Continuing Education credits are available on this article for subscribers by answering the questionnaire at www.dentalpractice.com.au

Optical diagnostic methods: Current status and future potential

By Professor Laurence J. Walsh

"A major advantage of optical diagnostic methods is that they use non-ionizing radiation, and can therefore be used with safety at high frequency, unlike dental X-rays...."

A range of optical methods are now available to assist in the diagnosis of oral diseases and in particular, in the recognition of early forms of soft and hard tissue diseases, so that less invasive treatments can be provided. As an example, detection of mineral loss from caries (or dental erosion) at a very early stage may permit more efficient reversal of the process of mineral loss than when lesions are detected at a more advanced stage. In other words, early intervention will reduce the need for irreversible restorative procedures. This is an essential part of the modern philosophy of minimal intervention dentistry.

A major advantage of optical diagnostic methods is that they use non-ionizing radiation, and can therefore be used with safety at high frequency, unlike dental X-rays. They are simple, painless and non-invasive, and can also be used in situations where radiographs are contra-indicated, such as with pregnant women. A broad range of applications now exist for optical diagnostic systems in dental practice (Table 1), and many of these show excellent performance and improved accuracy compared with traditional methods, with greater detection of early disease (sensitivity) and more reliable identification of healthy sites (specificity) (Table 2).

Figure 1. The Velscope unit which is used to facilitate recognition of pathologically altered oral mucosa, and identify areas for biopsy and other investigations.

Soft tissue pathology

Use of intense white light can aid thorough diagnosis of oral mucosal pathology, however particular benefits in recognizing pathologically

Figure 2. Two ultraviolet light-equipped intra-oral camera systems for oral diagnosis, the Morita PenViewer (left) and Dürr VistaProof (right).

Table 1. Current optical diagnostic methods

Method	Wavelength	Target detected	System
Fluorescence	400-500 nm	Abnormal oral mucosa	Velscope, Vizilite
		Dental caries	VistaProof
		Dental calculus and mature plaque	VistaProof, PenViewer
		Tetracycline dental staining	
		Tooth coloured restorations	
Fluorescence	655 nm	Dental caries	DiagnoDENT, KEY3
		Dental calculus	DiagnoDENT, KEY3
Differential Reflectometry	630 nm and 800 nm	Subgingival calculus	DetecTar
Optical coherence tomography	800-1064 nm	Dental caries	Lantis Laser
Laser Doppler flowmetry	633-635 nm	Pulpal blood flow	Various

Table 2. Indicative performance of optical diagnostic systems compared with conventional methods

Target	System	Sensitivity	Specificity
Occlusal caries (DEJ)	DiagnoDENT	82%	100%
	Sickle probe	49%	89%
Proximal caries (DEJ)	DiagnoDENT	95%	96%
	Bitewing radiographs	65%	92%
Subgingival calculus	DiagnoDENT	83%	98%
	DetecTar	75%	83%
	Periodontal probe	75%	67%

altered oral mucosa occur when fluorescence methods are employed. The most common way to detect oral mucosal disease is by visual inspection of the suspect tissue. However, the human eye is not optimized for this task because the perceived spectrum of light is divided into three channels, all of which have overlapping spectral sensitivity curves. Abnormalities in the oral cavity are optimally perceived when the excitation is in the long wave ultraviolet (UVA) band. Positive green autofluorescence emissions arise from the cytokeratins which are found in normal oral mucosal epithelial cells, when tissues are exposed to violet and blue light.

This approach, which is used in devices such as the Velscope (Figure 1) and Vizilite, allows the identification of areas of mucosal pathology, which require further investigation, such as ulcerations, hyperkeratinization, chronic inflammation, and areas of dysplastic change. UVA-induced autofluorescence emissions in human oral mucosa derive primarily from the keratin layers.[1] The lack of cytokeratin autofluorescence can be easily identified by the human eye in real time as a dark area. By checking for such dark areas, visual examination using autofluorescence enhances the contrast between normal and neoplastic oral mucosa.

A significant point with autofluorescence devices is that they assist in identifying areas that might have otherwise been overlooked because they appeared normal under white light examination, however they do not however provide a diagnosis. In the future, multiphoton imaging may provide this information, by exploiting the unique fluorescence signatures of particular enzymes and other biologically relevant molecules. A final clinical point is that while it has commonly been recommended that a brief mouthrinse with dilute (1%) acetic acid be used to reduce the burden of saliva prior to visual inspection under UVA light, clinical experience indicates that this may not add value to soft tissue diagnosis.[2,3] There is a growing supporting literature regarding the value of autofluorescence imaging of oral mucosa,[4-9] and current systems such as the Velscope are both simple to use and modest in cost.

Mineral loss

UVA, blue and green light causes visible green-yellow fluorescence in healthy enamel. Enamel fluorescence does not depend on the colour of the tooth. Dentine has a distribution spectrum which is similar to that of enamel. Reduced fluorescence from dental hard tissues can

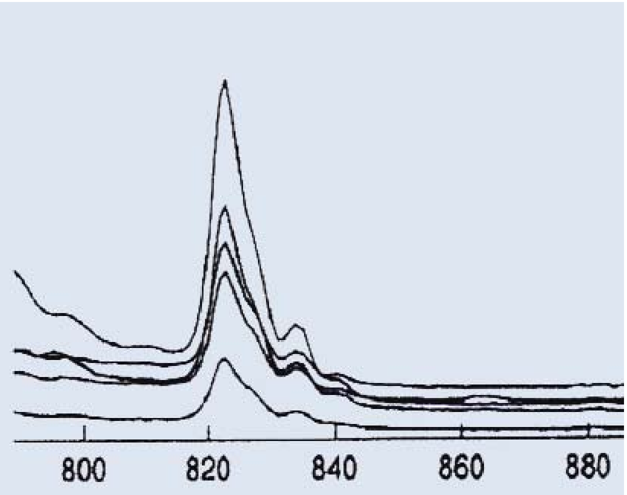

Figure 3. Near infrared fluorescence signals produced by 5 samples of dental calculus, in the near infrared spectrum (800-880 nm).

Figure 4. DiagnoDENT "Classic" unit from KaVo, fitted with a prototype sapphire tip for studies of subgingival calculus detection.

Figure 5. DiagnoDENT pen, with performance identical to the earlier "classic" unit, in a more compact device with a wider range of sapphire tips for oral diagnosis.

Figure 6. KaVo KEY-3 laser system with autopilot capabilities for removing subgingival calculus and dental caries. The newly released 2063 handpiece (left) and software upgrade (lower panel) allow for specific recognition and ablation of carious dentine.

indicate the presence of early forms of mineral loss from dental caries or dental erosion, or subsurface porosity. These lesions can then be arrested or reversed using remineralizing therapies such as Recaldent™ and fluoride. The underlying process used with UVA systems such as the Dürr VistaProof and Morita PenViewer (Figure 2), and the like, is that when excited by UVA and violet light, carious enamel appears dark compared to yellow-green luminescent sound enamel. Such negative fluorescence has been shown to detect more demineralized pre-cavitated enamel areas than a conventional visual examination.[10-12]

Restorative materials

The literature on hydroxyapatite fluorescence is relevant to the problem of forensic identification of restorative materials, since tooth-coloured restorative materials have a different fluorescence signature from human dental enamel. For example,

Figure 7. Red fluorescence of supragingival calculus, seen with the Morita PenViewer.

Figure 8. Red fluorescence of supragingival calculus, seen with the Dürr VistaProof.

the emission spectra of the dental porcelain comprises a wide band due to transition metals, and fine lines due to rare earth elements (terbium and europium). When the porcelain colour is more saturated, its fluorescence colour becomes greener, allowing it to be distinguished from adjacent yellow fluorescing enamel. As a further example, lack of fluorescence from tooth structure may indicate the presence and form of a non-fluorescing composite resin restoration, while red fluorescence may indicate strontium glass is present in a glass ionomer cement restoration, whether tooth coloured or otherwise. This can be done to assist a normal dental examination, and can also be used for forensic purposes when it is necessary to identify tooth coloured restorations for dental identification purposes.[13]

Bacterial deposits

There are many well developed diagnostic applications where fluorescence is used to identify dental deposits. DiagnoDENT technology from KaVo is based on a visible red 655 nm diode laser system which elicits near infrared fluorescence (Figure 3). Three variants of this technology exist - the DiagnoDENT classic (Figure 4) introduced for fissure caries diagnosis, the DiagnoDENT pen (Figure 5) with proximal caries and calculus detection capabilities, and the KEY-3 laser (Figure 6), which has autopilot capabilities for selective removal of both infected carious dentine and for subgingival calculus. A number of laboratory studies using extracted teeth and clinical studies have found that this laser fluorescence method yields higher levels of sensitivity and specificity than currently available techniques. The proviso for this improved performance is that saliva, stains and dental plaque are removed from the coronal tooth surfaces before readings are taken of enamel or root surfaces.[14-16] DiagnoDENT systems have particular optical tips which have been optimized for detection of proximal lesions and subgingival calculus, and the system has been used for autopilot control of ablation of subgingival calculus and dentine caries.[17,18]

Figure 9. DetecTar system for calculus detection from Ultradent.

At shorter fluorescence excitation wavelengths in the UVA-violet range, positive red fluorescence occurs from deposits of mature dental plaque and calculus on the surface of teeth, restorations, or dental appliances. This fluorescence, which can be elicited with systems such as the Morita PenViewer (Figure 7) and Dürr VistaProof (Figure 8) can be useful to assist in diagnosis as well as in oral hygiene education, since disclosing dyes are not required.[19] The fluorescence method can also be used to assess cleaning techniques for teeth as well as dental appliances, since residual deposits of mature plaque and calculus appear as red fluorescing areas. The maturity of dental plaque, rather than the presence of particular cariogenic streptococci, is the basis for the red fluorescence. The same wavelengths give red emissions from infected carious dentine in cavity preparations, once again indicating the presence of bacteria. In this way, red fluorescence can be used to guide caries removal.[20,21]

A further optical diagnostic method is differential reflectometry, as seen in the Ultradent DetecTar. This exploits the different patterns of light reflection and absorption when visible red light and near infrared light are used to illuminate subgingival calculus using a miniature fiberoptic handpiece shaped like a periodontal probe (Figure 9).

Light sources

Selecting an appropriate light generating system for use in optical diagnosis requires consideration of the desired optical output in terms of wavelength, power, intensity and stability of output over time, as well as product features which relate to the technology itself. Within the dental setting, key aspects are small size and a low mass (essential for portability, low power requirements, and stability of output over time. For these reasons, most contemporary optical devices use super-luminous LEDs and diode lasers, in preference to conventional LEDs. Super-luminous LEDs are a cross-over between diode lasers and conventional LEDs, since some degree of stimulated emission with amplification occurs, but there is insufficient feedback for sustained oscillation to occur.

Both LEDs and diode lasers have a high energy conversion efficiency from electrical energy to light. Diode lasers and LEDs in dental diagnostic devices in the UVA, violet and blue ranges typically use Indium Gallium Nitride (InGaN), aluminium nitride (AlN) and other semiconductor materials, require little power and generate little heat. They can be operated at low voltages (3.5-4.0 volts). Their electrical conversion efficiency is sufficiently high that the heat generated by their normal operation is not problematic and can be dealt with using passive heatsinks. Importantly, their power output is stable over extended periods of time, ensuring long term reliability for clinical use.

References

1. de Veld DC, Bakker Schut TC, Skurichina M, Witjes MJ, Van der Wal JE, Roodenburg JL, Sterenborg HJ. Autofluorescence and Raman microspectroscopy of tissue sections of oral lesions. Lasers Med Sci. 2005;19:203-9.
2. Svistun E, Alizadeh-Naderi R, El-Naggar A, Jacob R, Gillenwater A, Richards-Kortum R. Vision enhancement system for detection of oral cavity neoplasia based on autofluorescence. Head Neck. 2004;26:205-15.
3. Utzinger U, Bueeler M, Oh S, Heintzelman DL, Svistun ES, Abd-El-Barr M, Gillenwater A, Richards-Kortum R. Optimal visual perception and detection of oral cavity neoplasia. IEEE Trans Biomed Eng. 2003;50:396-9.
4. Gillenwater A, Jacob R, Ganeshappa R, Kemp B, El-Naggar AK, Palmer JL, Clayman G, Mitchell MF, Richards-Kortum R. Noninvasive diagnosis of oral neoplasia based on fluorescence spectroscopy and native tissue autofluorescence. Arch Otolaryngol Head Neck Surg. 1998;124:1251-8.
5. Betz CS, Mehlmann M, Rick K, Stepp H, Grevers G, Baumgartner R, Leunig A. Autofluorescence imaging and spectroscopy of normal and malignant mucosa in patients with head and neck cancer. Lasers Surg Med. 1999;25:323-34.
6. Paczona R, Temam S, Janot F, Marandas P, Luboinski B. Autofluorescence videoendoscopy for photodiagnosis of head and neck squamous cell carcinoma. Eur Arch Otorhinolaryngol. 2003;260:544-8.
7. Svistun E, Alizadeh-Naderi R, El-Naggar A, Jacob R, Gillenwater A, Richards-Kortum R. Vision enhancement system for detection of oral cavity neoplasia based on autofluorescence. Head Neck. 2004;26:205-15.
8. Ram S, Siar CH. Chemiluminescence as a diagnostic aid in the detection of oral cancer and potentially malignant epithelial lesions. Int J Oral Maxillofac Surg. 2005;34:521-7.
9. de Veld DC, Sterenborg HJ, Roodenburg JL, Witjes MJ. Effects of individual characteristics on healthy oral mucosa autofluorescence spectra. Oral Oncol. 2004;40:815-23.
10. Hafstrom-Bjorkman U, Sundstrom F, ten Bosch JJ. Fluorescence in dissolved fractions of human enamel. Acta Odontol Scand. 1991;49:133-8.
11. Angmar-Mansson B, al-Khateeb S, Tranaeus S. Monitoring the caries process. Optical methods for clinical diagnosis and quantification of enamel caries. Eur J Oral Sci. 1996;104:480-5.
12. Stookey GK. Quantitative light fluorescence: a technology for early monitoring of the caries process. Dent Clin North Am. 2005;49:753-70.
13. Stimpson PG. Post mortem detection of tooth coloured dental restorations by ultra violet radiation. Acta Med Leg Soc 1985; 35:278–284.
14. Al-Khateeb S. Quantification of formation and remineralization of artificial enamel lesions with a new portable fluorescence device. Adv Dent Res 1997;11:502-.
15. Bjelkhagen H. Early detection of enamel caries by the luminescence excited by visible laser light. Swed Dent J 1982;6:1-7.
16. De Josselin de Jong E. A new method for in vivo quantification of changes in initial enamel caries with laser fluorescence. Caries Res 1995;29:2-7.
17. Walsh LJ. Shining light on caries (and more): The new DiagnoDENT pen. Australas Dent Pract 2005; 16:122-4.
18. Walsh LJ, Mubarak S, McQuillan A. Autopilot laser-based systems for guiding caries and calculus removal: from concept to clinical reality. Australas Dent Pract 2007;18:122-8.
19. Coulthwaite L, Pretty IA, Smith PW, Higham SM, Verran J. . The microbiological origin of fluorescence observed in plaque on dentures during QLF analysis. Caries Res. 2006;40:112-6.
20. Walsh LJ, Shakibaie F. Ultraviolet-induced fluorescence: shedding new light on dental biofilms and dental caries. Australas Dent Pract 2007; 18: 52-6.
21. Borisova E, Uzunov T, Avramov L. Laser-induced autofluorescence study of caries model in vitro. Lasers Med Sci. 2006;21:34-41.

About the author

Professor Laurence J. Walsh is the technology editor of Australasian Dental Practice magazine. He is also a noted commentator on and user of new technologies and is the Head of The University of Queensland School of Dentistry.