VERIFIABLE CPD PAPER

IN BRIEF

- Low-level, non-cutting lasers are commonly used in many areas of general medicine and veterinary practice.
- Their use in treating pathology is based on photobiostimulation, in which laser energy is absorbed by inter- and intra-cellular targets, resulting in a secondary stimulation of tissue healing mechanisms.
- In dentistry, a number of clinical conditions affecting the teeth and jaws may be amenable to low-level laser therapy.
- Photo-dynamic therapy, where a drug or chemical is introduced and activated by laser light, can be used in dentistry to treat bacterial infection in endodontics and periodontology.
- Additional uses of low-level laser light include caries detection and scanning techniques in orthodontics and restorative dentistry.

Low-level laser use in dentistry

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The use of laser light at power levels below that capable of direct tissue change (protein denaturation, water vaporisation and tissue ablation), has been advocated in diverse branches of medicine and veterinary practice, yet its acceptance in general dental practice remains low. However, the scope for using low-level laser light (LLLT) has emerged through many applications, either directly or indirectly tissue-related, in delivering primary dental care. The purpose of this article is to explain the mechanisms of action and to explore the uses of this group of lasers in general dental practice.

LASERS IN DENTISTRY

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4. Lasers and soft tissue: 'loose' soft tissue surgery
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THE USES OF LOW-LEVEL LASERS IN GENERAL DENTAL PRACTICE

A number of applications of low-level laser light have emerged, which utilise either the specific wavelength/chromophore relationship, or the inherent accuracy of a collimated beam. The most significant uses are listed as follows:

- Photobiostimulation
- Composite resin curing
- Caries detection
- Photo-activated disinfection (PAD)
- Laser scanning (restorative dentistry, orthodontics)

PHOTOBIOSTIMULATION

Background

The therapeutic effects of sunlight in treating a wide range of diseases has been recognised over many centuries, and are known collectively as heliotherapy. Systemic diseases, ranging from dementia and tuberculosis to skin diseases such as lupus vulgaris and acne, were commonly treated in the early part of the 20th century by exposure to sun and other natural light. The development of treatments involving UV light, actinotherapy and photomedicine led to positive effects in helping patients suffering from rickets (vitamin D deficiency), together with claims of healing boils, carbuncles, neo-natal jaundice and for pain relief.[1-3]

Following the production of the first laser in 1960, itself a comparatively low-powered instrument, research into other lasers such as helium-neon (633 nm) followed. In Eastern Europe in the late 1960s, workers such as Mester,[4] encouraged by laboratory experiments into regenerative healing effects in mice, treated patients with open wounds where conventional therapies had failed, reporting success rates of 85%. During the 1970s and 1980s, the popularity of LLLT therapies grew, mainly in Europe and Asia, and with it, the development of diode lasers (GaAS 904 nm, GaAlAs 780-890 nm and, latterly, InGaAlP 630-700 nm). All these lasers have deep penetrating potential in tissue and are portable, easy to use and relatively inexpensive. The use of these wavelengths centred around research that supported claims of benefits in treating musculo-skeletal, neuro-muscular, cytogenic and trauma-related conditions through biologic effects known as photobiostimulation. The underlying principle is that improvement in a condition is through stimulation of cellular and biochemically-mediated (essentially indirect) elements.[5]

Application of LLLT in photobiostimulation

The triage of dental treatment can be summarised as the control/eradication of disease, the control/relief of pain, and the restoration of form/function. The inter-relationship of

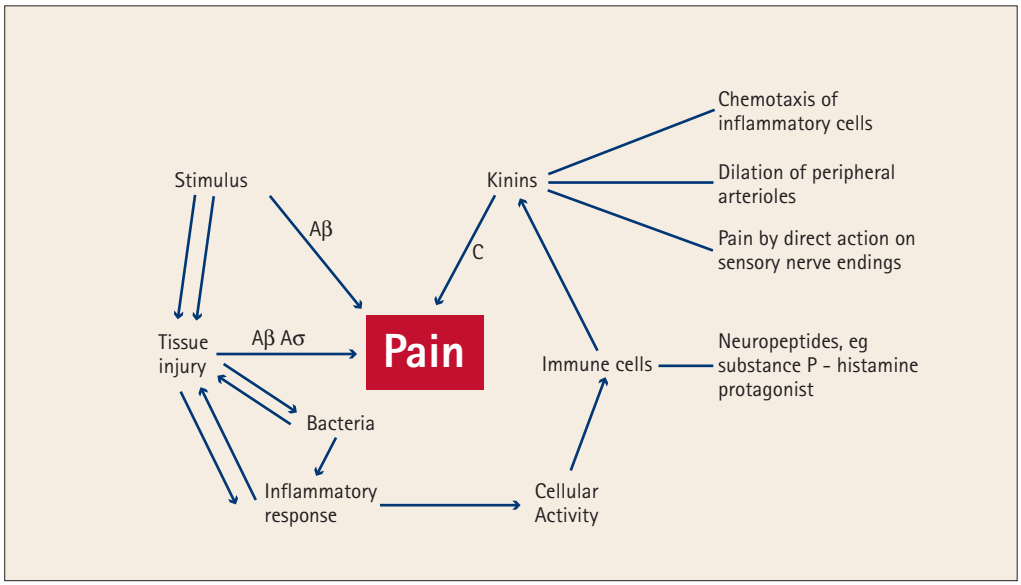

Fig. 1 'The circle of suffering' inter-relationship between stimulus, response and pain

Fig. 2 Self-contained low level laser device (figure courtesy of Dr G. Ross, Toronto)

any stimulus with injury, cellular response and pain can be the product of the nature and potency of the stimulus and the ability of the tissue to respond (Fig. 1). Research on peri-apical lesions has shown that there is a correlation between the release of cellular and biochemical mediators and the nature of the injury, with acute and traumatic injuries resulting in greater reactive processes, compared to chronic pathogenesis.[6]

Low-level laser therapy (photobiostimulation) involves the use of visible red and near-infrared light with tissue in order to stimulate and improve healing, as well as reduce pain. The incident wavelength determines the effect – visible light is transmitted through the superficial cellular layers (eg the dermis, epidermis and the subcutaneous tissue). Light waves in the near-infrared ranges potentially penetrate several millimetres and these wavelengths are used to stimulate deep cellular function. Light energy is absorbed within living tissue by cellular photoreceptors, eg cytochromophores. The incident electromagnetic energy is converted by cellular mitochondria into ATP (adenosine tri-phosphate), a product of cytochrome c-oxidase activity and the Krebs cycle.[7] Consequently, the stimulated increase in ATP production would suggest an increased cellular activity in eg fibroblasts, involved in tissue healing.[8] In addition, the conversion of some of the incident energy into heat would suggest an increase in local micro-circulation through vasodilation.

The stimulatory effects of LLLT include the following:[9-13]

- Proliferation of macrophages
- Proliferation of lymphocytes
- Proliferation of fibroblasts
- Proliferation of endothelial cells
- Proliferation of keratinocytes
- Increased cell respiration/ATP synthesis
- Release of growth factors and other cytokines
- Transformation of fibroblasts into myofibroblasts
- Collagen synthesis.

In addition, there is evidence to support the analgesic effects of LLLT, through an enhanced synthesis of endorphins and bradykinins, decreased c-fibre activity and altered pain threshold.[14,15] Other research suggests a therapeutic analgesic effect, through the release of serotonin and acetylcholine centrally, and histamine and prostaglandins peripherally, with the use of LLLT.[16]

Laser units

In comparison to surgical lasers, low-level laser units are much smaller, often self-contained, hand-held devices (Fig. 2), which are either battery-driven or charged via a pod in a bench-top master unit. There is no need for any integral cooling system and their power output levels often warrant no specific safety rules that apply to surgical laser units.

The dosimetry of low-level laser light is crucial to the infra-surgical effects of the wavelengths used. This is based on the Arndt Schultz law,[17] summarised as 'small doses stimulate living systems, medium doses impede, and large doses destroy'. This is illustrated in a study carried out where hamster ovarian cells were exposed to varying low laser energy.[18] The incident fluence, increasing through a range of infra-ablative values, gave rise to cellular effects as follows:

a) <60 mJ/cm^2 – zero bio-activation
b) 120-240 mJ/cm^2 – bio-stimulation
c) 240-300 mJ/cm^2 – zero bio-activation
d) 300-600 mJ/cm^2 – bio-inhibition (release of cellular singlet oxygen).

The amount of laser energy delivered to a target tissue is termed fluence, or energy density and is measured in J/cm^2. The power of the laser light is the product of fluence and time, which for a free-running emission mode can result in peak power values of several thousand Watts, albeit for periods of micro-seconds. With surgical or cutting lasers, vaporisation of intra- and inter-cellular water occurs at fluence levels of 1,000 J/cm^2.[19] In clinical practice, low-level laser therapy, effective through stimulatory rather than ablative mechanisms, delivers fluence of 2-10 J/cm^2, depending on the target tissue[20] as follows:

- Oral epithelium and gingival tissue – 2-3 J/cm^2
- Trans-osseous irradiation (target – peri-apical area) – 2-4 J/cm^2
- Extra-oral muscle groups/TMJ – 6-10 J/cm^2.

Clinical applications in dental practice

It is perhaps best to consider the scope of application of LLLT in dentistry through the underlying cellular mechanism, rather than the descriptive clinical term. For example, tooth hypersensitivity may be viewed as an inflammatory condition and an extraction socket as post-trauma. In this way, the use of LLLT is to stimulate the inherent cellular and biochemical pathways associated with resolution and healing (Figs 3-5).

Reported effects in clinical dentistry include the following:

- Dentine hypersensitivity[21]
- Post-extraction socket/post-trauma sites[22]
- Viral infections: herpes labialis, herpes simplex[23,24]
- Neuropathy: trigeminal neuralgia, paraesthesia[25]
- Apthous ulceration[26]
- TMJDS[25]
- Post-oncology: mucositis, dermatitis, post-surgery healing.[27]

LLLT – the debate?

Despite the numbers of published studies (2,500+), of which more than 100 are positive and double-blind, the acceptance of low-level lasers in primary dental therapy remains guarded. Approval and scepticism are curiously divided by geographical location, with greatest acceptance being expressed in Northern and Eastern Europe and Asia. Claims to the magnitude of the placebo effect in studies continue to fuel the lack of objective analysis.[28] There is an increasing popularity being expressed in North America for LLLT use in dental practice and, whilst clinicians may choose to include such modalities in their practice, the need for wider-ranging evidence-based research must remain paramount, both for the credibility of this treatment and with respect to patients.

Fig. 3 TMJ stimulation (figure courtesy of Dr G. Ross, Toronto)

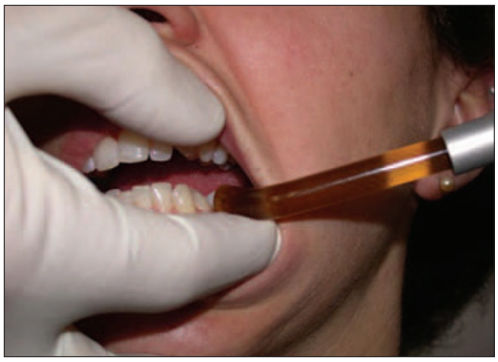

Fig. 4 Tooth hypersensitivity (figure courtesy of Dr G. Ross, Toronto)

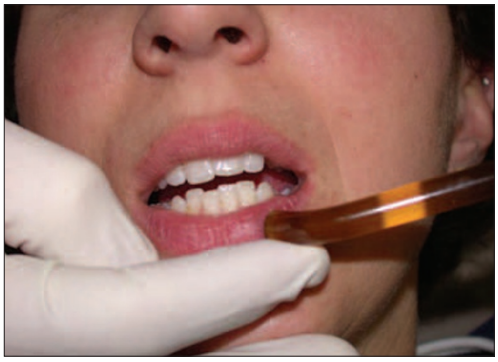

Fig. 5 Herpes labialis (figure courtesy of Dr G. Ross, Toronto)

Fig. 6 Argon curing laser (LaserMed UK)

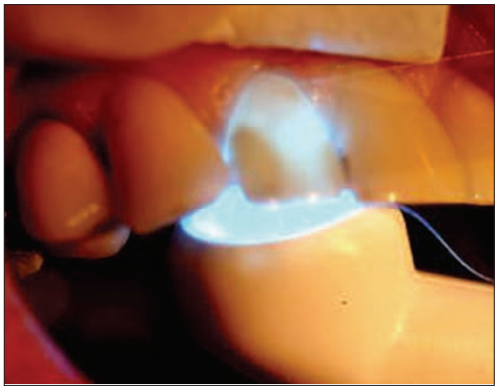

Fig. 7 Argon curing light

Fig. 8 (left) DiagnoDENT (Kavo GmbH)

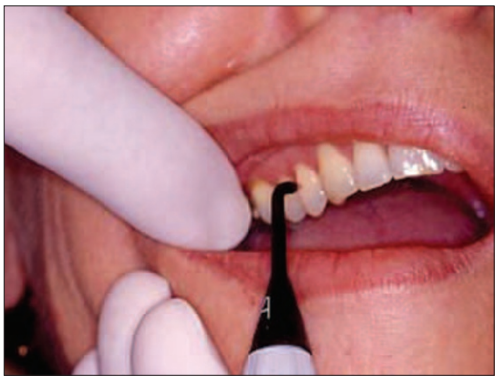

Fig. 9 (right) Laser probe in use

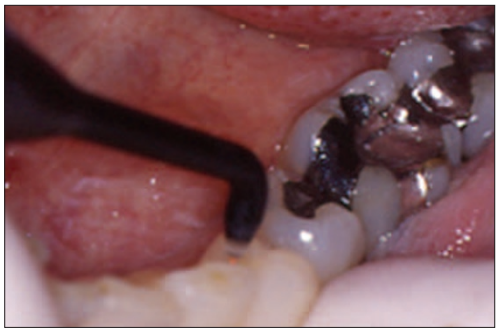

Fig. 10 (left) Occlusal scan

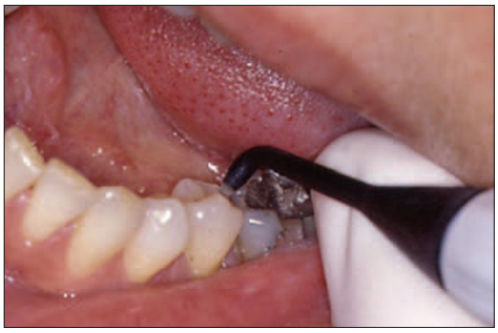

Fig. 11 (right) Interstitial scan

COMPOSITE RESIN CURING

One of the major emission wavelengths of argon lasers is the 488 nm 'blue'. This wavelength coincides with the absorption peak of camphorquinone, an accelerator used in composite resin restorative materials. The early work carried out on the effectiveness of a high density prime wavelength light source, suggested that the depth of curing and hardness of the set composite offered advantages over contemporary light curing systems.[29-32] The intensity of the incident laser beam, using low power levels (150-300 mW) offered a light source that would enhance desired restorative properties without excessive pulpal temperature rise.

Unfortunately, the duality of emission wavelengths of the argon active medium required selective filtering of the longer, 514 nm 'green' (soft tissue ablative) wavelength, together with the limitation of the hardware required to restrict emission light energy. Consequently, argon laser curing units were expensive and rendered suitable only for composite curing and some laser whitening uses (Figs 6 and 7). In addition, the simultaneous development of more powerful curing systems (eg plasma-arc curing lights), offered similar results without the cost and peripheral safety requirements of the laser unit.

CARIES DETECTION

Although the use of fluorescence had been suggested for caries detection already more than a century ago, the current optical caries detection techniques emerged with the introduction of laser technology into the dental field. In the 1980s, a clinically applicable visual detection[33,34] method focussing on the natural green fluorescence of tooth tissue was developed. The technique used a 488 nm excitation wavelength from an argon-ion laser to discriminate bright green fluorescing healthy tooth tissue from poorly fluorescing caries lesions. The technique was developed further in the early 1990s, into what is now known as quantitative light-induced fluorescence (QLF),[35,36] using the digitisation of fluorescence images to quantify the observed green fluorescence loss as an indirect measure of mineral loss.

Around that time, in veterinary dental research and human dental research, a red fluorescence method emerged. The red fluorescence, excited either using long UV (350-410 nm) or red (550-670 nm) wavelengths, was observed in advanced caries as well as plaque and calculus on teeth.[37,38] Opposite to the green fluorescence loss observed in caries, a substantial red fluorescence occurs between 650 and 800 nm in caries lesions that is much brighter than that of sound enamel or dentine.[39-41]

The first commercially available unit using a red laser was manufactured by Kavo (Kavo GmbH) in 1998, with an emission wavelength of 655 nm (Fig. 8). The effectiveness of this system is deemed to be best incorporated as an adjunct to other diagnostic methods (tactile, visual, radiographic), to limit the possibility of 'false positive' results, which is borne out in recent studies.[42] Nonetheless, the unit, which offers a reproducible analogue scoring of site examination, allows a degree of objective assay of those suspect areas of caries that are subject to on-going review as to treatment. Primarily, the use of this modality has been to detect occlusal or flat surface defects, although interstitial caries can be recorded (Figs 9-11). The presence of existing

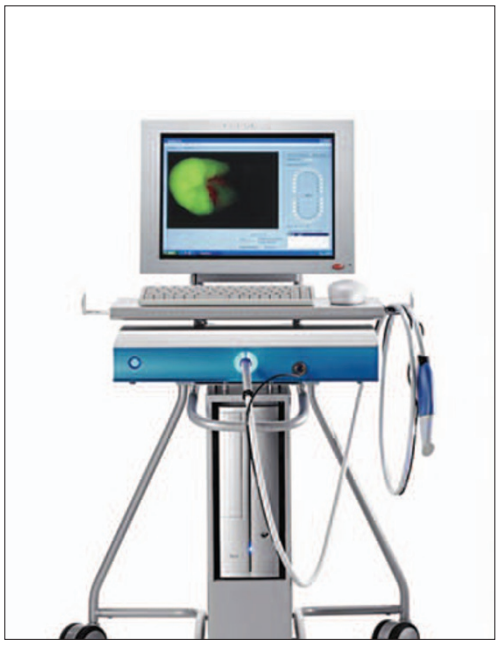

Fig. 12 (left) Quantitative light-induced fluorescence. QLF unit and computer hardware (courtesy of Inspektor Dental Care BV, Amsterdam, NL)

Fig. 13 (right) QLF hand-piece (courtesy of Inspektor Dental Care BV, Amsterdam, NL)

restorations, amalgam, gold, porcelain and composite, would only allow marginal caries to be detected.

New-emerging techniques in laser-assisted caries detection

Quantitative light-induced fluorescence. This is a highly sensitive method for determining short-term changes in lesions in the mouth.[43] The control unit consists of an illumination device and imaging electronics. The argon-ion laser was replaced in 1995 by a xenon-based arc-lamp and the light from this lamp is filtered by a blue-transmitting filter. A liquid light-guide transports the blue light to the teeth in the mouth and a dental mirror provides uniform illumination of the area to be recorded. The excitation wavelength around 405 nm produced by the system allows visualisation and quantification of both the dental tissues' intrinsic green fluorescence as well as the red fluorescence from bacterial origin as observed in calculus, plaque and (advanced) caries.[44,45] The green fluorescence loss observed from demineralised enamel as well as natural caries lesions is strongly correlated with mineral loss.[46-48] The red fluorescence offers insight into oral hygiene levels, allows visualisation of leaking margins of sealants and restorations[44] and is furthermore suggested for use during caries excavation.[49]

Dental calculus produces the most pronounced fluorescent intensity, carious regions produce a slightly weaker fluorescent intensity. Photo-images of this technique are given in Figures 12-16 (source www.inspektor.nl).

PS-OCT – polarisation-sensitive optical coherence tomography. Preliminary studies using OCT have proven successful at imaging hard and soft tissue in the oral cavity. Using polarisation-sensitive OCT (PS-OCT), a numerical analysis of the optical properties of the surface and subsurface enamel can be

Fig. 14 QLF unit in use in the mouth (courtesy of Inspektor Dental Care BV, Amsterdam, NL)

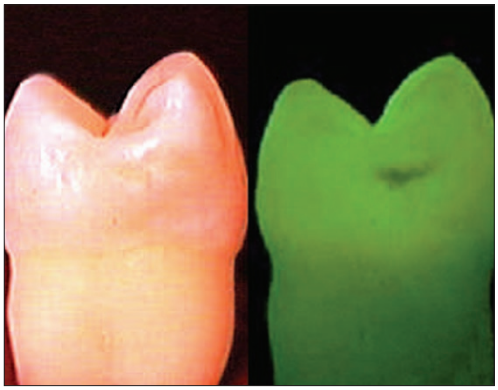

Fig. 15 Premolar before and after exposure, showing decalcified area (courtesy of Inspektor Dental Care BV, Amsterdam, NL)

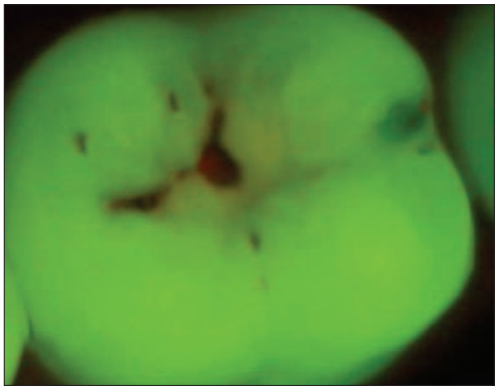

Fig. 16 Occlusal caries (courtesy of Inspektor Dental Care BV, Amsterdam, NL)

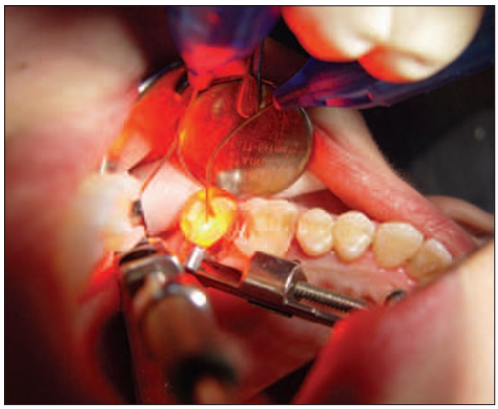

Fig. 17 (left) Photo-activated disinfection of prepared cavity, upper second molar (courtesy of T. Von Samson and Denfotex UK)

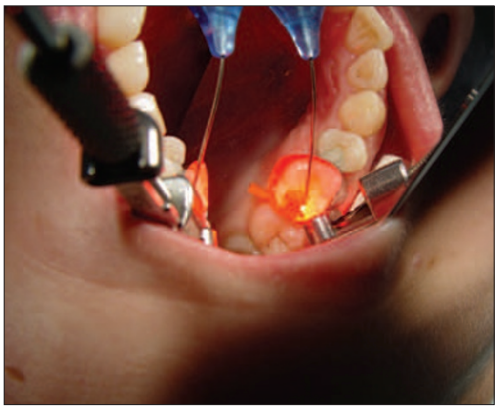

Fig. 18 (right) Photo-activated disinfection of prepared cavity, upper first molar (courtesy of T. Von Samson and Denfotex UK)

obtained. At research levels, using a near-infrared beam (λ 1,310 nm), caries detection is possible at both surface level and under composite restorations and sealants.[50,51]

Recent developments have seen the emergence of other spectroscopic analysis devices which are undergoing development, eg a blue InGaN laser diode operating at 405 nm.[52]

PHOTO-ACTIVATED DISINFECTION (PAD)

This is a development over and above the conventional use of chemicals to achieve bacterial decontamination in restorative dentistry. As opposed to chemicals that are spontaneously interactive with cellular structures, PAD employs a photo-activated liquid, a solution of tolonium chloride (a pharmaceutical grade of the vital stain toluidene blue O). Exposure of this chemical to low-level visible red light (635 nm) releases singlet oxygen that ruptures bacterial cell walls[53] (Figs 17 and 18).

During the early 1990s at the Eastman Dental Institute, London, Professors M. Wilson and G. Pearson first proved PAD killed *Streptococcus mutans*[54] in significant numbers, and reasoned that PAD could kill all bacteria involved in oral infections in caries, root canals, and periodontics,[55] thereby eliminating the most common oral infections. Research was undertaken to determine the susceptibility to photo-activated disinfection (PAD) of *Streptococcus mutans* when the organism was present in a collagen matrix[56] – an environment similar to that which would exist within a carious tooth. This research has led to the production of a commercial unit for use in dental surgery (Figs 19-22).

Recent *in vitro* and *in vivo* studies[57,58] into the use of PAD in endodontics have demonstrated the effectiveness of this therapy against a number of anaerobic bacterial strains associated with endodontic infections (*Fusobacterium nucleatum, Peptostreptococcus micros, Prevotella intermedia* and *Streptococcus intermedius*). In addition, PAD has been shown to be effective against *Enterococcus faecalis*.[59]

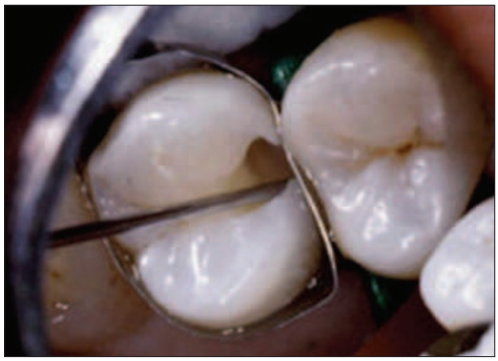

Fig. 19 (left) Laser probe in tooth cavity (courtesy of T. Von Samson and Denfotex UK)

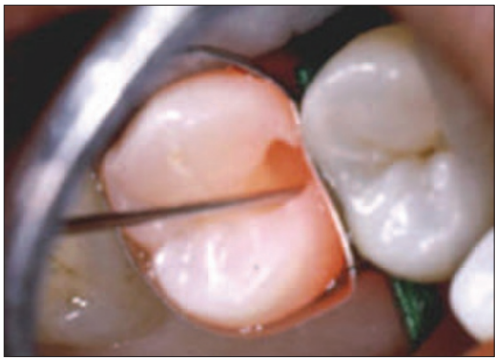

Fig. 20 (right) Cavity decontamination (courtesy of T. Von Samson and Denfotex UK)

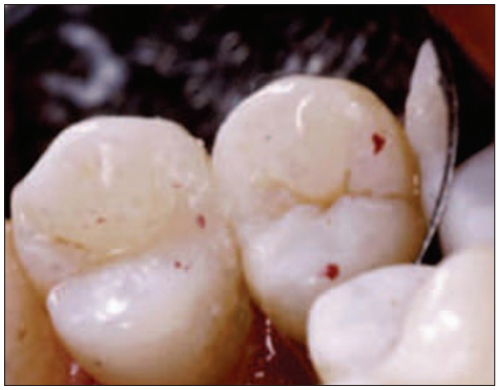

Fig. 21 (left) Completed restoration (courtesy of T. Von Samson and Denfotex UK)

Fig. 22 (right) Hand-piece and fibre. The fibre diameter equates to ISO #40 (reproduced with permission, Denfotex UK)

LASER SCANNING (ORTHODONTICS, RESTORATIVE DENTISTRY)

The development of laser-based measuring devices (eg the confocal micrometer), utilising beam-splitting of a low-energy laser and optical detector, has enabled accurate replication of the morphology of dental and oral structures and materials used in restorative dentistry.

The earliest use of laser scanning was in the field of orthodontics and facial development, to provide 3D imaging and recording of pre- and post-treatment of deformities.[60-62] Scanned data was linked to computer software using CAD (computer-assisted design).

This concept has been expanded during the last decade, to enable the scanning of restorative cavities prior to the production of cast or milled indirect restorations,[63] and the recording of oral and facial swellings.[64]

An additional associated use of laser light in oral medicine is through Raman spectroscopy. A Raman spectrum represents the scattering of incident laser light by molecular or crystal vibrations. Such vibration is quite sensitive to the molecular composition of samples being investigated, and areas of research include the *in vitro* and *in vivo* study of disease processes such as cancer, atherosclerosis and bone disease. With regard to the latter, Raman spectroscopic analysis *in vivo* of mineral and matrix changes has been shown to be useful in mapping early changes in bone tissue.[65]

Permission granted by Dr Gerry Ross, Toronto, Canada to reproduce clinical photographs, Denfotex UK in showing photo-activated disinfection and Inspektor Dental Care BV, The Netherlands for QLF information, is gratefully acknowledged.

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