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Pediatric laser-assisted dentistry: A clinical approach

Authors_Claudia Caprioglio, DDS, MS, Giovanni Olivi, MD, DDS, and Maria Daniela Genovese, MD, DDS

Abstract

The approach to pediatric dental patients demands close cooperation between dentists, parents and the children. Laser-assisted therapy is a modern and effective strategy. Laser technology has a wide application in dental care and treatment, oral traumatology and minor surgical procedures, and is suitable for the treatment both of primary and permanent teeth. The authors’ aim is to stimulate more extensive scientific research in this area and to offer a clinical overview, showing also some clinical procedures.

Introduction

One of the main roles of the pediatric dentist is to provide effective education on prevention in order to reduce the incidence of dental and oral disease throughout childhood and adolescence and into adulthood.

In this context, it is essential never to lose sight of a key aim: tissue preservation. Preferably, this is achieved by preventing disease from occurring in the first place, and by arresting its progress when it does occur. But tissue preservation also means removing diseased tissue and restoring defects with as little tissue loss as possible.

Today, we are assisted in this endeavour by techniques allowing early diagnosis (digital radiology with low radiation emission, diagnostic lasers and the dental operative microscope) and minimally invasive therapy (ozone therapy, air abrasion, rotary instruments for micropreparation and lasers). Laser-supported dental diagnosis and treatment, which allows us to meet the important aim of “filling without drilling,” is an excellent approach from the tissue preservation point of view and, as reported by Martens1 and reiterated by Gutknecht2, “children are the first in line to receive dental laser treatment.”

In this paper we will look at the use of the Erbium family of lasers in soft- and hard-tissue ablation, and also at how other lasers (diode, Nd:YAG, CO2) can help to make a trip to the dentist a minimally invasive and stress-free experience,3,4 which for children is particularly important.

The laser is a new instrument in pediatric dentistry that sometimes complements and sometimes replaces traditional techniques. Lasers, which are available in a variety of types with different wavelengths...
(see Table I, page 15), have a number of possible applications and can be used to treat both soft and hard oral tissue (see Table II, page 15).

Without going into the physics of laser therapy in detail, it is necessary to appreciate that different wavelengths interact differently with different chromophores (hemoglobin, water, hydroxyapatite) contained in the target tissue (mucous membranes, gingiva, dental tissue) and therefore that the therapeutic effect is determined by the optical affinity and coefficient of absorption of the target tissue for the given wavelength.

_Soft-tissue applications of lasers in pediatric dentistry_

**Oralsurgery**

Lasers offer a series of important advantages in the treatment of oral soft tissues. They are simple and rapid to use, they reduce the need for local anesthesia, they allow excellent control of bleeding during incision and they can also eliminate the need for sutures. Furthermore, the postoperative recovery is often asymptomatic thanks to the decontaminating, antalgic and biostimulant effects of laser radiation.

In short, the procedure, which produces excellent clinical results, is less invasive and less traumatic than the traditional approach. This is a particularly important consideration in children, who will more readily accept this treatment. Furthermore, laser treatments, compared with conventional procedures, are associated with a greatly reduced need for analgesics and anti-inflammatory medications.

Lasers are used in soft-tissue management to remove or treat lesions of the oral mucosa. All wavelengths of light with an affinity for hemoglobin and water (chromophores contained in the gingiva and mucosa) can be used for these applications: the argon, KTP, diode, Nd:YAG and CO2 lasers are useful for soft-tissue cutting, vaporization and decontamination, achieving very good coagulation and hemostasis; they are also ideal for vascular lesions,5,6

The erbium lasers, Er,Cr:YSGG and Er:YAG, are also suitable for these applications due to the good absorption of their light wavelengths by the water contained in the gingiva and oral mucosa, however, they are less effective at controlling bleeding. The performance of erbium lasers can be enhanced by the use of an air-water spray delivered through the laser handpiece. This ensures a clean incision and helps to avoid excessive increases in the temperature of the soft tissue during vaporisation; furthermore, the absence of peripheral necrotic tissue allows accurate biopsies (Figs. 1, 2).7,8

Periodontics and orthodontics

The decontaminating effect of different lasers in pockets of periodontal disease has been widely demonstrated in adults, but data on laser-assisted therapy of periodontitis in young patients are lacking. Conversely, in the context of orthodontic treatments, there emerge many clinical situations
in which soft-tissue intervention is required before, during and after treatment. These are procedures (Table II) that can be accomplished simply, safely and effectively using different laser wavelengths, depending on the laser-tissue interaction required (Fig. 3).9,10 Frenectomies are among the most common and widely documented laser applications in orthodontics.

Laser frenectomies, performed using diode, Nd:YAG, Er:YAG, Er:Cr:YSGG and CO2 lasers have been reported to be associated with less postoperative pain and discomfort and fewer functional complications (problems with speaking and chewing) compared to traditional techniques; these advantages improve the patient’s perception of the therapy,9, 10 which as mentioned, is an important consideration in children.

Lasers can be used to perform labial upper and lower frenectomies: The technique is extremely simple and effective even for lingual or labial frenectomies in newborns, and in cases of severe ankyloglossia or tight maxillary frenum that create breastfeeding difficulties. Gingivectomy, gingivoplasty and operculectomy can be performed easily and without anesthesia using all laser wavelengths, and brackets can be glued immediately.11,12

Low-level laser therapy (LLLT) has been successfully used to accelerate tooth movement in orthodontics, stimulating the modulation of the initial inflammatory response with the advantage of anticipating the resolution of normal conditions at earlier periods; other studies have reported a local effect of the CO2 laser, which was found to reduce pain associated with orthodontic force application without interfering with the tooth movement.15

Cariess prevention

The first in vitro studies exploring the potential of laser radiation to prevent dental caries (by increasing the acid resistance and microhardness of the enamel tooth surface) were conducted at the end of the 1980s. To date, several studies on this application have been performed, giving similar results, but clinical evidence is extremely limited. Studies in this area fall into two main categories: those using argon lasers at 488–514 nm and those using CO2 lasers at 9,300, 9,600 and 10,600 nm.

However, the capacity of the erbium 2,780 and 2,940 nm lasers to modify the physical-chemical characteristics of the enamel surface has also been investigated. The parameters assessed by these studies were cross-sectional microhardness and enamel solubility.

Argon laser irradiation combined with acidulated phosphate fluoride treatment (APF) was found to reduce lesion depth by more than 50 percent compared with control lesions, and by 26 to 32 percent compared with lased-only lesions. It was also reported that the use of a zinc fluoride and argon laser combination significantly reduced white spotting and etching. This treatment appeared to stabilize the hydroxyapatite crystal and repair its structural defects.15

In 2003, Hicks et al. argued that argon laser irradiation combined with APF may confer a protective barrier against cariogenic attacks in primary teeth, suggesting that the surface coatings associated with this treatment contain fluoride-rich calcium and phosphate mineral phases that could act as reservoirs for fluoride, calcium and phosphate and thus provide teeth with a certain degree of protection.16 It was also confirmed that enamel surface microhardness was found to be greater in teeth exposed to low argon laser irradiation only or to argon laser irradiation combined with APF than in untreated teeth (controls).16

Another line of research dates back to 1998 when Featherstone et al.17,18 reported inhibition of caries progression, obtained using 9,300 nm and 9,600 nm lasers (fluences from 1 to 3 J/cm²). The level of inhibition obtained compared with that obtained through daily fluoride toothpaste treatments was on the order of 70 percent.

Furthermore, the subsurface temperature elevation was minimal (< 1° C at 2 mm depth), supporting the findings of another study that reported no thermal damage to the pulp.57 In 2008, it was confirmed that the CO2 laser is efficient in reducing subsurface

Figs. 6a–c. Female patient, 5.2 years old. Deep caries on molar teeth. Panoramic view (a). X-ray control (b) and occlusal vision (c).
enamel demineralization and that its association with a high frequent fluoride therapy may enhance this protective effect.19

Recent research has indicated that the erbium laser wavelengths, too, may have the potential to increase acid resistance: Subablative erbium energies can decrease enamel solubility, thereby increasing caries resistance, without greatly altering the structure of the enamel. However, these results failed to reach statistical significance (alpha = 0.05).20

Clinical Implications
Subablative CO2 laser irradiation of young, healthy teeth could be an effective method of caries prevention; long-term clinical studies are needed to validate this hypothesis. There is also a need for further studies evaluating the capacity of erbium laser treatment to increase the acid resistance of permanent teeth.

Caries Detection
Of the various laser applications in pediatric dentistry, the one most investigated is their use as a means of detecting caries: the non-ablative laser emits fluorescence visible in the red spectrum at 655nm; this has made it a useful complement to conventional methods for detecting occlusal caries.

Lussi et al. in 2003 affirmed that laser fluorescence (LF) could be a useful additional tool in the detection of occlusal caries in deciduous teeth, also suggesting that, thanks to its good reproducibility, the laser could be used to monitor the carious process over time.21,22

Several studies have compared different caries detection methods: Visual inspection alone, visual inspection with magnification, bite-wing X-ray and LF. The reliability and the diagnostic validity (sum of sensitivity and specificity) of LF have been found to be very high, with the technique even outperforming bite-wing radiography as a means of proximal caries detection in primary teeth.

Other studies, too, have found that LF methods for detecting occlusal caries are more efficient in deciduous than in permanent teeth, even though LF proved unable, in primary teeth, either to detect in vitro remineralisation of natural incipient caries lesions or to quantify ongoing mineral loss due to carious processes.

According to the results of a 2008 study by Braqa et al., the LF device performs better at the dentin threshold than at the enamel threshold; the authors therefore concluded that this method is unsuitable for detecting initial enamel caries lesions, instead confirming its efficiency, which they had already demonstrated in previous studies, as a means of predicting the extent of caries lesions.23,24

Finally, studies conducted to establish the possible impact of the operator on LF treatment have concluded that the operator factor does not determine the reliability, predictability and reproducibility of outcomes obtained using this approach.

Clinical Implications
In daily dental practice, the LF system emerges as a reliable complementary tool for the visual exploration of occlusal surfaces, both in primary molars and permanent first molars. In addition, thanks to the availability of new tips, the system can now be used to detect proximal lesions.

Sealing of Pits and Fissures
Several in vitro studies have evaluated the possible role of lasers in the preparation, prior to sealant application, of pits and fissures on the occlusal surfaces of young teeth. Most of these studies compared invasive techniques and laser irradiation with or without acid etching, finding no significant difference between the two types of enamel preparation when etching was performed.

In one study, preparing and treating the enamel surface exclusively with the Er:YAG laser resulted in the highest degree of leakage,25 while in another, there emerged no difference in microleakage between lasing and acid etching, suggesting that the lasing technique may be efficacious.26

However, pre-treatment with the Er,Cr:YSGG laser was not found to influence the resistance to microleakage of bonded fissure sealant in primary teeth.

Other studies have investigated the energy level appropriate for this application: They found that mechanical preparation prior to fissure sealing did
Clinical overview

not enhance the final performance of the sealant, and that laser irradiation at 600 mJ and bur drilling eliminated the greatest amount of hard tissue.

Clinical implications

Laser irradiation does not appear to eliminate the need for acid etching of enamel prior to the application of a pit and fissure sealant. It may be considered a useful adjunct in the sealant application procedure thanks to its cleansing and disinfecting effects. Attention must be paid to the level of energy applied in order to avoid overpreparing the pit and fissure surfaces.

Cavity preparation and caries removal

The idea that a dental drill can be replaced by a laser instrument, which is less traumatic for the patient, led to the introduction of this device into the field of pediatric dentistry. Indeed, the laser, unlike the traditional dental drill, works on hard tissue without coming into contact with the tooth; furthermore, it does not generate vibration and noise and it is less painful.

Various studies and clinical reports have demonstrated the additional safety conferred by the laser when used as an alternative to rotary instruments in pediatric restorative dentistry and even in the treatment of very young children. This opens up the way for minimal interventions targeting only carious tissue and overall better acceptance compared to traditional techniques.9,10, 32–34

In this context, different laser wavelengths were studied for cavity preparation: the CO2 laser was investigated first and found to induce thermal damage of the irradiated dental tissues; other clinical and experimental investigations indicated the possibility of treating early childhood caries of the enamel with the Nd:YAG laser, but micromorphological analysis of the irradiated primary teeth revealed the presence of collateral damage to the dental tissues.

Today, just two wavelengths, the Er,Cr:YSGG at 2,780 nm and Er:YAG at 2,940 nm, are used successfully for treating dental hard tissues. The earliest studies on the use of the erbium laser for cavity preparation and caries removal date back to 1989, when Hibst and Keller were the first to evaluate the capacity of the Er:YAG laser to cut human hard dental tissue.3,4

The first decade of research saw various authors studying different parameters and variables of erbium laser application in caries removal and cavity preparation, evaluating its morphological effects on hard and pulp tissue, as well as the effects of energy density, pulse repetition rate and air-water spray use.27,28

Moritz et al., in 1998, found that the results of laser etching of the enamel were the same as those obtained with orthophosphoric acid etching.29 Finally, Olivi et al. confirmed the efficacy of the erbium laser in cavity preparation and removal of carious tissue.30, 31

Laser and resin composite adhesion

Different studies investigating composite adhesion to lased surfaces have given contrasting results, and this is still a controversial issue.

Many authors have reported that adhesion to laser-ablated or laser-etched dentin and enamel of permanent teeth is inferior to adhesion to dentin and enamel submitted to conventional rotary preparation and acid etching. These studies stressed how important it is to pay close attention to the energy output in order to avoid substructural damage. They also called for standard laser energy outputs for different tooth substrates and stressed that acid etching should be mandatory even after laser conditioning of dentin and enamel.35, 36

Studies on primary teeth reported that Er:YAG laser irradiation of dentin at 60 mJ/2 Hz, 80 mJ/2 Hz and 100 mJ/2 Hz prior to the adhesive protocol adversely affected bond strength.37

Conversely, other authors reported that primary dentin treated with the Er,Cr:YSGG laser at lower energy output 0.5 Watt (50 mJ) did not require etching; however, as the energy level increases, it is beneficial to add etching as part of the conditioning protocol in order to guarantee adequate bonding.38

Studies on shear bond strength to the enamel of primary teeth reported superior results in Er:YAG laser-
A search of the literature indexed in PubMed found few studies that investigate the use of lasers in maintaining pulp tissue vitality.

In this field, low-level laser energy (from 0.5 to 1.0 W) is usually used, delivered in defocused mode, preferably with low repetition rate and/or in super-pulsed mode. In 1997, Santucci, using an Nd:YAG laser for coagulation and glassionomeric cement as a pulp capping agent, reported a 90 percent success rate after six months. The following year, similarly high success rates were obtained by Moritz et al.: 89 percent and 93 percent after one and two years, respectively, compared with 68 percent and 66 percent in the calcium hydroxide control group.

The CO2 laser has a purely thermal effect on tissue, 90 to 95 percent of the energy delivered to the tissue being absorbed by a fine tissue layer (100 microns) and transformed into heat. The wavelengths of erbium lasers, too, are almost completely absorbed by the water in a superficial tissue layer and transformed into heat: However, these lasers do not have such a marked coagulating effect as the CO2 laser.

Olivi et al., in 2006, showed the Er,Cr:YSGG laser with adjustable air-water spray to be, by itself, an excellent mini-invasive instrument for caries removal and pulp coagulation, which does not overprepare or overheat the residual dental tissue and is associated with 80 percent tooth survival at four years.

The same author, in 2007, compared the efficacy of two laser systems, the Er,Cr:YSGG laser and the Er:YAG laser, with that of a conventional calcium hydroxide procedure, observing success rates of 80 percent in the Er,Cr group, 75 percent in the Er:YAG group, and 63 percent in the control group at two years.

Pulpotomy is very common technique in primary teeth. Although pulpotomy with formocresol (1:5 dilution) is used successfully, in view of the carcinogenic and mutagenic potential of its formaldehyde component, there is now a tendency to seek alternative techniques.

Lasers have been proposed for this application and, in 2002, Pescheck et al. favorably compared CO2 laser treatment to formocresol for pulpotomy in primary teeth, reporting a survival rate ranging from...
91 percent to 98 percent. Elliot et al., in 1999, also found a significant inverse correlation between the laser energy applied to the pulp and the degree of inflammation at 28 days; these authors reported a 99.4 percent clinical success rate at four years compared with 88.2 percent in the formocresol control group. Instead, Guellmann et al., in 2002, reported a correlation between healing and age and apex size of the primary teeth.

The Nd:YAG laser has also been used for pulpotomy on human primary teeth, but a recent study reported a clinical success rate of 85.71 percent and a radiographic success rate of 71.42 percent at 12 months, compared with the clinical and radiographic success rate of 90 percent recorded in the formocresol group. While clinical reports in pediatric endodontics are lacking, it is known that permanent teeth can be treated with the Nd:YAG and diode lasers, which have a high bactericidal effect in root and lateral canals.

Only one study on laser use in primary teeth is indexed in PubMed. It compared the effects of different procedures (Er,Cr:YSGG laser, manual and rotary instrumentation techniques) on root canal wall cleaning and shaping in primary teeth.

Treatment with the Er,Cr:YSGG laser provided cleanliness similar to that obtained using the rotary instrumentation technique and superior to that obtained with manual instrumentation; the laser technique required less time for completion of the cleaning and shaping procedures compared with both the other techniques.

Clinical implications
In pulp capping procedures, attention must be paid to the level of energy applied. Low energy delivered in defocused mode and pulsed or superpulsed mode guarantees good superficial coagulation, good decontamination and maintenance of the vitality of the residual pulp.

Due to the characteristic anatomy of the apex and the penetration depth of near infrared lasers, particular care must be taken when introducing laser energy into primary root canals for root canal cleaning and disinfecting purposes.

Laser applications in dental traumatology

Dental trauma in children, sometimes complex and occasionally genuine emergencies, are frequent events in which laser-assisted therapy offers new treatment possibilities.

There is very little on this topic in the international literature and there are no well-coded guidelines for the use of lasers in this field, although the advantages offered by laser techniques already described by others make them useful options in the treatment of hard and soft dental tissue and exposed pulp.

Hard-tissue traumatic injuries
A crown fracture involves the enamel and dentin and, if complicated, exposes the pulp. As underlined in the section on hard-tissue applications, only lasers belonging to the erbium family can guarantee good results in tooth excavation, reducing postoperative discomfort and sensitivity as well as ensuring a minimally invasive approach.

These lasers can be used for the entire procedure: tooth margin preparation and finishing, coagulation of the exposed pulp, pulpotomy or pulpectomy (if needed) and soft-tissue procedures (Figs. 9, 10).

A crown fracture exposes a large number of dentinal tubules: Erbium lasers, when used with only a little or no water spray, have the capacity to fuse and seal the dentinal tubules (to depths of up to 4 μm), thereby reducing the tissue’s permeability to fluids and reducing dentinal hypersensitivity. The other laser wavelengths (diode, Nd:YAG, CO2) also exert this beneficial therapeutic action.

Soft-tissue traumatic injuries
Indirect traumas are lesions to the supporting structures, in particular the alveolar bone, gums, ligaments, frenum and lips.

Lasers are currently an available option for the manipulation of dental soft tissue and, as reported in the literature cited above, they provide good coagulation (with an extremely clean working area), effective decontamination, photobiostimulation and analgesic effects.

For these reasons, they are indicated for the treatment of traumatic soft-tissue injuries, eliminating the need for sutures, allowing good and rapid healing by second intention and reducing patient discomfort to a minimum.

In the authors’ own experience, the use of laser systems improves the following procedures:

• decontamination of the alveolus following a traumatic avulsion
• treatment of periodontal defects following dental luxations or subluxations
• microsurgical surgery for the treatment of traumatic dental injuries
• gingivectomy and gingivoplasty
• surgical cutting (e.g., to remove tooth fragments)

Clinical implications
All the advantages of laser applications (on hard and soft tissue and on exposed pulp tissue) make laser technology useful in this field.
_Low-level laser applications_

**Biostimulation and pain control (LLLT)**

Low-level laser therapy (LLLT), or soft laser therapy, may provide a patient with a non-traumatic introduction to dentistry. There is a large body of literature on this topic, even though opinion on methods and doses still varies widely. Even though helium-neon lasers (632.8 nm) were the first lasers used for LLLT, they have now been replaced by semiconductor diode lasers (830 nm or 635 nm). These lasers exert a marked antalgic and biostimulating effect and speed up tissue repair processes.

In short, they influence a large number of cell systems (fibroblasts, macrophages, lymphocytes, epithelial cells, endothelium), and can also have a series of benefits on the inflammatory mechanism, reducing the exudative phase and stimulating the healing process.

These are important clinical advantages, especially in youngsters with impaired defenses (patients with insulin-dependent diabetes, a history of endocarditis, cardiac dysfunction or malformations, or who have undergone cardiac surgery or have prosthetic valves, oncological patients undergoing chemotherapy or radiation).

In LLLT, the power delivered is around 10/50 mW with an irradiation energy ranging from several millijoules to 1 or 2 Joules. After one to three days of biostimulation, it is already possible to observe a considerable reduction of swelling and an acceleration of the epithelization and collagen deposition phase.

LLLT has a number of applications in dentistry, both at the soft-tissue level (biostimulation of lesions, aphtous lesions, stomatitis, herpetic lesions, mucosity, pulpotomy) and at the hard-tissue level (acceleration of orthodontic movement); it also has important neural effects (analgesia, neural regeneration, reduction of temporo-mandibular pain, postsurgical pain, orthodontic pain).61–63

**Conclusions**

The diverse parameters of use and different clinical and experimental results reported in the international literature tend to disorient the non-expert wishing to explore applications of laser technology in pediatric dentistry.

The studies on soft-tissue applications are for the most part in line with each other, following similar protocols and recording reproducible results, and this is due to the fact that the lasers involved (diode, Nd:YAG, CO2) use a similar technology.

Instead, the studies on hard-tissue applications use the erbium family of lasers, of which various types are available, differing not only in their wavelengths (2,780 and 2,940 nm), but also in their overall construction. The studies performed to date cannot be compared for various reasons: Power density and fluence are only one aspect of the energy delivered to the target tissue.

Above all, these lasers have different delivery systems: Optical fibers (hollow fibers) and articulated arms transmit energy in substantially different ways and, as a result, the energy reaching the tissue can be very different from that selected on the display. Air/water spray flow and pressure, pulse length and beam profile are other parameters that affect the results of the laser-tissue interaction.

The success of minimally invasive laser therapy, in which it is crucial to apply the correct energy (the minimal effective level), is conditioned in part by the operator’s familiarity with laser technology. The operator must thus learn to act on the tissues with precision.

Before using a contact-free instrument effectively, it is necessary to acquire the correct technique through a period of training with a more or less extended learning curve. Professionals also need to understand the physical characteristics of the different laser wavelengths and their interaction with biological tissues in order to ensure that they are used safely and that young patients reap the benefits of this technology.

Finally, a correct psychological approach to the patient also contributes considerably to the success of laser therapy, which is often seen by patients and their families as almost magical.

**Editorial notes:** A complete list of references is available from the publisher.

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### Table I. Classification of lasers.

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<td>Helium-Neon 635</td>
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<td>Diode 810, 940, t980</td>
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### Table II. Laser dentistry procedures.

- Carious detection
- Cavity preparation
- Enamel-dentin
- Carious removal
- Hard- and soft-tissue surgery
- Traumatic injuries
- Endodontics
- Orthodontics
- Biostimulation
- Pain relief

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C.E. article clinical overview
The use of an Er:YAG laser in periodontal surgery: Clinical cases with long-term follow-up

Author: Frank Y.W. Yung, DDS

Introduction

While the regimen of scaling and root planing (SRP) remains an essential part of any management of periodontal diseases, there are clinical situations in which the surgical excision of infected tissues or modifications of healthy structures is required after the initial mechanical debridement. Conventional surgical techniques, such as curettage, gingivectomy, full- or split-thickness flap and other procedures have been proven to be effective in treating moderate to advanced periodontitis, but the need to improve postoperative morbidity and control over-treatment outcome have provided the impetus to explore further for better surgical techniques and treatment alternatives.

The principle behind laser surgery is the selective absorption of optical energy delivered by a specific laser wavelength to produce thermal effects on the target tissues to be excised or modified. The advantages of utilizing a laser for surgery over “cold steel” or electrosurgery are well documented in the literature, with some specific benefit differences among wavelengths. The overall recovery experiences and surgical results are so much more pleasant and predictable than those of conventional surgery so that for some surgical procedures, such as in the fields of ophthalmology, otolaryngology and dermatology, the use of lasers have replaced other modalities in many instances.

During the 1960s and 1970s, different kinds of lasers with different wavelengths were invented, and they were studied for possible dental applications. Laser instruments, including carbon dioxide (CO2), neodymium:yttrium, aluminum, garnet (Nd:YAG), argon, gallium arsenide (diode), and erbium:yttrium, aluminum, garnet (Er:YAG) were found to be effective for soft-tissue surgery, including periodontics.

The Er:YAG laser, which was developed in the early 1970s, also offered hard tissue applications. The 2,940 nm wavelength of the Er:YAG laser has absorption characteristics completely different from Nd:YAG, argon and diode lasers; it is very highly absorbed by water and moderately so by dental enamel. Whereas the optical energy is very strongly absorbed by the water molecules within the superficial layers of the target tissue, the penetration depth of this laser beam is limited to a few micrometers close to the surface.
Based on this unique combination of strong superficial absorption and shallow penetration, tissues with high water content, such as dentin or gingival tissues, can be ablated or excised precisely by these microexplosions with almost nonexistent thermal damage to the underlying tissues as long as there is proper water irrigation at the site.

An Er:YAG laser device was cleared for marketing by the U.S. Food and Drug Administration in 1997 for certain hard- and soft-tissue procedures, such as caries removal and cavity preparation, as well as incision and excision of intraoral soft tissues. Other Er:YAG laser instruments were then cleared for sulcular debridement in 1999, and in 2004 for osseous surgery.

Animal studies have shown that this laser wavelength demonstrates suitability for vaporizing bone with minimal thermal damage and good postoperative healing. While the use of this laser wavelength for dental hard tissue is relatively well-established in contemporary dentistry, there is some debate about its usefulness for soft tissue or periodontal procedures.

On the one hand, the Er:YAG laser’s radiation has been found to be strongly absorbed by many pathogenic bacteria that are related to periodontal infections, and it has been shown to be effective in removing root-bound calculus without damage to the cementum and dentin. Therefore, it has been studied for nonsurgical periodontal therapy, and significant gains in clinical attachments have been reported. However, for periodontal surgery, there are two common concerns for the use of this laser wavelength:

- There is a lack of selective energy absorption between the target tissues and the contiguous non-target tissues, such as the root and bone surfaces.
- The shallow energy penetration provides coagulation that is not as profound, and hemostasis is not concurrent with tissue ablation as the other soft tissue lasers, such as CO₂, argon, diode or Nd:YAG.

The purpose of this study, therefore, was to evaluate these concerns clinically and determine whether the Er:YAG laser with full-time water irrigation was suitable for periodontal surgery in a safe and effective manner.

**Materials and methods**

In this study, 60 patients (33 males and 27 females with a mean age of 49 years) were treated for various periodontal conditions, such as acute periodontitis, refractory periodontitis, gingival naevi, pre-prosthetic and orthodontic periodontal surgery. The patients were selected based on the following criteria:

1. no existing systemic diseases such as diabetes or hemorrhagic disorder that could affect the treatment outcome,
2. no history of antibiotic therapy one month prior to the surgical procedures, and
3. teeth directly related to the surgical site should be vital and their periodontal conditions were, if possible, stabilized with conventional scaling, root planing and prophylaxis.

Consent for periodontal and especially laser treatment was obtained. Provisions of the Helsinki Declaration of 1975, ethical principles in medical research involving human subjects, as revised in 2000, were observed throughout this study. Surgical interventions, such as surgical curettage, gingivectomy, gingivoplasty, osteoectomy and osteoplasty, were considered only in cases of acute periodontitis or when the periodontal inflammation failed to improve in three months after conventional mechanical debridement.

Documentation, such as clinical attachment levels, tooth vitality tests, intraoral photographs and panoramic and periapical radiographs, were collected before the laser treatment. The surgical sites were locally infiltrated with Xylocaine (lidocaine HCl, with 1:100,000 epinephrine (DENTSPLY Canada Ltd., Woodbridge, Ontario, Canada), and no nerve block was used. All of the laser surgical procedures were performed with Er:YAG (2,940 nm) lasers (DELIGHT and VersaWave, HOYA ConBio, Fremont, Calif.) and

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**Patient No. 1**

**Fig. 4** Laser gingivoplasty or festooning of the new gingival margin completed.

**Fig. 5** Two-week postoperative view, before the final insertion and after the abutments were etched with the same Er:YAG laser.

**Fig. 6** Four-month recall with healthy gingival margin.
strict laser safety requirements in the operatories were observed.\textsuperscript{26,30} The surgical sites were irradiated with multiple laser pulses, with individual pulse energies varying between 30 and 120 mJ, pulse repetition rates between 10 and 30 Hz, and pulse duration of approximately 250–300 μs.

The laser beam was delivered through an optical fiber connected to a round-exit contact tip 600 μm in diameter. The exit power at the contact tip was monitored by a power meter (PowerMax 600\textsuperscript{TM}, Molectron Detector, Inc., Portland, Ore.) before each procedure. This contact tip was kept in near or direct contact with the target tissues, with variations of spot diameters between 0.6 and 1 mm.

Power densities of 162 to 12W/cm\(^2\), based on the 600 μm contact tip and power output measured by the power meter, were applied; higher density was used for tissue ablation and lower setting for bacterial reduction and tissue coagulation. The surgical site was irrigated throughout the laser procedures with filtered water emitted from the contact tip itself and from an external air and water syringe.

At the completion of the surgical procedure, hemostatic cotton pellets (Racellet #3, Pascal Co., Inc., Bellevue, Wash.) and/or 4-O silk sutures were used as necessary. The patients were instructed to follow the postsurgical care protocol, and no prescriptions for analgesics or antibiotics were prescribed. No special mouth rinse was given and regular home care, except at the surgical site, was suggested.

All of the patients were contacted the next day for postoperative assessment. Regular home maintenance resumed after the surgical sites were re-examined, and the sutures were removed at the one-week recall appointments.

All of the clinical observations, along with the patients’ assessments, were collected one week, one month, three months and up to four years later. It is important to note that this study made no attempt to gather statistics that would be analyzed for probability significance; rather it attempted to show that the use of the laser was beneficial in the treatment of the patients’ periodontal disease.

\textbf{Results}

A total of 67 vital teeth were directly treated with a combination of 104 individual surgical procedures for this group of patients. The most common procedures were surgical curettage (n = 52), followed by gingivectomy (n = 47). The most common surgical site was the posterior maxilla (n = 29), followed by the posterior mandible (n = 24). The most common indication for laser periodontal surgery (24 out of 60 procedures) was moderate-to-severe acute periodontitis.

The average amount of local anesthetic used was 0.5 ml; only local infiltration was used and no nerve block was required. Despite the extensive nature of some of these procedures, there were only two cases...
in which conventional full periosteal flaps were raising; sutures were required for these two cases, as well as for five other surgical sites. The blood clotting process was enhanced through the use of the hemostatic cotton pellets in 16 sites. There was no report of air emphysema at any of the surgical sites.

After the laser treatments, one of the patients was prescribed a course of antibiotics as a precaution due to the severity of the initial infection, and because the surgical site was very close to the maxillary sinus; otherwise no medication was prescribed for the other patients. They were contacted the next day and no bleeding or swelling was reported.

One of the patients took an over-the-counter analgesic, and another complained of soreness but did not require any medication; mild soreness to no discomfort were reported by the rest of the group. One patient did complain of sensitivity to temperature which required one week for the symptoms to be resolved. Follow-up periods ranged from 6 to 54 months, with an average mean follow-up period of 2.4 years. The probing depths were normal, and there were signs of clinical attachment improvements. All of the treated teeth remained vital and functional during the follow-up period.

_Clinical Cases_

**Patient No. 1**

The patient was a 63-year-old female recovering from breast cancer treatment. Although her medical history was not ideal, she was selected because her last chemotherapy treatment had been more than three months prior, and her periodontal health was excellent. For this patient to have a more balanced gingival appearance, crown lengthening was required (Fig. 1).

After the surgical area was anesthetized and the new parabolic level was initially designed with superficial lasing (Fig. 2), the excess gingival tissues were removed with the Er:YAG laser.

To achieve normal biological width at the new gingival level, the underlying dental alveolar bone was reduced (Fig. 3). Laser gingivoplasty, or festooning, was used to bevel the surface geometry of the new attached gingiva (Fig. 4), and the final impression was taken after the abutment was prepared.

The subsequent healing was uneventful, mild sensitivity was reported, but she did not require any medication. The gingival margin was stable and healthy enough for the final insertion in two weeks (Fig. 5). The surgical results remained stable, and the central incisor was asymptomatic six months later (Fig. 6).

Because gingiva and bone are composed of varying densities of fibrous connective tissues, extracellular components, and high water content (approximately 70 percent for gingiva and 10 to 20 percent for bone), through selective laser energy absorption and by keeping the contact tip either angled away from the root and bone surfaces for the selective gingivectomy or along the edges of the alveolar bone for marginal osteotomy, both the soft and hard tissues were ablated and modified with the same laser.

With proper water irrigation, there was no surface carbonization, smoke formation, or tissue shrinkage. The treatment outcome of this procedure was relatively predictable, and hemostasis was stable enough that the final impression was taken at the end of the surgical procedure. There was a safety concern when this hard tissue laser was employed in such close proximity to the root surface and the alveolar bone.

As demonstrated, if the intention and the direction of the energy application are carefully planned ahead, this laser may be used safely for selective ablations, even in such a confined surgical site. In spite of the initial concern over her possible weakened immune response and healing capacity for which conventional treatment had been refused, as noted before, the wound healing was uneventful and took place without the assistance of medication.

**Patient No. 2**

For this patient, surgical periodontal treatment was also refused because the prognosis for his infected premolar was deemed hopeless. For this 66-year-old male patient, who was taking antihypertensive medication, it was recommended that his upper right second premolar be extracted because of acute periodontitis and severe bone loss (Figs. 7, 8). The patient’s blood pressure was stable and under control, and the rest of his dentition was functional and normal.

After the buccal and lingual areas were anesthetized, a buccal mucoperiosteal flap was raised. The infected granulation tissues were removed around the root surfaces and on the raised flap (Fig. 9). Granulation tissues usually carry much higher water content than healthy fibrous tissues such as the attached gingiva, a fact that can be exploited quite well by the strong water-affinity of erbium lasers.

With water irrigation, the exposed bone surfaces were lightly irradiated in noncontact mode with the lowest power density setting. Once stable hemostasis was accomplished, the surgical wound was closed with a 4-O silk suture.

Despite the initial infection and gingival swelling, no antibiotics or analgesic medications were prescribed. There was no report of any swelling or pain, and most importantly, there was no bleeding at the day-after reassessment.

The surgical area was monitored further for one week (Fig. 10), one month (Fig. 11) and six months (Fig. 12). Clinically, the premolar was asymptomatic.
and functional in two months, and there were radiographic signs of bone regeneration in six months (Fig. 13).

Patient No. 3
This patient was only 26 years old when the extraction of her periodontally weakened right lateral incisor (Fig. 14) was recommended (Fig. 15).

Although her overall periodontal condition improved after sessions of conventional debridement (Fig. 16), this extensive periodontal pocket (Fig. 17) became an urgent concern when orthodontic treatment was considered. The surgical approach was very similar to the one taken for patient No. 5 (no figures shown) in terms of controlled access, granulation tissue removal, root surface irradiation (Fig. 18) and suturing (Fig. 19).

The recovery of her surgical site was uneventful one week later (Fig. 20) and remained asymptomatic throughout her ensuing orthodontic treatment. Two-and-a-half years later, both the periodontal probing (Fig. 21) and radiograph (Fig. 22) show quite satisfactory clinical reattachment (Fig. 21) and bone remodeling around the initially ‘hopeless’ incisor.

Patient No. 4
This patient was a healthy 58-year-old male who presented with an infected periodontal pocket (Fig. 23). After it was probed and calibrated (Fig. 24), the inflamed granulation tissues were selectively separated from the remaining healthy attached gingiva and within the periodontal pocket (Fig. 25).

Although infection was initially present, no medication was prescribed and the patient reported no need for any; the surgical site recovered without any incident (Fig. 26). Clinical attachment was eventually reestablished in a month (Fig. 27) and remained stable two years later (Fig. 28).
Discussion

There were 23 similar clinical scenarios in the study. The patients typically presented with varying degrees of symptoms and contributing factors, which would normally require invasive conventional open-flap surgery and prescriptions for antibiotics and analgesics, followed by a long period of convalescence.

With the flexibility of the Er:YAG laser contact tip, the surgical sites were carefully and precisely designed, the subsequent instrumentations were less invasive, and laser energy transfer was finely controlled.

As a result, the healing experiences of these patients were much more pleasant, and the surgical outcomes were more controlled.

Although there were signs of clinical reattachments for all of the treated areas consistent with Gaspirc and Skaleric in their five-year, 25-patient study, there was no attempt to compare the quantitative assessment of the clinical attachment levels, since the gold standard for surgical reassessment of the actual bone level is not appropriate for clinical studies of this nature.

Then, again, if the main objective of periodontal surgery is the establishment of a new connective tissue attachment to a root surface previously exposed to periodontal disease, the collective clinical and radiographic observations are quite supportive of the effectiveness of this new treatment modality.

With the ablation of both hard (alveolar bone) and soft tissue (granulation and gingival tissue) precisely controlled, periodontal tissue reshaping or recontouring can be planned and performed efficiently with the Er:YAG laser.

The bactericidal and possible biostimulation effects of this radiation with no carbonization or intense coagulation allow faster wound healing without any major postoperative swelling, pain, or bleeding. By allowing the various growth factors involved in wound healing to work soon after the surgery, the less-than-profound hemostasis from the Er:YAG lasers compared with other intense coagulation, can be beneficial and in many situations preferable.

While these laser surgical benefits can be helpful in certain aspects of periodontal surgery, it is important to note that the use of lasers should be considered as an addition to our present armamentarium, not as a replacement for the well-established surgical principles and techniques that have been developed since the first gingivectomy was reported.

Because of the non-touch to light-touch requirements, the use of lasers is technique-sensitive, and due to the proximity of the irradiation to dental and bone tissues, proper training and understanding of basic laser physics is required.
‘The principle behind laser surgery is the selective absorption of optical energy delivered by a specific laser wavelength to produce thermal effects on the target tissues to be excised or modified.’

Appropriate laser parameters, such as power density, pulse duration, exposure time, and water irrigation, should be carefully considered. Although the laser treatments in this study have been successfully carried out, one cannot ignore an enormous contributing factor to success: the patient’s compliance with respect to his or her daily bacterial plaque control. It is normal to expect a better treatment outcome, or at least better control of it, when we incorporate any new technology into our operatory.

The object of this study was to document tissue responses to Er:YAG laser radiation use in surgical periodontal procedures. In particular, we wanted to evaluate whether it was safe and effective to operate the laser in close proximity to root and bone surfaces with less profound coagulation.

In the present study, there were no reports of any postoperative hemorrhagic complications or side effects among the 60 patients, and the dental hard tissues that surrounded the target sites remained vital, functional, and asymptomatic.

The average amount of anesthetics that were reported and the way the anesthetics were used seem to suggest that the demand for anesthetics was reduced. This may be related to the more confined and superficial surgical sites, which in turn reduced the possibility of bacteremia and the demand for antibiotics and analgesics. This was of benefit to some of the patients in this study who had significant medical history.

Conclusion

This was an uncontrolled clinical study that has evolved from a private practice setting; however, the potential benefits of using an Er:YAG laser for periodontal surgery are quite evident. Based on the clinical observations collected, it is both safe and effective to use this laser wavelength in the manner described for periodontal surgery. Further investigation, ideally in the form of a randomized, controlled clinical study, will be required to validate these clinical results.

Disclosure: Dr. Yung lectures for the Institute for Laser Dentistry and receives an honoraria as compensation.

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A complete list of references is available from the publisher.

About the Author

Frank Y.W. Yung, DDS, graduated with honors from the Faculty of Dentistry at the University of Toronto, Ontario, Canada in 1980. He achieved Standard (2001) and Advanced Proficiency (2003) in the use of the diode (980 nm) laser from the Academy of Laser Dentistry. In 2004, Yung achieved Advanced Proficiency in the use of the Er:YAG (2940 nm) laser. In 2005 he was awarded the Educator Certificate from the Academy at the University of California San Francisco. In 2007, Yung was the recipient of the Leon Goldman Award for Clinical Excellence. Presently, Yung is a fellow of the American Society for Laser in Medicine and Surgery, and a member of the Society for Oral Laser Applications and the American Dental Education Association.

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Today’s patients expect restorations that are both functional and esthetic. Unlike yesterday’s, today’s patients have better knowledge of the advanced materials available and state-of-art equipment. Consequently, they have high expectations when designing their smile and other procedures to achieve optimum results. The specialist’s main aim is to achieve complete oral rehabilitation in the most conservative manner.

When choosing a treatment option, dentists and technicians must satisfy both the clinical criteria and the patient’s expectations. To design the optimal outcome for a patient during esthetic enhancement, the dentist must seek to create a symmetrical and harmonious relationship between the lips, gingival architecture and the positions of the natural dentition.

Case report

A 27-year-old patient visited our practice with the chief complaint of attrition in the lower front teeth and generalised discoloration of all the teeth. He also complained of reduced visibility of the lower anterior teeth along with blackish discoloration of the gingiva.

Examination and treatment plan

Clinical examination revealed attrition of the lower anteriors up to the level of the middle third of the coronal tooth structure in relation to teeth #31, 32, 41 and 42. All the teeth were discolored and extrinsic stains due to the patient’s seven-year history of tobacco chewing (as reported by the patient) were present. Overall gingival asymmetry was observed. Generalized pigmentation of the gingiva was also observed (Figs. 1, 2). It was decided to treat the patient in four phases.

Phase 1: Preliminary phase

Impressions were taken and study models were prepared. An OPG was taken. Oral prophylaxis was done. The patient was recalled after two days for further treatment.

Phase 2: Surgical phase

The second phase entailed a laser-assisted gingivectomy and laser-assisted endodontic sterilization.

Gingivectomy

Lasers offer increased operator control and minimal collateral tissue damage. The fine tip of the diode laser can be manipulated easily to create the gingival margin contours required to perform the aesthetic crown-lengthening procedure. The surgical site was anaesthetised and the biological width was determined.

A 980 nm diode laser with a 400 μ cable was used for the surgical procedure. The amount of gingival tissue to be incised was outlined. Initial incision for the laser-assisted gingivectomy was similar to that of using a blade with an external bevel approach. The distance of the incision from the coronal marginal gingiva is based on the pocket depth and the amount of attached gingiva.

The gingival chamfer is achieved and the initial cut is made slightly apical to the pocket depth measurement. A slow, unidirectional hand motion is used, moving the tip at an external bevel towards the tooth structure. Caution is necessary, especially near the root structure, because of a possible laser–hard tissue interaction, which could harm the tissue. During
the course of surgery, care was taken to maintain the biological width and to preserve the attached gingiva (Figs. 3–5). The access cavity was prepared according to the traditional method. The rotary instruments were used along with the ProTaper files for cleaning and shaping the root canals.

**Sterilization**

A 980 nm diode laser with a 200 μcable was used for sterilization of the canals along with regular chemical disinfectants.

The advantage of laser sterilization to a conventional irrigant regime to provide sterilization is that while irrigating solutions have a limited depth of penetration, the laser beam transmitted through the tip of a fiber is emitted in a lateral direction and has an effective penetration depth of more than 1,000 μm.

This was followed by obturation and coronal access restoration with composites. The patient was recalled after one week for further treatment.

**Phase 3: Esthetic phase**

The third phase entailed laser-assisted depigmentation and laser-assisted bleaching.

**Depigmentation**

The diode laser was used at 2 W, continuous wave in a defocused mode. This causes a reduced depth of penetration, ablating only the superficial epithelium, which primarily contains the melanin pigments, leaving behind a carbonized layer. Only a surface anaesthetic spray was used for this procedure.

**Bleaching**

Laser light has the unique property of being absorbed by the chromospheres. These emulsions can be added to the bleaching gel, which are capable of absorbing laser energy and thus inducing and promoting a fast, safe and effective reaction. Cheek and tongue retractors were positioned and a dry operatory was maintained. The gingival protection material was applied along the margin of the gingival covering approximately 1 mm from the tooth surface in the cervical region.

The bleaching gel was applied to teeth #11, 21, 12 and 22. Each tooth was then irradiated for 30 seconds in the same sequence, constantly moving the tip of the laser, so that the laser energy was not directed at one place (at 1 W). Fluoride gel was applied to each tooth and irradiated with the laser for 15 seconds to provide resistance to acid attacks on enamel and dentine. The patient was recalled after two weeks.

**Phase 4: Prosthetic phase**

Crown preparation of teeth #42, 41, 32 and 31 was done. Elastomeric impressions were taken. Bite registration records were taken and the appropriate shade was sent to the laboratory for the fabrication of the crowns.

Temporary restorations were fabricated using temporization material. The patient was recalled after six days for the cementation of the crowns. Excess cement was removed, the occlusion was adjusted and contours were checked.

**Inference**

The final result showed that the definitive restorations and the soft-tissue procedures had restored the normal form, function and harmony of the oral cavity, while keeping the patient’s functional and esthetic concerns in mind.

**Conclusion**

Dental lasers promote patient compliance through the non-invasive nature of treatment, faster recovery time and reduced postoperative discomfort. The use of laser reduces chairside time and improves operator efficiency and thereby reduces fatigue.
The use of the Er:YAG in laser-assisted broken abutment screw treatment

Authors: Avi Reyhanian, DDS, Steven Parker, BDS, LDS, RCS, MFGDP, Joshua Moshonov, DMD, and Natan Fuhrman, DDS

Abstract

Dental implants are a functional and esthetic solution to partial and total edentulism. Although the overall success rate of implant dentistry is very high, more than 90 percent of the treatment modality is not free of complications and dental implants occasionally fail. The chronic loosening or fracturing of implant screws continue to be a problem in restorative practices and generally are challenging to remove.

This report describes and demonstrates the management and technique used for the removal of fractured screw fragments and the successful utilization of the Er:YAG laser as an important auxiliary tool.

Introduction: The problem

Success in implant-supported prosthetic replacement of teeth will be due to a combination of appropriate placement criteria (receptor site quality, implant stability, osseo-induction), appropriate (non-excessive) loading and prevention of bacterial contamination.

The failure of dental implants is due not only to biological factors, such as unsuccessful osseo-integration or the development of peri-implantitis, but it may also result from technical complications. Dental implant complications may be considered under the following main categories:

Early
- Failure/inadequate surgical preparation.
- Failure of osseo-integration.
- Peri-surgical infection.

Late
- Implant overloading, leading to bone loss.
- Peri-implantitis.
- Soft tissue complications.
- Fracture of mechanical components and esthetic/phonetic considerations.

Failures of implant-supported restorations result from technical problems and can be divided into two groups: those relating to implant components, and those relating to the prosthesis. Technical problems related to implant components include abutment screw fracture. The abutment screw fracture presents a rare, but quite unpleasant failure and can be a serious problem, as the fragment remaining inside the implant.
may prevent the implant from functioning efficiently as an anchor.\textsuperscript{13} The primary reason for screw fracture is undetected screw loosening which can be due to bruxism, an unfavorable superstructure, overloading\textsuperscript{16,17} or malfunction\textsuperscript{10,11,18,19}.

Fractures of the implant abutment or of the abutment screw have been observed as a consequence of screw loosening and undetected micro-movements of the abutment under functional loading\textsuperscript{20} and consequently, it is advised that the repeated loosening of an abutment screw should alert the clinician to possible significant contributing causes.

However, the behavior of the implant/abutment joint components with respect to critical bending force is still unclear.\textsuperscript{20,21}

Studies show that implant abutment failure occurs when lateral forces exceed 370 Newtons for abutment with a joint depth of at least 2.1 mm and 530 Newtons with a joint depth of at least 5.5 mm.\textsuperscript{7}

\textbf{Preventive recommendations}

\begin{itemize}
  \item The number, position, dimension and design of implants, as well as the design of the prosthesis are critical factors to be considered during the treatment planning phase.\textsuperscript{11–13,22,23}
  \item To withstand high bending stresses, implants should be as long and as wide as possible, used in adequate numbers, and be positioned such as to allow axial loading.\textsuperscript{13,21,24,27}
  \item Implant components are known to fracture more frequently in the posterior region and in partially dentate patients compared with completely edentulous patients.\textsuperscript{5,21,11,12,16,20,24}
  \item Retightening an abutment screw ten minutes after the initial torque applications should be routinely performed, and increasing the torque value for abutment screws above 30 Newtons can be beneficial for the abutment, implant stability and to decrease the possibility of the screw becoming loose.\textsuperscript{25}
  \item Select proper cases, use excellent surgical technique, place an adequate restoration on the implant, educate the implant patient as to the importance of maintaining meticulous oral hygiene, evaluate results at frequent recall visits\textsuperscript{26} and reinforce periodic maintenance.
  \item A procedure for using dimples inside the abutment screw cylinder above the screw, and filling the holes with elastomeric impression material will prevent the screw-retained prosthesis from loosening.\textsuperscript{27}
  \item Use the correct fixation screw.
  \item Replace loose screws instead of retightening them.
  \item Immediately investigate if looseness of the prosthesis is detected by the clinician or patient.\textsuperscript{26,29}
\end{itemize}

\textbf{Fragment retrieval methodology}

The methods employed to grasp the broken fragments or screw are determined according to the location of the fracture abutment — above or below the head of the implant. If an abutment screw fractures above the head of the implant, an explorer, a straight probe or haemostats\textsuperscript{30} might be successful.

The tip of the instrument is moved carefully in a counter-clockwise direction over the surface of the screw segment until it loosens.\textsuperscript{1} If the screw fracture occurs below the head of the implant, other methods
are required. There are several available implant repair kits:

- ITI® Dental Implant System (Institut Straumann AG, Switzerland), consists of drills, two drill guides and six manual tapping instruments.¹
- IMZ® TwinPlus Implant System¹ (Dentsply Friadent, Germany)
- Screw Removal Kit Replace (Nobel Biocare™, Yorba Linda, Calif.)
- Certain®-Screw Removal Kit (Biomet 3i™, Florida³)

The application of these systems is to permit a hole to be drilled into the centre of the broken screw and drive a removal wedge into the hole that engages the broken screw when reverse torque is applied by removing the instrument. If no thread damage has occurred and the screw has not "bottomed out" or torqued into a seating stop, then the force necessary to remove the screw may be minimal.⁸

If none of these systems is available, another method for broken screw retrieval involves the following procedure: After the prosthesis or abutment is removed, the screw hole is vigorously flushed with an air/water spray from a three-way syringe. Pressurized air is applied to dry the screw hole, and a drop of mineral oil (delivered on the tip of an explorer) is introduced into the screw hole.

A sharp 1/4-round bur in a high-speed handpiece is activated and lightly applied to the exposed side of the fractured screw. The objective is to have the spinning bur’s blades contact the metal surface of the screw so that the screw will spin itself out of the hole. When repeated several times, the screw can be backed out and retrieved easily with forceps.⁶ If this technique fails, a slot can be created using a surgical drill, on the head of the fractured screw, and then a screwdriver is used to back out the broken abutment screw.

Sometimes just a gentle touch with the drill to the head of the broken screw will be enough to back it out. If the hexagonal head of the screw is stripped, it should be filed away completely using a round carbide bur or heatless stone, the head of the implant should be straightened, and a new abutment may be rotated into the implant.

_Case study_

This clinical report describes a situation in which a fractured implant abutment screw was successfully retrieved by using the Er:YAG laser as an auxiliary tool, and the advantages of this 2,940 nm wavelength versus conventional methods.

_Examination_

A 36-year-old male presented for treatment, reporting the detachment of an implant-supported crown in the region of the upper left central incisor. The patient stated that the implant and crown had been placed four years earlier and that looseness of the crown had occurred on two occasions during this period.

On both occasions, the screw had been re-tightened with no further investigation. Clinical examination of the patient revealed a missing tooth at the location of #9 with no sign of an implant (Fig. 1). The patient brought the abutment, crown and broken screw with him (Fig. 3).
Radiographic examination of the area showed the presence of a root-form cylindrical implant, consistent in appearance with a 13 mm long, 3.75 mm diameter abutment with an internal hex. The apical part of the screw remained threaded into the implant, but had fractured at the level of the hexagonal lock. Although the implant was osseointegrated, there were radiographic signs of peri-implantitis with some crestal bone loss having occurred (Fig. 2).

_Treatment options_

The treatment options available were: 1) retrieve the fractured screw, or 2) remove the old implant and insert a new implant in one sitting.

Following discussion with the patient and evaluation of the possibilities for success, it was decided to try and retrieve the fractured screw.

Treatment would involve the use of the Er:YAG laser to perform the following, based upon accepted research:

- The flap incision.\textsuperscript{31,32,33}
- Ablation of granulation tissue around the implant.\textsuperscript{34–36}
- Remodelling, shaping and ablating of the bone.\textsuperscript{32,34,37,38}
- Detoxification of the infected surfaces of the implant.\textsuperscript{36,39,40–42}
- An associated osteogenic (GBR) procedure to prevent soft tissue in-growth and maintain the form of the alveolus treatment alternatives, using a more conventional approach, would include the use of traditional scalpel, curettage, and rotary instruments.

_Treatment_

A dual-wave laser system with operating wavelengths of 2,940 nm and 10,600 nm (OpusDuo™ AquaLite™, Lumenis, Ltd. Yokneam, Israel) was employed for this procedure. The laser operating parameters employed for the various surgical stages were as follows:

- Flap Access: Wavelength: 2,940 nm (Er:YAG), 200-micron sapphire tip, in contact mode; 450 mJ per pulse at 20 Hz. Total power: 9 Watts.
- Granulation Tissue Removal: Wavelength: 2,940 nm (Er:YAG), 1,300-micron sapphire tip, in non-contact mode; 700 mJ per pulse at 12 Hz. Total power: 8.4 Watts.
Bone Surgery: Wavelength: 2.940 nm (Er:YAG), 1,300-micron sapphire tip, in non-contact mode; 450 mJ per pulse at 20 Hz. Total power: 9 Watts.

Detoxification of the implant: Wavelength: 2.940 nm (Er:YAG), 1,300-micron sapphire tip, in non-contact mode; 150 mJ per pulse at 20 Hz. Total power: 3 W.

Decortication for GBR technique: Wavelength: 2.940 nm (Er:YAG), 1,300-micron sapphire tip, in non-contact mode; 500 mJ per pulse at 17 Hz. Total power: 8.5 Watts.

A "V" shape incision was made with the Er:YAG laser. An intrasulcular incision was made (after anaesthesia) at the buccal and palatal side of the implant, together with two vertical relieving incisions: one at the mesial side of tooth #8 and the second at the mesial side of tooth #11 (Figs. 4, 5). The buccal and palatal flaps were lifted and the area explored (Fig. 6); there was granulation tissue around the neck of the implant. The granulation tissue was ablated using the laser (Fig. 9).

Vaporization of granulation tissue (if any exists) after raising a flap is efficient with the Er:YAG laser, offering a lower risk of overheating the bone than that posed by the current diode or CO2 lasers,43 and often obviates the need for hand instruments. Results from both controlled clinical and basic studies have pointed to the high potential of the Er:YAG laser and its excellent ability to effectively ablate soft tissue without producing major thermal side-effects to adjacent tissue has been demonstrated in numerous studies.35–37

The broken hexagon slot was straightened, using a round diamond bur and the head of the implant was rendered smooth. A slot was created with a surgical drill on the head of the fractured screw, and a screwdriver was successfully used to unscrew the broken abutment screw (Figs. 7, 8).

The Er:YAG laser was aimed at the surface of the exposed implant for the purpose of decontaminating the infected exposed surfaces, without damaging them.36,40,41,42,43 Studies have shown that Er:YAG laser energy effects on bone include bacterial reduction.41,44 Following this, all accessible bone surfaces were exposed to laser energy to ablate necrotic bone and to shape and remodel the surface, in accordance with established clinical protocols.32,34,36,39

Decortication of the buccal bone was then performed (Fig. 10). The purpose of decortication is to encourage bleeding, providing progenitor cells to the site. A new abutment was then inserted into the implant (Fig. 11).

All spaces between implant and existing osteotomy site were filled with a xenograft bone substitute (Bio-Oss®, Geistlich Biomaterials) and covered with an absorbent bilayer membrane (Bio-Gide®, Geistlich Biomaterials), (Figs. 12, 13).

The mucoperiosteal flap was re-positioned and sutured with silk 3-0, paying particular attention to primary closure of the flap (Fig. 14).

**Postoperative instructions**

The patient was prescribed Clindamycin 150 mg x 50 tabs to avoid infection. He was also given Motrin 800 mg x 15 tabs for pain. Instructions were given to rinse with Chlorhexidine 0.2 percent, starting the next day for 2 weeks x 3 per day.

**Management of complications and follow-up care**

The following day the patient reported moderate pain and moderate swelling. There was no tissue bleeding and the site was closed. The flap was showing signs of attachment and was healing nicely. At 10 days postoperative, the patient returned for inspection and removal of sutures. The swelling had resolved, there were no signs of fistula and healing was progressing well.

After five months, the soft tissue was completely healed without complications (Figs. 16, 17). The soft issue had healed over the bone and there were no bony projections observed under the soft tissue. The prognosis is excellent.
**Conclusion**

The use of osseo-integrated implant-supported prostheses in the replacement of missing natural teeth has become an accepted clinical protocol in dentistry. Success in this area is enhanced through correct diagnosis, treatment planning and maintenance; however, complications often occur, which may be significant and compromise the long-term success of the implant abutment and associated prosthesis. The management of such complications has given rise to several techniques to address failings, such as component fracture and bacterial contamination.

The Er:YAG (2,940 nm) laser can be employed as an auxiliary tool for the purpose of decontamination of infected implant surfaces and it has been shown to be effective and safe.

The use of the 2,940 nm wavelength for these procedures presents many advantages vs. conventional methods, including enhancing the surgical site and minimizing bleeding during the operation, providing the practitioner a better field of visibility and reducing patient discomfort.

In addition, anecdotal claims have been made that postoperative effects such as pain and swelling are less pronounced. A summary of possible serious complications associated with implant placement has been given, together with a report of a clinical case in which the use of the Er:YAG laser has been shown to be beneficial in the management of the consequences of a fractured abutment screw.

Editorial note: A complete list of references is available from the publisher. This article first appeared in Laser, the international magazine of laser dentistry, Vol. 2, 3/2010, published by Oemus Media AG, Leipzig, Germany.

All photos were provided by the authors.
As the emphasis shifts from damage mitigation to disease prevention or reversal of early disease in the oral cavity, the need for sensitive and accurate detection and diagnostic tools becomes more important. Many novel and emergent optical diagnostic modalities for the oral cavity are becoming available to clinicians with a variety of desirable attributes, including: (a) non-invasiveness; (b) absence of ionising radiation; (c) patient friendly; (d) real-time information; (e) repeatability; and (f) high-resolution surface and subsurface images.

In this article, the principles behind optical diagnostic approaches, their feasibility and applicability to imaging soft and hard tissue, and their potential usefulness as a tool in the diagnosis of oral mucosal lesions, dental pathologies, and for other dental applications will be reviewed.

Introduction

Light-based imaging of tissue detects minimal changes, such as: (a) cell microanatomy (e.g. nuclear/cytoplasmic ratio); (b) redox status; (c) expression of specific biomarkers; (d) tissue architecture and composition; (e) chemical changes (e.g. mineralisation); and (f) vascularity/angiogenesis and perfusion. These properties are ideal for the detection of minimal (early) changes, for assessing the margins of lesions and potentially the presence of subclinical abnormalities beyond the clinical margins, for repeated non-invasive monitoring of existing lesions, and for rapidly examining at-risk populations.

Oral cancer

Chemiluminescence: ViziLite
This imaging device has been used in the oral cavity since 2001. After rinsing with an acetic acid mixed solution, the oral cavity is examined under chemiluminescent illumination at 430, 540 and 580 nm wavelengths. This method allows increased visual distinctions between normal mucosa and oral white lesions (Huber et al. 2004; Kerr et al. 2006; Epstein et al. 2006; Epstein et al. 2008). The detected signals may be related to the altered thickness of the epithelium, or to the presence of a higher density of nuclear content and mitochondrial matrix that preferentially reflect light. Hyper-keratinised or dysplastic lesions appear distinctly white when viewed under a diffuse low-energy wavelength light. In contrast, normal epithelium will absorb light and appear dark (Lingen et al. 2008). Since the majority of studies investigating
chemiluminescence reported subjective perceptions of intraoral lesions in terms of brightness, sharpness and texture versus routine clinical examination, data interpretation may vary significantly between examiners (Huber et al. 2004; Kerr et al. 2006). In January 2005, a combination of both toluidine blue and ViziLite systems (ViziLite Plus with TBlue system) received FDA clearance as an adjunct to visual examination of the oral cavity in populations at increased risk for oral cancer. In a multicenter study of high-risk patients, it was reported that the majority of lesions with a histological diagnosis of dysplasia or carcinoma in situ were detected and mapped using ViziLite and toluidine blue (Epstein et al. 2008). Recently, a new chemiluminescence device (Microlux/DL, AdDent) has been introduced as an adjunct tool for oral lesion identification (McIntosh & Farah 2009).

Spectroscopy and autofluorescence

Tissue autofluorescence has been applied in the screening and diagnosis of pre-cancer and early cancer of the lung, uterine cervix, skin and, more recently, of the oral cavity. During the disease process, the altered cellular structure (e.g. hyperkeratosis, hyper-chromatin and increased cellular/nuclear pleomorphism) and/or metabolism (e.g. concentration of flavin adenine dinucleotide and nicotinamide adenine dinucleotide) affect tissue interaction with light. Spectroscopy or autofluorescence imaging can provide information about these altered light interaction properties.

In the last decade, several forms of autofluorescence technology have been developed for inspection of the oral mucosa. LED Medical Diagnostics Inc. in partnership with the British Columbia Cancer Agency has marketed the VELscope system (Lingen et al. 2008; Patton et al. 2008; De Veld et al. 2005). When viewed through the instrument eyepiece, normal oral mucosa emits a pale green autofluorescence upon stimulation with intense blue excitation at 400 to 460 nm wavelength, whilst dysplastic lesions exhibit decreased autofluorescence and appear darker with respect to the surrounding healthy tissue. Several studies have investigated the effectiveness of the VELscope system as an adjunct to visual examination, and determined an improvement in the ability to distinguish between oral lesions and healthy mucosa, and between different lesion types (De Veld et al. 2005).

Overall, the technique appears to show high sensitivity, but low specificity (De Veld et al. 2005). Using histology as the comparative gold standard, VELscope demonstrated high sensitivity and specificity in identifying areas of dysplasia and malignancy that extended beyond the clinically evident tumours (Lingen et al. 2008; Patton et al. 2008; De Veld et al. 2005; Onizawa et al. 1996; Schantz et al. 1998). A direct clinical application entails assessing pathology margins in patients with potentially malignant oral lesions, thereby assisting in guiding surgical management (Poh et al. 2007; Rosin et al. 2007). However, reported evaluations of the VELscope system are from case series and case reports rather than clinical trials, and no published studies have assessed the VELscope system as a diagnostic adjunct in screening patient populations (including patients with or without a history of dysplasia/oral squamous cell carcinoma).

In another study using quantitative fluorescence imaging in 56 patients with oral lesions and 11 normal volunteers, healthy tissue could be discriminated from dysplasia and invasive cancer with a sensitivity of 95.9 percent and specificity of 96.2 percent in the training set, and with a sensitivity of 100 percent and specificity of 91.4 percent in the validation set. Lesion probability maps qualitatively agreed with both clinical assessment and histology (Roblyer et al. 2009). Further clinical studies are needed in diverse populations to evaluate fully the clinical usefulness of this promising technology. Other devices using a range of spectroscopic techniques are under development, often combined with other technologies. These include the FastEEM4 System, the IdentiFt (Remicalm) and the PS2-oral (Schwarz et al. 2009; McGee et al.
Fig. 1. Indispensable part of a successful therapy: optical diagnostic.

Fig. 1

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user report

optical diagnostics

2008; Lane et al. 2006; De Veld et al. 2005; Wagnieres et al. 1998; Ramanujam et al. 2000; Culha et al. 2003; Choo-Smith et al. 2002; Bigio et al. 1997; Farrell et al. 1992). Clinical studies are still at a relatively early stage, but preliminary results are encouraging. The Identafi technology combines anatomical imaging with fluorescence, fiber optics and confocal microscopy to map and delineate precisely the lesion in the area being screened. In a screening of 124 subjects, a sensitivity of 82 percent and specificity of 87 percent were determined for differentiating between neoplastic and non-neoplastic sites in the oral cavity. Results appeared to vary between sampling depths, and keratinized versus non-keratinized tissue (Schwarz et al. 2009). Major challenges to diagnostic spectroscopy include the often low signal-to-noise ratio, difficulty in identifying the precise source of signals, data quantification and difficulty in establishing definitive diagnostic milestones and endpoints, especially given the wide range of tissue types within the oral cavity. The depth of tissue penetration is an inherent limitation of the technology. Additional concerns relate to the potential mutagenicity induced by UV light in the clinical setting.

Photosensitizers

When topical or systemic photosensitizers are administered, their ability to accumulate in cancer cells and to fluoresce under specific wavelengths can be used to identify and delineate areas of microscopic changes (Kennedy et al. 1992; Cassas et al. 2002). This approach permits 3-D mapping of the epithelial surface and subepithelial boundary, screening of large surface areas and offers the option of subsequent photodestruction of the photosensitized lesion. Some promising agents for photodetection include aminolevulinic acid (Levulan), hexyl aminolevulinate (Hexvix), methyl aminolevulinate (Metvix), tetra(meta-hydroxyphenyl)chlorin, as well as porfimer sodium (Photofrin; Ebihara et al. 2003; Leunig et al. 1996, 2000, 2001; Chang & Wilder-Smith, 2005).

In a blinded clinical study of 20 patients with oral neoplasms, diagnostic sensitivity using unaided visual fluorescence diagnosis or fluorescence microscopy approximated 93 percent. Diagnostic specificity was 95 percent for visual diagnosis, improving to 97 percent using fluorescence microscopy (Chang & Wilder-Smith, 2005). A recent study using epidermal growth factor–targeted fluorescent agents by topical application to oral mucosal lesions, combined with in vivo imaging, demonstrated encouraging results with regard to lesion detection, margin delineation and as an adjunct guiding tool for biopsy (Nitin et al. 2009). Depending on the photosensitizer and its mode of application (systemic versus topical), limitations include systemic photosensitization over prolonged periods, penetration-related issues, the need for specialized fluorescence detection and mapping equipment, and lack of specificity when inflammation or scar tissue is present.

Optical coherence tomography

Optical coherence tomography (OCT) was first introduced as an imaging technique in biological systems in 1991 (Huang et al. 1991). The non-invasive nature of this imaging modality, coupled with a penetration depth of 2 to 3 mm, high resolution (5–15 μm), real-time image viewing and capability for cross-sectional, as well as 3-D tomographic images, provides excellent prerequisites for in vivo oral screening and diagnosis. OCT has frequently been compared to ultrasound imaging. Both technologies employ back-scattered signals reflected from different layers within the tissue to reconstruct structural images, with the latter measuring sound rather than light. The resulting OCT image is a 2-D representation of the optical reflection within a tissue sample. Cross-sectional images of tissue are constructed in real time, at near histological resolution (approximately 5–15 μm with current technology). These images can be stacked to generate a 3-D reconstruction of the target tissue. This permits in vivo non-invasive imaging of epithelial and subepithelial structures, including depth and thickness, histopathological appearance and peripheral margins of the lesions.

Several OCT systems have received U.S. FDA approval for clinical use, and OCT is deemed by many as an essential imaging modality in ophthalmology. In vivo image acquisition is facilitated through the use of a flexible fiber-optic OCT probe. The probe is simply placed on the surface of the tissue to generate real-time, immediate surface and subsurface images of tissue microanatomy and cellular structure, whilst avoiding the discomfort, delay and expense of biop-
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sies. Several studies have sought to investigate the diagnostic utility of in vivo OCT to detect and diagnose oral pre-malignancy and malignancy (Tsai et al. 2008; Wilder-Smith et al. 2009). In a blinded study involving 50 patients with suspicious lesions, including oral leukoplakia and erythroplakia, the effectiveness of OCT for detecting oral dysplasia and malignancy was evaluated (Wilder-Smith et al. 2009).

OCT images of dysplastic lesions revealed visible epithelial thickening, loss of epithelial stratification, and epithelial downgrowth. Areas of oral squamous cell carcinoma of the buccal mucosa were identified in the OCT images by the absence or disruption of the basement membrane, an epithelial layer that was highly variable in thickness, with areas of erosion and extensive epithelial downgrowth and invasion into the subepithelial layers. Statistical analysis of the data gathered in this study substantiated the ability of in vivo OCT to detect and diagnose pre-malignancy and malignancy in the oral cavity with excellent diagnostic accuracy. For detecting carcinoma in situ or squamous cell carcinoma (SCC) versus non-cancer, sensitivity was 0.931 and specificity was 0.931; for detecting SCC versus all other pathologies, sensitivity was 0.931 and specificity was 0.973.

In another study of 97 patients using OCT imaging to detect neoplasia in the oral cavity (Tsai et al. 2009), the results revealed that the main diagnostic criterion for high-grade dysplasia/carcinoma in situ was the lack of a layered structural pattern. Diagnosis based on this criterion for dysplastic/malignant versus benign/reactive conditions achieved a sensitivity of 83 percent and specificity of 98 percent with an inter-observer agreement value of 0.76. This study concluded that OCT, with high sensitivity and specificity combined with good inter-observer agreement, is a promising imaging modality for non-invasive evaluation of tissue sites suspicious for high-grade dysplasia or cancer.

Other studies have utilized direct analysis of OCT scan profiles, rather than image-based criteria, as a means of delineating the site and margins of oral cancer lesions (Tsai et al. 2008). Using numerical parameters from A-scan profiles as diagnostic criteria, the decay constant in the exponential fitting of the OCT signal intensity along the tissue depth decreased as the A-scan point moved laterally across the margin of a lesion. Additionally, the standard deviation of the OCT signal intensity fluctuation increased significantly across the transition region between the normal and abnormal portions. The authors concluded that such parameters may well be useful for establishing an algorithm for detecting and mapping the margins of oral cancer lesions. Such a capability has huge clinical significance because of the need to better define excisional margins during surgical removal of oral pre-malignant and malignant lesions.

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_Dental pathologies and other applications_

Light scattering, reflection, absorption and laser-induced fluorescence can provide much information regarding hard-tissue structure and pathology. The techniques described below — OCT, polarization-sensitive OCT (PS-OCT), laser fluorescence (DIAG-NOdent, KaVo), quantitative laser fluorescence (QLF), fiber-optic transillumination — exploit this concept, achieving varying degrees of specificity and sensitivity for detecting demineralization and decay of the dental matrices, the anatomical structure of the tooth organ, as well as the attached microbial biofilms and calculus.

_Dental caries_

Optical coherence tomography

As described above, OCT measures the intensity of back-scattered light to create images. Light does not travel at a constant velocity when it passes through different structures, travelling faster in material with a low refractive index and slower in media with a high refractive index. Additionally, when the light hits a sharp change in refraction, the wave is reflected either externally or internally. The amount of reflection depends on the amount of change in refraction, the angle the light is travelling at and the polarisation of the light.

If the change of refraction between the media is gradual, the reflection will be minimal (Brenzinski et al. 2006; Colston et al. 1998; Feldchtein et al. 1998; Otis et al. 2000). The changes between the hard tissues such as enamel and dentine and between healthy and demineralized or carious states can then be interpreted to create 2-D and 3-D images of the hard tissues.

As such, various optical properties are under investigation as potential quantifiers of the mineralisation changes to detect dental caries (Li et al. 2009). In the relatively early days of OCT, two groups of researchers investigated the feasibility of using OCT in vivo to image sound and demineralized tissue, and even monitored restorative procedures (Colston et al. 1998). A recent publication described the use of in vivo OCT to determine the effectiveness of a proton pump inhibitor in treating gastro-oesophageal reflux by monitoring dental erosion with OCT (Wilder-Smith et al. 2009). The study was significant in that the researchers were able to identify an association between the medication and a reduction in enamel erosion.

_Polarization-sensitive OCT_

Since both enamel and dentine have strong polarizing effects, changes in polarisation provide more structural information than conventional OCT.
(Brezinski, 2006). Light is delivered in one polarization, and the reflection is read in both polarisations. Although we were unable to find clinical studies that used PS-OCT, extensive research has been conducted by Fried and others that demonstrates that this technology has the potential to monitor demineralization/remineralization and quantify demineralized tooth structure, even below dental sealant (Manesh et al. 2009; Chen et al. 2005; Jones et al. 2006; Jones & Fried 2006; Ngaetheppitak et al. 2005; Chong et al. 2007; Jones et al. 2004). Unfortunately, PS-OCT technology has not been as effective in identifying root caries (Lee et al. 2009).

**Laser fluorescence**

Back-scattered light from laser-induced fluorescence has been reported as a tool to detect and quantify caries activity (Zandona & Zero 2006). A red laser light (655 nm wavelength) is absorbed by organic and inorganic matter in the tooth and then re-emitted from the organic material as near-infrared fluorescent light. The device provides a numerical printout and an audible signal when decay is detected. The results of studies investigating diagnostic usefulness of DIAGNOdent vary considerably (Chong et al. 2003; Kuhnisch et al. 2008).

The lack of diagnostic consistency may reflect: (a) the need for clinicians to learn how to use the correct position for the unit; (b) staining and/or calculus affecting the readings; and (c) difficulty in determining the numerical value at which surgical intervention is indicated (Shi et al. 2000).

However, the literature appears to be consistent in describing DIAGNOdent as a better tool for detecting dental caries than enamel caries. Additional benefits of the DIAGNOdent may be its ability to identify completed removal of infected tooth structure during excavation (Lussi et al. 2004). While DIAGNOdent’s high rate of false-positive results may be a limitation in some clinical practices, in a high-risk population with limited access to dental care, this tool may be quite predictive in caries screening.

**Quantitative light fluorescence**

QLF uses fluorescence induced by multi-wavelength excitation at 290 to 450 nm to measure mineral loss in enamel and dentine (Hall & Girkin 2004). Unlike the DIAGNOdent system, this device provides colour-coded images of the target tissue. Sound tooth structure fluoresces and carious tooth structure appears dark. As the caries scatters the light, mapping the carious lesion can be difficult. Interestingly, the predictive nature of this technology depends on the population (Hall et al. 2004). In a high-risk population, QLF is highly predictive (.90–.98) of future caries (Zandon & Zero 2006). In a low-risk population, it is much less predictive, and stains, plaque, and fluorosis can affect QLF accuracy (Zandona & Zero 2006). High-intensity UV light can generate free radicals, potentially resulting in toxicity to live tissue.

**Fiber-optic transillumination**

This approach uses changes in the scattering and absorption of photons by structural characteristics to detect caries in real time. Advantages of this technology include safety, as UV light is not used. In digital-imaging fiber-optic transillumination (DIFOTI), the light that passes through the tooth is interpreted by a digital device on the other side of the tooth. DIFOTI seems to perform well for early surface lesions; however, it seems to have low specificity, which can result in overtreatment and is also unable to determine lesion depth, which limits potential sites of use (Young et al. 2005; Bin-Shuwaish et al. 2008; Schneiderman et al. 1997).

Recently, Wu and Fried used near infra-red (NIR) transillumination to image dental caries (Wu & Fried 2009). This technology takes advantage of the transparency of sound enamel at 1310 nm, which decreases considerably in unhealthy tooth structure. Demineralized areas on the enamel surface appear lighter, while deeper lesions appear darker.

However, low contrast as compared to the high reflectance signal and decreasing effectiveness with
increasing tooth thickness are important clinical challenges. Although we were unable to identify clinical studies using NIR transillumination, the concept holds great promise, for example, allowing clinicians to monitor remineralization of enamel.

Other dental applications

**Periodontics**

Fluorescence using the periodontal probe for DIAGNODent

Because calculus fluoresces differently than healthy tissue, the use of laser fluorescence has been proposed as an aid to detect residual calculus following root planing and scaling. The DIAGNODent perio probe may aid in clinical detection of sub-gingival calculus deposits far better than conventional methods (Kasa et al. 2008; Krause et al. 2003; Krause et al. 2005). Audible sounds and measurable values as signals for presence of calculus during screening may increase patients’ awareness of their calculus levels, leading to increased patient compliance with the recommended treatment.

Optical coherence tomography

Several in vitro studies have demonstrated the potential use of OCT as an adjunct tool for diagnosis of periodontal disease. Studies in a porcine model showed high-resolution images of periodontal tissue, the enamel–cementum and the gingiva–tooth interfaces (Colston et al. 1998). While results of early in vivo studies were promising, consistent imaging of the periodontal tissue remains challenging owing to the limited penetration depth and scan sizes of OCT (Colston et al. 1998). In another study by Baek et al. the successful use of OCT for monitoring periodontal ligament changes during orthodontic tooth movements in rats was reported (Baek et al. 2009).

Endodontics

Fluorescence using the DIAGNODent perio probe

Real-time assessment of the microbial status of the root canal system would be useful in clinical endodontic practice for determining endpoints of biomechanical treatment. In an ex vivo study using extracted teeth, the DIAGNODent, in combination with a prototype sapphire tip designed for periodontal assessment, was used to evaluate the pulp chamber and coronal third of the root canal system. The fluorescence properties of bacterial colonies, biofilms in root canals, pulpal soft tissue and sound dentine were evaluated in 50 extracted teeth with known endodontic pathology. Sound dentine and healthy pulpal soft tissue gave an average fluorescence reading of 5 (on a scale of 100), whereas biofilms of *Enterococcus faecalis* and *Streptococcus mutans* colonising the root canals showed a progressive increase in fluorescence signals over time. Fluorescence readings reduced to the “healthy” threshold range when root canals were endodontically treated, and the experimentally created bacterial biofilms were removed completely. High fluorescence readings were recorded in the root canals and pulp chambers of extracted teeth with radiographic evidence of peri-apical pathology and scanning electron microscopy evidence of bacterial infection (Sainsbury et al. 2009).

Optical coherence tomography

In a study on extracted teeth, the diagnostic accuracy of high-resolution OCT using a 0.5 mm diameter intra-canal probe for mapping canal walls, uncleaned fins, risk zones and root perforations approached that provided by histology (Shemesh et al. 2007). The probe easily fitted into a prepared root canal and its flexibility allowed penetration and advancement through curvatures. The optical probe rotated within a probe sheath so that adjacent lines in each rotation could be stacked to generate a frame showing a cross-section of the tissue architecture in the wall. The scan was quick, about 15 seconds for a 15 mm-long root. The authors concluded that fibre-optic OCT probing holds promise for full in vivo endodontic imaging. Another ex vivo study assessed apical micro-leakage following endodontic treatment using OCT (Todea et al. 2009). OCT imaging was found to be effective in identifying the apical seal. However, in the real clinical situation, OCT use for peri-apical diagnostics is limited by its short penetration depth into the bone in which the tooth is embedded.

Conclusion

Emergent optical technologies show promise for a wide range of oral diagnostic applications with capabilities for high-resolution, cross-sectional tomographic imaging of microstructure in several biological systems. OCT can achieve image resolution one to two orders of magnitude finer than standard ultrasound. As such, OCT functions more effectively as a unique “optical biopsy” to delineate the cross-sectional images of tissue structure at the micro-scale. This promising biomedical optical imaging technology provides images of tissue in situ and in real time, without the need for surgical biopsy and multiple-specimen processing. OCT imaging allows detection and diagnosis of early stages of disease in teeth, periodontal tissue and mucosa, and facilitates large-scale screening for high-risk populations. Because of the rapid pace of innovation in this field, the cost and ease of use of such modalities are improving rapidly, such that many such devices are becoming available to dental clinicians. We envisage many benefits to patients and clinicians from the use of these devices.
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2012
The clinical use of the Er,Cr:YSGG laser in endodontic therapy

Author: Justin Kolnick, DDS

Total elimination of bacteria from infected root canal systems remains the most important objective of endodontic therapy. However, in spite of a plethora of new products and techniques, achieving this objective continues to elude our profession.

Historically, endodontic treatment has focused on root canal disinfection with “entombment” of remaining bacteria within dentinal tubules and inaccessible areas of the root canal system. Although many factors have been implicated in the etiology of endodontic failures, it has become evident that these “entombed” bacteria play a pivotal role in the persistence of endodontic disease (Siqueira and Rocas 2008).

Although impressive results have been obtained in vitro, laser energy alone has not been able to achieve total bacterial kill in extracted teeth. From a clinical perspective it is apparent that a combination of different treatment modalities is needed to sterilize root canal systems.

In addition, many clinical obstacles exist that further complicate the clinician’s ability to achieve this goal. These include, but are not limited to: restricted endodontic access, complex root canal anatomy, limitations of irrigation and instrumentation techniques, inability to entomb bacteria and the inability to reach and eliminate bacteria deep within the tooth structure.

While the purpose of this article is to focus on the clinical use of the Er,Cr:YSGG laser with radial-firing tips, a definitive treatment protocol needs to be in place to reduce the intra-canal bacterial load prior to laser usage and also to facilitate delivery of the laser energy to the most critical part of the root canal, the apical third.

The Er,Cr:YSGG laser (erbium,chromium:yttrium-scandium-gallium-garnet) emits at a wavelength of 2,780 nm and is highly absorbed by water. The lower the penetration depth in water or tissue (or the higher the absorption), the greater is the ability of the laser to cut or ablate tissue (Fig. 1). Since this wavelength is very similar to the absorption maximum of water in hydroxyapatite, photo-ablation occurs where water evaporates instantaneously, thereby ablating the surrounding tissue.

Gordon et al (2007) found that it was possible to achieve expansion and collapse of intratubular water...
as deep as 1,000 μm or more. This micropulse-induced absorption was capable of producing acoustic waves strong enough to disrupt and kill intratubular bacteria.

These findings are significant as bacteria have been identified at depths of 1,000 μm (Kouchi et al. 1980), with *E. faecalis* at depths of 800 μm (Haapasalo and Orstavik 1987). Irrigants such as sodium hypochlorite have a limited effect on these bacteria with penetration depths of only 100 μm (Berrutti et al. 1997). Increasing concentration, exposure time and temperature was recently found to improve NaOCl penetration (Zou et al. 2010).

Promising bacterial kill rates using the Er,Cr:YSGG laser with radial-firing tips have been reported in extracted teeth. A disinfection reduction of 99.7 percent was obtained for *E. faecalis* at depths of 200 μm into dentin (Gordon et al. 2007) and 94.1 percent (1 log) at depths of 1,000 μm (Schoop et al. 2007).

The development of the radial-firing laser tip (Biolase Technology Inc.) with a tip shape that emits the laser energy as a broad cone, allows better coverage of the root canal walls than end-firing tips (Fig. 2). This facilitates entry of the emitted laser energy into the dentinal tubules reaching bacteria that have penetrated deep into the dentin.

**Treatment protocol**

Current techniques incorporating hand and/or rotary instrumentation, positive pressure irrigation, with or without sonic and ultrasonic agitation,
fall short of total canal disinfection. The treatment protocol presented in this article incorporates three main components: management of the working width of the root canal, negative pressure apical irrigation and intracanal laser therapy.

**Working width management**

The working width (WW) of a root canal is the diameter of the canal immediately before reaching its apical constriction. Allen (2007) found that 97 percent of canals not cleaned to their WW had residual debris in the critical apical region, while 100 percent of those cleaned to their WW were free of debris 1 mm from the apical constriction.

Studies have shown that we need to clean to larger sizes to remove bacteria and debris (Kerekes 1977, Wu 2000). Conventional tapered files cannot accomplish this without transporting the canal, creating strip perforations, weakening the tooth or separating instruments.

The LightSpeed LSX (Discus Dental) file is a unique, extremely flexible, taperless, nickel titanium instrument capable of cleaning to the WW. The final apical size (FAS) is the instrument size that completes WW preparation and is determined when the LSX file binds 4 mm (or more) from the working length and requires a firm push to reach WL.

The customized apical preparations created are critical for predictably successful endodontics and provide significant advantages:

- Effective removal of infected material, debris, inflamed and necrotic tissue from the apical region.
- Allows placement of irrigating needle to WL for negative pressure apical irrigation.
- Facilitates placement of radial-firing laser tip within 1 mm of WL.

**Negative pressure apical irrigation**

There are two main reasons why irrigants fail to reach the critical last 3 mm of a root canal. Firstly, using positive pressure irrigation with a side-vented needle there is little flushing beyond the depth of the needle (Chow 1983). Most of the irrigant follows the path of least resistance and backs out of the canal with apical flushing penetrating only 1 to 2 mm apical to the end of the needle. To achieve effective apical flushing, the needle tip needs to be placed 1 mm from working length which dramatically increases the risk of a sodium hypochlorite accident.

Secondly, the presence of apical vapor lock from air trapped in the canal as well as ammonia and carbon dioxide released from the dissolving action of sodium hypochlorite on pulp tissue prevents penetration of irrigants into the apical third. This vapor lock cannot be removed with hand or rotary files, sonic or ultrasonic activation. In a recent study, vapor lock resulted in “gross retention of debris and smear layer remnants” in the apical 0.5 to 1.0 mm of closed root canal systems (Tay et al. 2010).

The EndoVac (Discus Dental) is a true apical negative pressure irrigating system that provides continuous, high volume irrigation of fresh fluids to the canal terminus with simultaneous evacuation. It is composed of a master delivery tip (Fig. 4) that delivers fluid to the pulp chamber and a macro- and microcannula (Fig. 5) that draw the fluid from the chamber to the canal terminus by way of evacuation.

This system eliminates vapor lock and provides superior cleaning, disinfecting and smear layer removal while virtually eliminating the threat of so-
Intracanal laser therapy

The final stage of root canal preparation and disinfection is completed with the Waterlase MD laser (Er,Cr:YSGG) using radial-firing tips (Biolase Technology Inc.).

The laser tips are available in two sizes: RFT2 and RFT3 with diameters of 275 μm and 415 μm respectively (Fig. 3). The RFT2 tip is inserted 1 mm short of WL, requiring canal preparation sizes of ISO 30 or more while the RFT3 tip is inserted to the junction of middle and apical thirds, requiring canal sizes of ISO 45 or more.

These sizes fall well within typical working width preparation sizes prepared with LSX files. Intracanal laser therapy is performed in two phases, the Cleaning Phase for smear layer and debris removal and the disinfection phase for tissue ablation and bacterial elimination.

Cleaning phase

(1.25 W; 50 Hz; 24 percent air; 30 percent water)

This phase uses water and removes smear layer and debris without using chemical irrigants. It takes 2–3 minutes per canal and uses Hydrophotronics™ to create a powerful micro-agitation effect throughout the canal system. It is generally accepted that smear layer removal facilitates the cleaning and disinfecting of the dentinal tubules and improves the sealing of the root canal.

When merging results of two studies, the Er,Cr:YSGG with radial-firing tips produced significantly better smear layer removal in the apical, middle and coronal thirds than two rotary techniques (Sung et al. 2007, Peters and Barbakow 2000). This extremely efficient action opens the dentinal tubules, lateral canals and isthmuses in preparation for disinfection (Figs. 6–8).

The technique for the cleaning phase after completion of access, working width preparation and negative-pressure irrigation entails the following:

- Use the RFT2 to perform apical and partial coronal 2/3 cleaning.
- Select the recommended laser settings in the wet mode.
- Fill canal with sterile solution.
- Insert RFT2 tip 1 mm short of working length (WL).
- Activate laser on withdrawal of tip coronally at approximately 1 mm/s. Maintain tip in contact with the side surface of the canal wall during the entire apical to coronal pass.
- Repeat steps 4 and 5 one or two more times to ensure that the entire inner canal has been cleaned (Fig. 9).
- Place the RFT3 tip in handpiece to perform final cleaning of the coronal 2/3.
- Fill canal with sterile solution.
- Insert the tip to the junction of apical and middle third of the root canal.
- Repeat steps 5 and 6.

Disinfection phase

(.75 W; 20 Hz; 10 percent air; 0 percent water)

As stated previously, the laser energy emitted from the Er,Cr:YSGG laser is highly absorbed by water in tissue and micro-organisms resulting in instantaneous photo-ablation. In addition, the resulting micro-pulse expansion and collapse of intratubular water produce acoustic waves strong enough to disrupt and kill intratubular bacteria.

This effect is most effective in a dry mode as the laser energy is not absorbed by the water spray and can exert its full effect on the bacteria. This was confirmed by Gordon et al. (2007) who achieved a 99.7 percent kill rate for E. faecalis in the dry mode.

The technique for the disinfection phase is the same as the cleaning phase but with different laser settings in the dry mode.

Clinical applications

While this protocol is recommended for all endodontic treatments (Figs. 10–13), it is most valuable in the following clinical situations:

- Infected cases with apical, lateral and/or furcal radiolucencies.
- Retreatment with periapical periodontitis.
- Acutely inflamed cases, especially those diagnosed with Cracked Tooth Syndrome.
- Internal and external resorption.
- Persistent infections not responding to conventional endodontic treatment.
- Unexplained, prolonged postoperative discomfort.

Summary

A root canal cleaning, shaping and disinfection protocol has been described that maximizes the removal of tissue, debris, smear layer and bacteria...
‘Total elimination of bacteria from infected root canal systems remains the most important objective of endodontic therapy. However, in spite of a plethora of new products and techniques, achieving this objective continues to elude our profession.’

from root canal systems. Utilizing a combination of working width management with LightSpeed LSX instruments, high volume apical negative pressure irrigation and evacuation with the EndoVac system and intracanal laser therapy with radial-firing tips using the WaterlaseMD laser, the ability to totally eliminate bacteria from infected root canal systems may soon be within our grasp.

References

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Justin Kolnick, DDS, attended dental school at the University of the Witwatersrand in Johannesburg, South Africa, and obtained his endodontic training at Columbia University in New York. Kolnick is in private practice limited to endodontics and lectures extensively on a local, national and an international level.

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Photodynamic therapy (PDT), also known as photoradiation therapy, phototherapy or photochemotherapy, involves the use of a photoactive dye (photosensitizer) that is activated by exposure to light of a specific wavelength in the presence of oxygen (Konopka et al.).

The transfer of energy from the activated photosensitizer to available oxygen results in the formation of toxic oxygen species, such as singlet oxygen and free radicals. These very reactive chemical species can damage proteins, lipids, nucleic acids, and other cellular components. Depending on the type of agent, photosensitizers may be injected intravenously, ingested orally, or applied topically.

Although a number of different photosensitizing compounds such as methylene blue, rose bengal, and acridine are known to be efficient singlet oxygen generators (and therefore potential photodynamic therapy agents), a large number of photosensitizers are cyclic tetrapyroles or structural derivatives of this chromophore; in particular porphyrin, chlorin, bacteriochlorin, expanded porphyrin and phthalocyanine (PCs) derivatives.

This is possibly because cyclic tetrapyrrolic derivatives have an inherent similarity to the naturally occurring porphyrins present in living matter; consequently they have little or no toxicity in the absence of light (Leanne et al.).

Photosensitizers can be categorized by their chemical structures and origins. In general, they can be divided into three broad families:

I) Photosensitizer families (Allison et al.)
   A) Porphyrin-based photosensitizer (e.g., Photofrin, ALA/PpIX, BPD-MA)
      • HpD (hematoporphyrin derivative)
      • HpD-based
      • BPD (benzoporphyrin derivative)
      • ALA (5-aminolevulinic acid)
      • Texaphyrins
   B) Chlorophyll-based photosensitizer (e.g., chlorins, purpurins, bacteriochlorins)
      • Chlorins
      • Purpurins
      • Bacteriochlorins

II) Dye (e.g., phthalocyanine, naphthalocyanine) (Zheng Huan et al.)
   • Phtalocyanine
   • Naphthalocyanine

Authors: D. Koteeswaran, MDS, FICD, C. Pravda, DMD, and Ekta Ingle, DMD
Generations of photosensitizers

Most of the currently approved clinical photosensitizers belong to the porphyrin family. Traditionally, the porphyrins and those photosensitizers developed in the 1970s and early 1980s are called first-generation photosensitizers ([e.g., Photofrin]). Photofrin® ([dihematoporphyrin ether]) is available for 30 years in its commercial form, and hematoporphyrin derivatives (HPDs) are referred to as first-generation sensitizers. Photofrin is the most extensively studied and clinically used photosensitizer.

Porphyrin derivatives or synthetics made since the late 1980s are called second generation photosensitizers ([e.g., ALA]). Second-generation photosensitizers include 5-aminolevulinic acid (ALA), benzoporphyrin derivative (BPD), lutetium texaphyrin, temoporfin (mTHPC), tinethyletiopurpurin (SnET2), and talaporfin sodium (LS11). Foscan® (mTHPC), the most potent second-generation photosensitizer, has been reported to be 100 times more active than Photofrin in animal studies.

These photosensitizers have a greater capability to generate singlet oxygen; however, they can cause significant pain during therapy, and because of their high activity, even dim light (60 Watt bulb) can lead to severe skin photosensitivity ([Dougherty et al.]).

The third agent, ALA, is an intrinsic photosensitizer that is converted in situ to a photosensitizer, protoporphyrin IX. Topical ALA and its esters have been used to treat pre-cancer conditions, and basal and squamous cell carcinoma of the skin.

Third-generation photosensitizers generally refer to the modifications such as biologic conjugates ([e.g., antibody conjugate, liposome conjugate]) and built-in photo quenching or bleaching capability. Third-generation photosensitizers include currently available drugs that are modified by targeting with monoclonal antibodies. These terms are still being used although not accepted unanimously, and dividing photosensitizing drugs into such generations may be very confusing.

In lot of cases, the claim that newer generation drugs are better than older ones is unjustified. The premature conclusions on novel or investigational photosensitizers may send a misleading message to researchers or clinicians by suggesting that the older drugs should be replaced by the newer ones or wrongly imply to patients that newer photosensitizing drugs are superior to older ones.

Currently, only four photosensitizers are commercially available: Photofrin, ALA, Visudyne® (BPD; Verteporfin), and Foscan. The first three have been approved by the FDA, while all four are in use in Europe.

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