Chapter 4

Optical Diagnostics to Improve Periodontal Diagnosis and Treatment

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Abstract

The performance of clinicians undertaking periodontal assessment or periodontal therapy can be improved by using optical methods as adjuncts to visual inspection and periodontal probing. Subtle changes that occur over time in periodontal tissues that are below the detection limit of visual examination or periodontal probing can be found and tracked accurately over time using 3D imaging, fluorescence spectroscopy, and optical coherence tomography. During debridement of teeth and dental implants, the effective removal of subgingival microbial biofilms and dental calculus deposits can be enhanced using magnifying loupes and operating microscopes and by novel methods based on the interactions of light with bacterial deposits, such as differential reflectometry and light-induced fluorescence. While such techniques can also be used using initial case assessment, their primary purpose is for checking debridement procedures, since the point when bacterial deposits are no longer present represents an endpoint for treatment. The concept of real-time feedback has been developed, using fluorescence readings to control the removal of deposits. Overall, optical methods can support traditional periodontal diagnosis and improve treatment planning and clinical periodontal care.

Keywords: periodontal diagnosis, fluorescence imaging, laser-induced fluorescence, porphyrins, fluorescence spectroscopy, differential reflectometry, optical coherence tomography

1. Introduction

The standard approaches that are used in periodontal diagnosis are less than perfect in terms of their clinical performance. Tactile assessment of periodontal soft tissues and root surfaces using periodontal probes of various types provides useful information, but the results are influenced by the design of the probe, the probing force applied, and the extent of inflammation in the tissue

Technology	Clinical applications
3D Optical scanning	Monitor graft sites
	Track recession over time
	Track gingival enlargement over time
Optical spectroscopy	Distinguish periodontitis sites from gingivitis
	Distinguish peri-implantitis from peri-implant mucositis
OCT	All of the above applications, plus the following:
	Measure the thickness of the gingival tissues
	Assess biological width
	Detect deposits of subgingival calculus
	Early detection of bone loss and bone formation

Table 1. Applications of optical diagnostic systems for periodontal patient assessment.

[1–3]. It is not possible to relate periodontal probing measurements to precise histological measurements of actual sulcus or pocket depths. During clinical probing, the periodontal tissues are compressed and displaced, and the junctional epithelium may or may not be perforated [4, 5].

There are also issues with being able to reliably detect subgingival calculus on root surfaces using tactile feedback from a periodontal probe [6, 7]. While supragingival calculus is easily seen, deposits of subgingival calculus are hidden from view and are difficult to detect [8, 9].

Given these limitations, there has been long standing interest in additional methods that could be used to augment traditional periodontal clinical examination (**Table 1**). Using optical methods has the major advantage of patient safety, since light with low photon energy is nonionizing (unlike dental X-rays). This chapter summarizes the use of optical diagnostic devices in periodontics, for the assessment of periodontal soft or hard tissues (including the subgingival surfaces of tooth roots and dental implants), and discusses the use of such devices to better inform the clinician during subgingival debridement. By better monitoring the progress of debridement during a treatment session, the frequency of iatrogenic problems such as instrument-induced damage to the treated surfaces and excessive removal of root structure should be reduced.

2. Assessment of periodontal tissues at baseline and recall periodontal examinations

2.1. Three dimensional optical scanning

Intra-oral 3D scanners that are used to scan tooth preparation for CAD-CAM restorations also record exquisite details of the form and color of the periodontal soft tissues. Periodontal parameters of interest that can be measured from such scans include the height and width of

areas of recession, the changes in contours of sites that have undergone grafting or augmentation procedures, and the progressive development of areas of gingival enlargement. By comparing measurements from 3D scans over time, the clinician can track subtle changes in soft tissue architecture between dental appointments [10, 11].

Studies comparing clinical measurements with digital measurements taken from intra-oral 3D scans, or from 3D scans of study models, have shown that digital measurements taken from 3D scans are more reliable than those taken in the clinical measurements [12]. A series of 3D scans will document changes in tissue volume and color over time, making it an ideal way to track outcomes of grafting procedures. One can predict that data from 3D intra-oral scans will become the new gold standard in periodontal practice for monitoring patients being treated surgically for muco-gingival problems or who have undergone surgery for gingival overgrowth. It has been suggested that high definition color 3D intra-oral scans could even eventually replace both intraoral photographs and study models. This trend has already been seen in orthodontics [13].

2.2. Optical spectroscopy using near-infrared light

This optical method is a simple, yet powerful addition to the diagnostic armamentarium of periodontal practice. It has been used for many years in medicine and agriculture for the noninvasive assessment of the composition of biological tissues. In periodontics, a portable spectrometer can be used to measure blood flow and inflammation in the periodontal tissues. Optical spectroscopy using near-infrared light provides information on tissue oxygenation, the various forms of hemoglobin present, and tissue edema. There are higher concentrations of deoxyhemoglobin (and thus less tissue oxygenation) at sites of periodontitis, compared to sites with gingivitis or healthy sites [14]. Thus, in any one patient, this method can be used to discriminate between sites with periodontitis, as opposed to sites with gingivitis [15–17]. The same approach can be used to monitor peri-implant disease, because tissue oxygenation at peri-implantitis sites is lower than at healthy sites [18, 19], even when the patient is a smoker.

2.3. Optical coherence tomography

For detailed examination of periodontal hard and soft tissues, optical coherence tomography (OCT) is superior to other approaches because it can provide the three dimensional tissue contour information of an intra-oral 3D scan, as well as cross-sectional images at high resolution that are comparable to histology.

The use of OCT systems for imaging of hard and soft tissues in the oral cavity has been investigated for more than 20 years. Dental OCT systems work on the same principles as their medical OCT counterparts, such as the systems used in ophthalmology, but they require specially designed delivery systems for use in the confined environment of the mouth. The light source in a typical OCT system is a near infrared diode laser that emits light with a wavelength between 850 and 1310 nm. This light penetrates well through teeth, bone, and soft tissues [20]. OCT images have very high resolution (1–15 μm), with a level of detail that surpasses other clinical imaging systems, including ultrasound and radiography [20, 21].

The first dental OCT system suitable for intra-oral use was built in 1998, and was used to obtain high resolution images of periodontal tissues in the laboratory setting. The OCT images revealed details of the cemento-enamel junction and the interface between the teeth and the gingival tissues [21, 22]. When used in the clinical setting, this OCT system provided visual recordings of periodontal tissue contour, sulcular depth, and connective tissue attachment [23, 24], and provided a cross-sectional "optical biopsy" of tissue, up to a depth of 3 mm from the surface [25, 26]. In later OCT systems, the penetration was increased to 4 mm by using longer wavelengths of light (up to 1325 nm) [27].

Using OCT, the thickness of the gingival tissues and the constituent epithelial and connective tissues can be measured, as well as the biological width and the position of alveolar bone crest [28], and the location of any deposits of subgingival calculus, to a high resolution that surpasses traditional methods [29, 30].

The high resolution of OCT allows cellular level details to be seen, including subtle changes in the width of the periodontal ligament, or in the depth of the gingival sulcus [31–34]. Early detection of bone loss is possible. OCT can also be used for checking debridement, and for monitoring the response to periodontal treatment [35].

As the technology for deploying OCT systems into intra-oral handpieces improves, it will become more accessible for use in clinical dental practice as a noninvasive method for imaging the microstructural detail of periodontal tissues *in situ*. Over time, it could replace some current applications of radiology or other diagnostic approaches, as has occurred in some fields of medicine [36].

3. Optical devices for assessing subgingival deposits and monitoring their removal during periodontal debridement

3.1. Conventional optical magnification devices

During closed periodontal debridement or open debridement, improved visibility for ensuring that all deposits are removed properly can be gained using optical magnifying devices, such as operating microscopes and telescopic loupes. Operating microscopes are particularly useful during surgical periodontal therapy, because the lighting is coaxial, giving a well-illuminated site [37–39]. In contemporary specialist periodontal practice, telescopic loupes are more popular than operating microscopes [40].

Fiber optic periodontal endoscopes ("perio-scopes") are an important further part of the armamentarium. These devices are a modification of medical endoscope technology, and use a small rigid optical element or a fixed, fused fiber optic bundle. In both cases, the tip is less than 1 mm in diameter, so that it can be fitted inside a periodontal pocket with only minimal reflection of the adjacent soft tissues. The images from a perio-scope are displayed on a video monitor. In some perio-scopes, a dual lumen allows irrigation of the periodontal environment to improve the clarity of the field that is being viewed [41].

Because effective debridement is difficult in deep pockets and furcation areas [42], perio-scopes are particularly useful for monitoring the removal of subgingival deposits in such

locations [41, 43, 44]. Perio-scope images will also show scratches and gouges of the root surface created by instruments. These types of surface irregularities make tactile assessment of root surfaces challenging, as the roughness could be misinterpreted as indicating that calculus deposits are still present [41]. The benefits of using a perio-scope have been shown in clinical studies using teeth destined for removal during a complete dental clearance. In these studies, the quality of subgingival debridement of interproximal root surfaces was improved when perio-scopes were used, with a significantly reduced area of residual deposits compared to conventional debridement [43, 44].

To use a perio-scope effectively, the clinician has to learn how to position and manipulate the imaging tip while viewing the image [43, 44]. Interpreting the image requires training, as the typically dark color of subgingival calculus may be less apparent due to variations in lighting as the perio-scope tip approaches the surface of the calculus. The clinician must use considerable care when moving the perio-scope tip, to prevent damage to the optical components. In some cases, using gas shielding or irrigation during viewing is necessary to gain a clear image and overcome problems of fogging and fouling of the optics during use [45].

3.2. Differential reflectometry

In this optical approach, the root surface is illuminated through a narrow optical tip that is similar in size to a periodontal probe. Two light sources are used, typically visible red light (623 nm) and near infrared light (880 nm). The spectral distribution of the reflected light is analyzed to detect the presence of calculus. The readout indicates when calculus is present, via an audible alert tone. Differential reflectometry is more accurate than tactile assessment for assessing deposits of subgingival calculus on the root surfaces of teeth than a periodontal probe [46].

3.3. Laser fluorescence using visible red light and the DIAGNOdent™

As a means to detect subgingival deposits of calculus remaining after debridement, laser-induced fluorescence (LF) seems ideal, since it can provide a numerical assessment of the volume of the remaining deposits in real time, using an optical probe that is similar in shape to a periodontal probe. LF readings are highly reproducible over time. When using LF at intervals during debridement, LF scores will reduce as calculus is removed. When the LF score reaches the threshold for a healthy root surface, the clinician has reached the endpoint of complete removal of calculus.

When LF is undertaken using 655 nm visible red laser light as the excitation source, the remaining deposits of subgingival calculus emit strong near infrared fluorescence at 720 nm, but these do not occur with sound root surfaces [47]. Using visible red excitation means that the light penetrates through blood and is not masked by any bleeding from the site [48].

In the DIAGNOdent™ Classic and the DIAGNOdent™ Pen (KaVo, Biberach, Germany), the 655 nm light is generated by an In:Ga:As:P diode laser. This light then elicits the near infrared fluorescence from the bacterial porphyrins contained within the subgingival calculus deposits [49]. The optical pathway is designed so that reflected light and any ambient light (from daylight and operatory lighting) is removed using a high-pass (680 nm cutoff) filter. The longer

near infrared wavelengths of light pass through the filter to reach a time-gated detector. Finally, the intensity of the fluorescent radiation is presented to the user as a digital value (on a 0–99 scale). Once the LF reading has reduced to the baseline value for cementum or healthy dentine (e.g. an LF score of 7), no further calculus deposits remain, and the endpoint for instrumentation has been reached [50, 51]. Key clinical aspects of using LF devices are summarized in **Table 2** below.

In terms of overall performance, LF is superior to both differential reflectometry and conventional periodontal probing for detecting subgingival calculus [52, 53]. The usefulness of LF has led to the concept of fluorescence-controlled ablation of subgingival bacterial deposits. The debridement component is undertaken using a pulsed Er:YAG laser which generates middle infrared light that is strongly absorbed in water [54]. The Er:YAG laser gives effective calculus removal when low energy pulses are applied onto the root surface at a shallow angle [55–57]. In addition to physically removing calculus and biofilms, the Er:YAG laser pulses have little or no effect on the surfaces of teeth or dental implants. The laser pulses inactivate or vaporize bacteria, and reduce the biological activity of bacterial endotoxins [58–60].

In the KEY3™ laser system (KaVo, Biberach, Germany), the firing of Er:YAG laser pulses is controlled using the LF readings, which provide the feedback for the "autopilot". When used with LF control, the laser debridement process causes no adverse thermal effects on root surfaces [59, 60]. The treated root surfaces are biocompatible, and new cementum formation and the formation of new connective tissue attachment can occur following treatment [61]. Clinical studies of root surface instrumentation have shown that superior removal of subgingival calculus occurs, but without any undesirable surface alterations caused by instrumentation [62, 63]. This means that fluorescence-controlled Er:YAG laser debridement of root surfaces is a direct but superior replacement for conventional closed periodontal debridement undertaken with hand or ultrasonic instruments [64–66].

The same concepts of LF guidance can be applied to subgingival implant surfaces. Er:YAG laser treatment guided by LF removes microbial contamination. The lased surface is biocompatible, and supports adhesion and growth of osteoblasts [67, 68].

When using LF, it is essential that the clinician interprets correctly the readings that guide their decision around when to stop treatment. The LF readings from the DIAGNOdent Classic, Pen, and KEY3 laser correlate to the surface area and volume of subgingival calculus deposits [69].

• Keep the optical components (tips) free of visible contamination
• Calibrate the fluorescence system daily as per the manufacturer's instructions
• Hold the working tip with a light touch and do not apply strong force against the surface being assessed
• When working around restorations, be aware of endogenous fluorescence of restorative materials
• Teeth with discoloration from first and second generation tetracycline antibiotics will have elevated background fluorescence
• Lesions of root surface caries will give strong fluorescence readings
• Ensure that the correct threshold value is being used for the instrument readings

Table 2. Major aspects of clinical technique when using laser fluorescence for detection of subgingival calculus and dental plaque biofilms.

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Thus, if readings remain high at a particular site, deposits remain and further debridement is needed. Depending on which LF device is being used, the clinician may need to adjust their decision point. The reason for this is that there are subtle performance differences between the three systems. The KEY3 gives superior accuracy and reproducibility over the DIAGNOdent Pen and the DIAGNOdent Classic [52, 69, 70]. The threshold LF reading for the boundary between a healthy root surface (or implant surface) and bacterial deposits is 5 for the DIAGNOdent Classic, but 7 for the DIAGNOdent Pen and KEY3 laser.

3.4. Fluorescence detection of dental calculus using other wavelengths of light

The fluorescence concepts that underpin LF can be applied using nonlaser light sources, using wavelengths of light other than those in the visible red portion of the spectrum to excite the target tissue. Ultraviolet light (315–400 nm), violet light (405 nm) and visible blue light (400–420 nm) will all generate fluorescence emissions in the visible red region [71–75] (**Figure 1**). The major fluorophores are the porphyrins, particularly protoporphyrin IX, which emits at 633 nm [73]. This approach has been used for detecting mature deposits of supragingival plaque and calculus.

In an intra-oral camera, a long pass orange filter placed over the imaging sensor will remove reflected light [72]. This direct imaging approach cannot however be used for viewing subgingival surfaces during patient examination or during debridement.

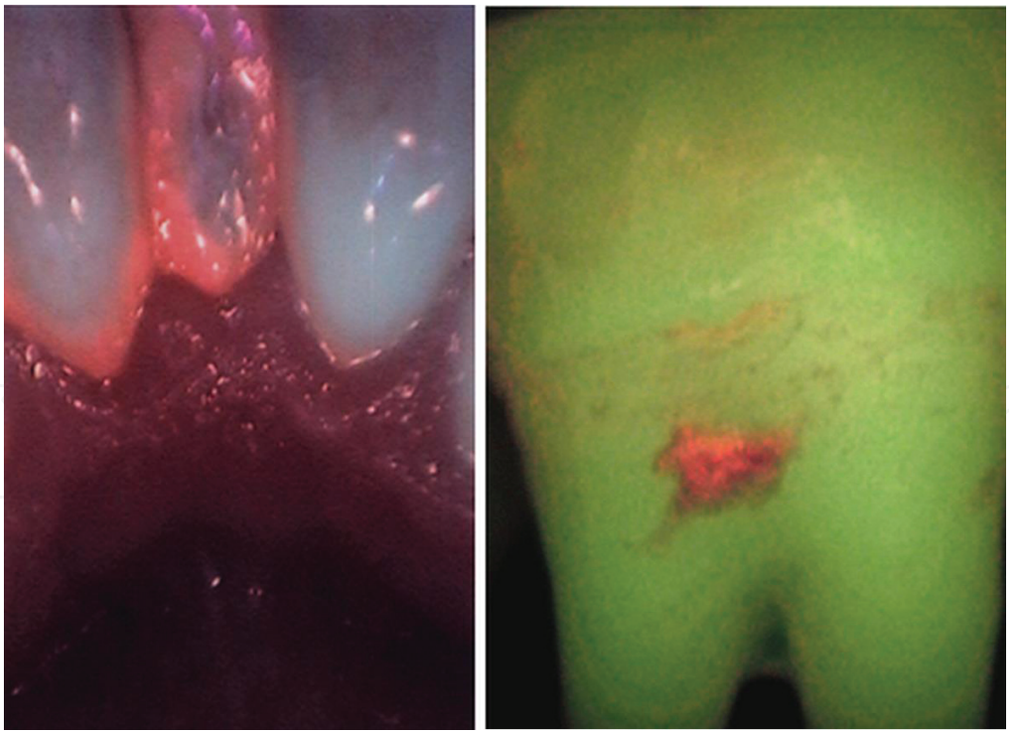

Figure 1. Visible red fluorescence emissions produced by calculus when excited with 405 nm violet light. Left side, supragingival calculus deposits on lingual aspects of mandibular incisor teeth, prior to a debridement visit. Right side, subgingival calculus deposits in the buccal furcation area of an extracted mandibular molar tooth. This location would not be visible using an intra-oral camera unless the patient was having periodontal flap surgery.

4. Conclusions

Optical methods are promising diagnostic technologies that can be used to augment traditional periodontal examination. A key factor that supports the use of optical devices as diagnostic adjuncts is that they are safe, and employ nonionizing radiation, thus making them suitable for frequent use in clinical practice on the same patient. 3D scanning, fluorescence spectroscopy and OCT can all provide valuable information on periodontal soft tissues and their relationship to teeth and dental implants. Light-induced fluorescence can provide improved detection of subgingival calculus during debridement.

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