The antibacterial effects of lasers in endodontics

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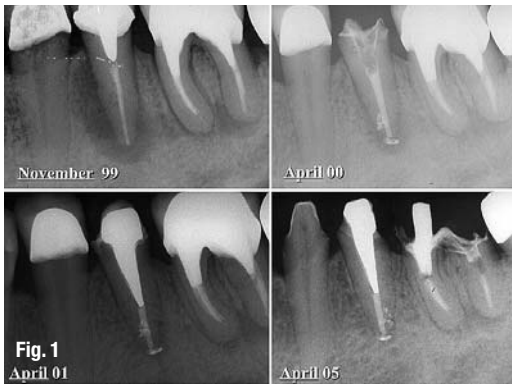


Fig. 1_Success in endodontic treatment: apical radiolucency repair.

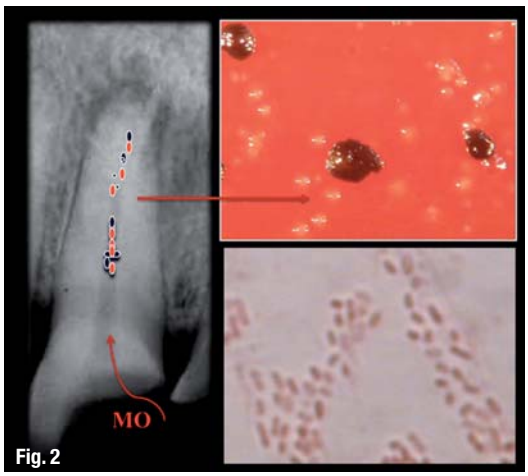
_Endodontic infection

The success of endodontic treatment reaches values between 85 to 97 per cent.[1] Adequate treatment protocols, knowledge and infection control are the basic components to achieve such values (Fig. 1).[2] It is well known that apical periodontitis is caused by the communication of root-canal microorganisms and their by-products with the surrounding periodontal structures. Exposure of dental pulp directly to the oral cavity or via accessory canals, open dentinal tubules or periodontal pockets, are the most probable routes of the endodontic infection.[2,3]

Clinically, apical periodontitis is not evident as long as the necrotic tissue is not infected with microorganisms.[4–6] There are up to 40 isolated species of bacteria present in the root canal. Cocci, rods, filaments, spirochetes, anaerobic and facultative anaerobic are frequently identified in primary infection, fungus can also be isolated.[2,7] Endodontic microbiota can be found suspended in the main root canal, adhered to the canal walls and deep in the dentinal tubules at a depth of up to 300 µm (Fig. 2). The absence of cementum dramatically increases bacteria penetration into dentinal tubules.[8–11]

It has been shown that bacteria can also been found outside the root-canal system, located at the apical cementum and as an external biofilm on the apex.[12–15] Following conventional endodontic treatment, 15 to 20 per cent of non-vital teeth with apical periodontitis fail.[16–18] The presence of bacteria after the decontamination phase or the inability to seal root canals after treatment are reasons for failure.[2] The remaining contamination in endodontically treated teeth is able to maintain the infectious disease process in the periapical tissue.

Retreatments are the first choice in failed root canals. The microbiota found in persistent infections



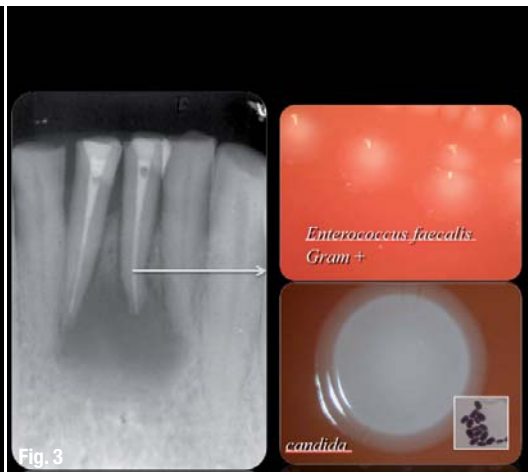


Fig. 2_Primary infection. Black pigmented strains (a) and G-rods (b).
Fig. 3_Persistent infection.

Fig. 4a

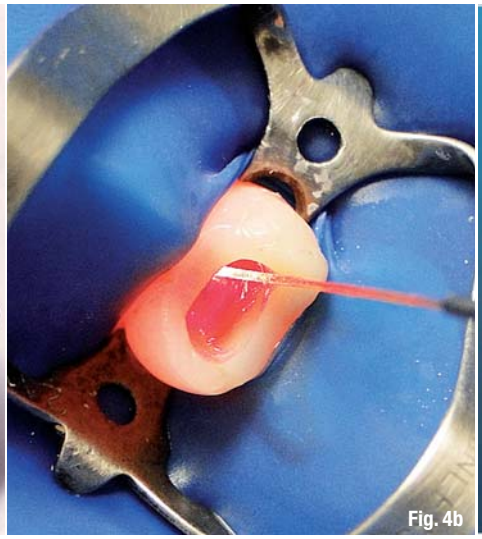


Fig. 4b

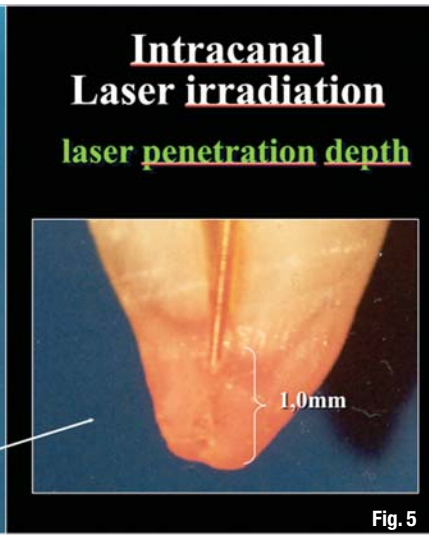


Fig. 5

differs from that in primary infection (Fig. 3). Facultative anaerobic gram positive (G+) and negative (G-) microorganisms and fungus are easily found.[19–21] Special attention is given to *E. faecalis*, a resistant facultative anaerobic G+ cocci, identified in a much higher incidence in failed root canals.[22–25] The importance of bacterial control plays a significant role in endodontic success. Adequate and effective disinfection of the root-canal system is necessary. Based on that, all efforts must be done in order to achieve this result.

_Endodontic therapy

The bacterial flora of the root canal must be actively eliminated by a combination of debridement and antimicrobial chemical treatment. Mechanical instrumentation eliminates more than 90 per cent of the microbial amount.[26] An important point of note is the adequate shaping of the root canal. Evaluating the antibacterial efficacy of mechanical preparation itself, Dalton *et al.*[27] concluded that instrumentation to an apical size of #25 resulted in 20 per cent of canals free of cultivable bacteria, when a #35 size was made, 60 per cent showed negative results.

Irrigating solution has been associated with mechanical instrumentation to facilitate an instrument's cutting efficiency, remove debris and the smear layer, dissolute organic matter, clean inaccessible areas and act against microorganisms. Sodium hypochlorite is the most common irrigant used in endodontics.[28] It has an excellent cleansing ability, dissolves necrotic tissue, has a potential antibacterial effect and, depending on the concentration, is well tolerated by biological tissues. When added to mechanical instrumentation, it reduces the number of infected canals by 40 to 50 per cent.

Other irrigating solutions are also used during endodontic preparation. EDTA, a chelating agent used primarily to remove the smear layer and facilitate the removal of debris from the canal has no antibacterial effect.[29] Chlorhexidine gluconate has a strong antibacterial activity to an extensive number of bacteria species, even the resistant *E. faecalis*, but it does not breakdown proteins and necrotic tissue as sodium hypochlorite does.[30]

Because the association of mechanical instrumentation and irrigating solutions are not able to totally eliminate bacteria from the canal system—a status that is required for root-canal filling—additional substances and medicaments have been tested in order to suppress the gap that occurs in standard endodontic protocols. The principal goal of dressing the root canal between appointments is to ensure safe antibacterial action with a long-lasting effect.[31] A great number of medicaments have been used as dressing material, such as formocresol, camphorated parachlorophenol, eugenol, iodine-potassium iodide, antibiotics, calcium hydroxide and chlorhexidine.

Calcium hydroxide has been used in endodontic therapy since 1920.[31] With a high pH at saturation over pH 11, it induces mineralisation, reduces bacteria and dissolves tissue. For extended antibacterial effectiveness, the pH must be kept high in the canal and in the dentine as well. This ability depends on the diffusion through dentine tubules.[32]

Although most microorganisms are destroyed at pH 9.5, a few can survive over pH 11 or higher, such as *E. faecalis* and candida.[21] Because of the resistance of some microorganisms to conventional treatment protocols—and the direct relation between the presence of viable bacteria in the canal system and the reduced percentage of treatment success—additional effort has to be made to control canal system infection.

Fig. 4a & b_Nd:YAG laser intra canal irradiation.
Fig. 5_Nd:YAG laser irradiation, deep penetration.

Fig. 6a


Fig. 6b


Fig. 7

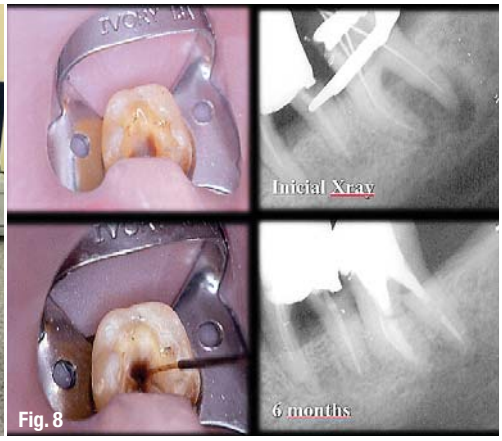


Fig. 8

Fig. 6a & b_Diode 980 nm intra-canal irradiation.
Fig. 7_Er:YAG laser.
Fig. 8_Endodontic laser therapeutic plan.

_Lasers in endodontics

Lasers were introduced in endodontics as a complementary step to increase antibacterial efforts in conventional treatments. The antibacterial action of Nd:YAG, diodes, Er:YAG and photo activated disinfection (PAD) have been explored by a number of investigators. In the following section, each laser is evaluated with the aim of selecting an adequate protocol that will result in a high probability of success in teeth with apical periodontitis.

_Nd:YAG laser

The Nd:YAG laser was one of the first lasers tested in endodontics. It is a solid-state laser. The active medium is usually YAG-yttrium aluminum grenade (Y2AL5O12) where some Y3+ are substituted for Nd3+. It is a four-level energy system operating in a continuous or pulsed mode. It emits a 1,064 nm infrared wavelength. Thus, this laser needs a guide light for clinical application. Flexible fibers with a diameter between 200 nm and 400 µm are used as delivery systems. It can be used intra canal, in contact mode (Fig. 4).

The typical morphology of root-canal walls treated with the Nd:YAG laser show melted dentine with a globular and glassy appearance, and few areas are covered by a smear layer. Some areas show dentinal tubules sealed by fusion of the dentine and deposits of mineral components.[33,34] This morphologic modification reduces dentine permeability significantly.[35,36] However, because the emission of the laser beam from the optical fiber is directed along the root canal, not laterally, not all root-canal walls are irradiated, which gives more effective action at the apical areas of the root.[37] Undesirable morphologic changes, such as carbonisation and cracks, are seen only if high parameters of energy are used.

One of the major problems for intra-canal laser irradiation is the increase of temperature at the external surface of the root. When laser light reaches a tissue, a thermal effect occurs. The heat is directly associated to energy used, time and irradiation mode. An increase in temperature levels over 10° Celsius per one minute can cause damage to periodontal tissues, such as necrosis and anquilose.

Lan (1999)[38] evaluated *in vitro*, the temperature increase on the external surface of the root after irradiation with a Nd:YAG laser under the following parameters of energy: 50 mJ, 80 mJ and 100 mJ at 10, 20 and 30 pulses per second. The increase of temperature was less than 10 degrees. The same results were obtained from Bachman *et al.* (2000)[39], Kimura *et al.* (1999)[40] and Gutknecht *et al.* (2008).[41] In contrast to the external surface, intra-canal temperature rises dramatically at the apical area, promoting an effective action against bacteria contamination. For the Nd:YAG laser, 1.5 W and 15 Hz, are safe parameters of energy for temperature and morphological changes.[33,41]

The primary use of the Nd:YAG laser in endodontics is focused on elimination of microorganisms in the root-canal system. Rooney *et al.* (1994)[42] evaluated the antibacterial effect of Nd:YAG lasers *in vitro*. Bacterial reduction was obtained considering energy parameters. Researchers developed different *in vitro* models simulating the organisms expected in non-vital, contaminated teeth. Nd:YAG irradiation was effective for *B. stearothermophilus*,[43,44] *S. faecalis*, *E. coli*,[45] *S. mutans*,[46] *S. sanguis*, *P. intermedia*[47] and a specific microorganism resistant to conventional endodontic treatment, *E. faecalis*.[48–50] Nd:YAG has an antibacterial effect in dentine at a depth of 1,000 µm (Fig. 5).[50]

Histological models were also developed in order to evaluate periapical tissue response after intra-canal Nd:YAG laser irradiation. Suda *et al.* (1996)[51] proved in dog models that Nd:YAG irradiation that 100 mJ/30 pps (pulses per second) during 30 seconds was safe to surrounding root tissues. Maresca *et al.* (1996),[52] using human teeth indicated for apical surgery, confirmed Suda *et al.*[51] and Ianamoto *et al.* (1998)[53] results. Koba *et al.* (1999)[54] analysed histopathological inflamma-

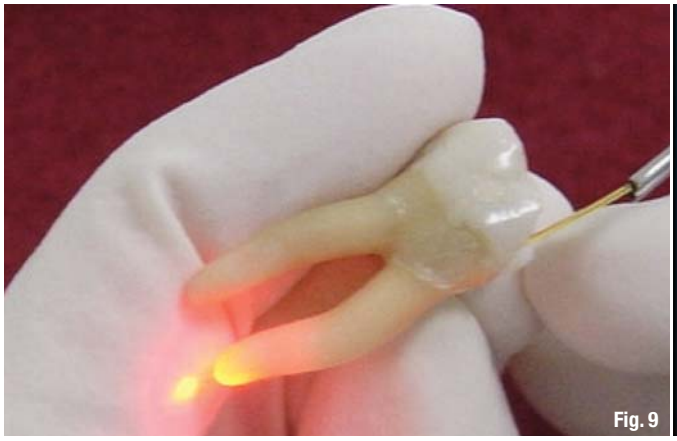


Fig. 9

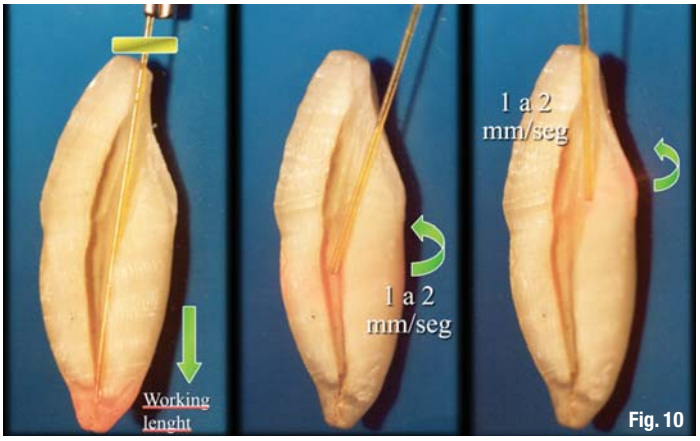


Fig. 10

Fig. 9_Intra-canal laser irradiation, molars.
Fig. 10_Intra-canal laser irradiation, technique.

tory response after Nd:YAG irradiation in dogs using 1 watt and 2 watts. Results showed significant inflammatory reduction in 4 and 8 weeks compared to the non-irradiated group.

Clinical reports published in the literature confirm the benefits of intra-canal Nd:YAG irradiation. In 1993, Eduardo *et al.*[55] published a successfully clinical case that associated conventional endodontic treatment with Nd:YAG irradiation for retreatment, apical periodontitis, acute abscess and perforation. Clinical and radiographic follow-up showed complete healing after 6 months.

Similar results were shown by Camargo *et al.* (1998).[56] Gutknecht *et al.* (1996)[57] reported a significant improvement in healing of laser-treated infected canals, when compared to non-irradiated cases.

Camargo *et al.* (2002)[58] compared *in vivo* the antibacterial effects of conventional endodontic treatment and conventional protocol associated to the Nd:YAG laser. Teeth with apical radiolucency, no symptoms and necrotic pulps were selected and divided into two groups: conventional treatment and laser irradiated. Microbiological samples were taken before canal instrumentation, after canal preparation and/or laser irradiation and one week after treatment. Results showed a significant antibacterial effect in the laser group compared to the standard protocol. When no other bactericidal agent was used, it is assumed that the Nd:YAG laser played a specific role in bacterial reduction for endodontic treatment in patients.

_Diodes

The diode laser is a solid-state semiconductor laser that uses a combination of galium, arsenide, aluminium and/or indium as the active medium. The available wavelength for dental use ranges between 800 and 1,064 nm that emits in continuous and gated pulsed mode using an optical fibre as the delivery system (Fig. 6). Diode lasers have gained increasing importance in dentistry due to their compactness and affordable cost. A combination of smear layer removal, bacterial reduction and less apical leakage brings importance to this system and makes it viable for endodontic treatment. The principal laser action is photo-thermal.

The thermal effect on tissue depends on the irradiation mode and settings. Wang *et al.* (2005)[59] irradiated root canals *in vitro* and demonstrated a maximum temperature increase of 8.1° Celsius using 5 watt for seven seconds. Similar results were obtained by da Costa Ribeiro.[60] Gutknecht *et al.* (2005)[61] evaluated intra-canal diode irradiation with an output set of 1.5 watts observed a temperature increase in the external surface of the root of 7 degrees Celsius with 980 nm of diode irradiation at a power setting of 2.5 watts at a continuous and chopped mode and demonstrated that the temperature increase never exceeded 47 degrees Celsius, which is considered safe for periodontal structures.[41]

Clean intra-canal dentine surfaces with closed dentinal tubules, indicating melting and recrystallisation, were morphological changes observed at the apical portion of the root after intra-canal diode irradiation.[62] In general, near infrared wavelengths, such as 1,064 nm and 980 nm, promote fusion and recrystallisation on the dentine surface, closing dentinal tubules.

The apparent consensus is that diode laser irradiation has a potential antibacterial effect. In most cases, the effect is directly related to the amount of energy delivered. In a comparative study designed by Gutknecht *et al.* (1997),[63] an 810 nm diode was able to reduce bacteria contamination up to 88.38 per cent with a distal output of 0.6 watts in CW mode. A 980 nm diode laser has an efficient antibacterial effect in root canals contaminated with *E. faecalis* at an average between 77 to 97 per cent. Energy outputs of 1.7 watts, 2.3 watts and 2.8 watts were tested. Efficiency was directly related to the amount of energy and dentine thickness.[64]

_Er:YAG laser

Er:YAG lasers are solid-state lasers whose lasing medium is erbium-doped yttrium aluminium garnet (Er:Y3Al5O12). Er:YAG lasers typically emit light with a wavelength of 2,940 nm, which is infrared light. Unlike Nd:YAG lasers, the output of an Er:YAG laser is strongly absorbed by water because of atomic resonances. The Er:YAG wavelength is well absorbed by hard dental tissue. This laser was approved for dental procedures in 1997. Smear layer removal, canal preparation and apicoectomy are the indications for endodontics (Fig. 7).

The morphology of dentinal surface irradiated with an Er:YAG laser is characterised by clean areas showing opened dentinal tubules free of smear layer in a globular surface. The effects on bacterial reduction by Er:YAG was observed by Moritz *et al.* (1999).[65] Stabholz *et al.* (2003)[37] described a new endodontic tip that can be used with an Er:YAG laser system. The tip allows lateral emission of the radiation rather than direct emission through a single opening at the far end. It emits through a spiral tip located along the length of the tip. In order to examine the efficacy of the spiral tip in removing smear layer, Stabholz *et al.* (2003)[66] showed cleaned intra-canal dentine walls free of smear layer and debris under SEM evaluation.

_Photo-activated disinfection

Another method of disinfection in endodontics is also available. PAD is based on the principle that photo-activatable substances that bind to the target cells and are activated by light of suitable wavelength. Free radicals are formed, producing a toxic effect to bacteria. Toluidine blue and methylene blue are examples of photo-activatable substances. Tolonium chloride is able to kill most of the existing bacteria. *In vitro* studies, PAD has an effective action against photosensitive bacteria such as *E. faecalis*, *F. nucleatum*, *P. intermedia, P. micros* and *Actinomycetemcomitans*.[67,68] On the other hand Souza *et al.* (2010),[69] evaluating PAD antibacterial effects as a supplement to instrumentation/irrigation in infected canals with *E. faecalis*, did not prove significant effect regards to intra-canal disinfection. Further adjustments in the PAD protocols and comparative research models may be required to before clinical usage recommendations.

_Discussion and conclusion

There are good reasons to focus the treatment of non-vital contaminated teeth upon the destruction of bacteria in the root canal. The chances for a favourable outcome of the treatment are significantly higher if the canal is free from bacteria when it is obturated. If, on the other hand, bacteria persist at the time of root filling, there is a higher risk of failure treatment. Therefore, the prime objective of treatment is to achieve the complete elimination of all bacteria from the root-canal system.[2,31]

Today, the potential antibacterial effect of laser irradiation associated with the bio-stimulation action and accelerated healing process is well known. Research has supported the improvement of endodontic protocol. An endodontic laser therapeutic plan brings benefits to conventional treatment, such as minimal apical leakage, effective action against resistant microorganisms and on external apical biofilm, and an increase in periapical tissue repair. Based on that, laser procedures have been incorporated into conventional therapeutic concepts to improve endodontic therapy (Fig. 8).

Clinical studies have shown the benefits of an endo-laser protocol in apical periodontitis treatment. For endodontic treatment, laser protocol is a combination of standard treatment strategies associating cleaning and shaping the root canal with a minimal adequate shape up to #35, irrigating solutions with antibacterial properties and intra-canal laser irradiation using controlled parameters of energy. Ideal sealing of the root canal and adequate coronal restoration are needed for an optimal result.

In practice, little additional time is required for laser treatment. Irradiation technique is simple once flexible optical fibres of 200 µm in diameter are used. The fibre can easily reach the apical third of the root canal, even in curved molars (Fig. 9). The released laser energy has an effect in dentine layers and beyond the apex in the periapical region. The laser's effect is applicable in inaccessible areas, such as external biofilm adhered at the root apex.

Irradiation technique must follow basic principles. A humid root canal is required and rotary movements from the coronal portion to the apex should be carried out, as well as scanning the root canal walls in contact mode (Fig. 10). The power settings and irradiation mode depend on one's choice of a specific wavelength.

Nd:YAG, diodes in different wavelength emissions, Er:YAG, Er:CrYSGG and low-power lasers can be used for different procedures with acceptable results. Laser technology in dentistry is a reality. The development of specific delivery systems and the evolution of lasers combined with a better understanding of laser-tissue interaction increase the opportunities and indications in the endodontic field._

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

_contact laser

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