to 0.4), moderate agreement (0.41 to 0.6), substantial agreement (0.61 to 0.8), and almost perfect agreement (0.81 to 1.0).

3 Results

The mean values for sensitivity, specificity, and accuracy were significantly higher for DetecTar than for periodontal probing ($P < 0.02$; $P < 0.005$, and $P < 0.005$, respectively) (Table 1). There were small variations in outcomes between the three examinations (days 1, 2, and 14), but in all cases the DetecTar showed the better performance of the two methods (Table 1).

There was a significant effect of tooth type on the performance of both diagnostic methods (Table 2). The DetecTar gave a higher mean specificity and accuracy for single-rooted teeth than for multirooted teeth, but sensitivity was lower for single rooted teeth. Periodontal probing had better sensitivity, specificity, and accuracy for single-rooted teeth than for multi-rooted teeth.

The optical method was more reproducible of the two, when comparing scores obtained between the three different recording days ($P < 0.005$) (Table 3). The mean Cohen kappa score of 0.54 was rated as "moderate" as it lies between 0.41 and

Table 1 Sensitivity, specificity, and accuracy of DetecTar and PRO 14W compared on 3 different days (days 1, 2, and 14).

| | DetecTar (%) | Probe (%) |
|----------------------|--------------|-----------|
| Sensitivity (day 1) | 74.6 | 50.8 |
| Sensitivity (day 2) | 75.4 | 56.8 |
| Sensitivity (day 14) | 75.4 | 47.5 |
| Mean sensitivity | 75.1 | 51.7 |
| Specificity (day 1) | 77.0 | 63.1 |
| Specificity (day 2) | 88.5 | 73.0 |
| Specificity (day 14) | 82.8 | 67.2 |
| Mean specificity | 83.0 | 67.8 |
| Accuracy (day 1) | 75.8 | 57.0 |
| Accuracy (day 2) | 82.0 | 64.9 |
| Accuracy (day 14) | 79.1 | 57.4 |
| Mean accuracy | 79.0 | 60 |

Table 2 Effect of tooth type on detection.

| | | Single-rooted teeth (%) | Multirrooted teeth (%) |
|----------|------------------|-------------------------|------------------------|
| DetecTar | Mean sensitivity | 67.9 | 77.2 |
| | Mean specificity | 94.2 | 75.9 |
| | Mean accuracy | 81.1 | 76.6 |
| Probe | Mean sensitivity | 60.2 | 49.3 |
| | Mean specificity | 73.2 | 64.5 |
| | Mean accuracy | 66.7 | 56.9 |

Table 3 Intra-examiner reproducibility.

| Reproducibility Cohen kappa | DetecTar | Probe |
|-----------------------------|----------|-------|
| K _{1,2} | 0.56 | 0.46 |
| K _{1,14} | 0.47 | 0.27 |
| K _{2,14} | 0.6 | 0.43 |
| Mean Cohen kappa | 0.54 | 0.39 |

Note: Data show agreement between scores obtained at days 1, 2 and 14.

0.60, whereas periodontal probing was rated as showing “fair” agreement between repeat assessments.

4 Discussion

This study adds to previous investigations of differential reflectometry by showing that the method is superior in terms of accuracy and reproducibility to periodontal probing. Our study employed an examiner, who was experienced in using this method. In a preliminary investigation, we assessed the performance of an inexperienced operator (a fifth-year dental student), who also scored the same 8 sites per tooth on the same series of models as the experienced examiner used in the current study. The student performance was less than the experienced operator (sensitivity 62.7% versus 74.6%, specificity 73.0% versus 77%, and overall accuracy 67.9% versus 75.8%), with modest inter-examiner reliability (Cohen kappa 0.32). This suggests that performance with differential reflectometry is influenced by clinical experience; however, this aspect requires further investigation.

The results of the present study show an effect of root configuration on the performance of both methods. By having only 2 mm of the root in the mounting base, the pocket depths were large and the majority of the root surface was available for examination. The ability of the two methods to assess a particular site was affected by the ability to access the root surface, a process limited by the impression material and by the normal clinical factors of tooth position and root morphology.

Our methodological approach involved first examining sites with the DetecTar rather than with the probe since its flexible tip was considered less likely to dislodge small calculus deposits from the root surface than the more rigid periodontal probe.

We did not alternate the methods to reduce the possibility of introducing errors from using the periodontal probe as the first in the sequence.

A previous investigation compared the performance of differential reflectometry with tactile examination, and gave positive results; however, all the patients in this study suffered from advanced periodontitis.¹⁴ The teeth examined were hopeless, destined for extraction, including an unknown number of anterior teeth and other single-rooted teeth, which are less challenging to examine. The presence of recession was a further unreported variable in that investigation. In the present study, a worst-case scenario was deliberately used, with the simulated gingival tissues extending to 1 to 2 mm above the cemento-enamel junction, giving pocket depths of 10 to 15 mm, and allowing only a shallow contact angle between the tips of the probes and the root surfaces. Nevertheless, the DetecTar method proved to be better than periodontal probing for the detection of subgingival calculus.

A further point of interest is that the present results showing an accuracy of $79 \pm 3.1\%$ for DetecTar are similar to the values reported in a previous laboratory study of extracted teeth (82.5%) when the probe was used at angles between 0 deg and 10 deg.¹³ The issue of contact angle is critical for the emission and collection of reflected and scattered light. This factor explains part of explanation for a reduced performance for multirooted teeth, where furcations are difficult to access and where the contact angles will be lower. As the contact angle increases, the sensitivity and specificity will improve as the light scatters less,¹³ thus, a 90-deg angulation to the root surface will achieve the most accurate outcomes.

Based on these considerations, a DetecTar probe tip with a single reflective facet that functions as a “periscope” may achieve better optical performance as it would ensure that near to the ideal 90-deg angulation is achieved. A downside of this approach is that the correct positioning of the tip through rotation would be needed, making the clinical technique more sensitive to operator skill and experience. Using a conical tip would overcome this problem of angulation. Various designs for optical diagnostic tips that have lateral light emission and collection capabilities have been described;^{16,17} however, the system would need to be recalibrated to deal with the fact that a conical tip would also collect light from the adjacent soft tissues.

5 Conclusion

The results of this study indicate that the differential reflectometry method has superior performance in an *in vitro* setting, which is more challenging in terms of access to the root surface than the clinical situation. The method has better accuracy and higher reproducibility than periodontal probing. The lower performance of the differential reflectometry method when for diagnosis of subgingival deposits of calculus on multirooted teeth could be addressed in part using different tip designs. Further laboratory and clinical studies are needed to test such a prediction.

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