Lasers in endodontics

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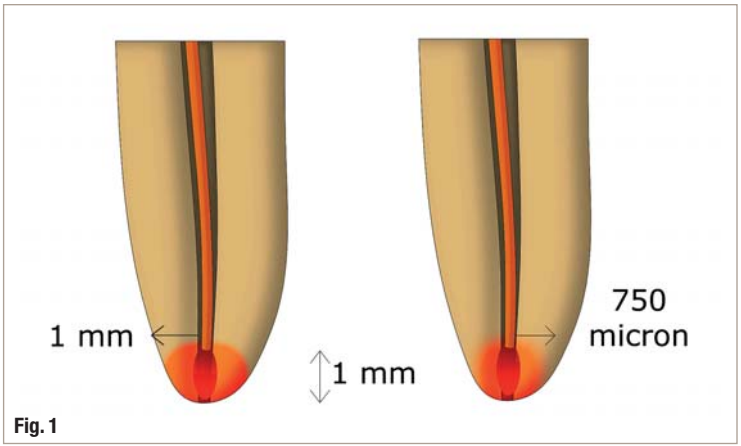


Fig. 1

_Introduction

This article will analyze some of the most important research in the international literature today and the new guidelines for the use of the laser as a source of activation of chemical irrigants.

_Laser-assisted endodontics

Preparation of the access cavity

The preparation of the access cavity can be performed directly with Erbium lasers, which can ablate enamel and dentine. In this case, the use of a short tip is recommended (from 4 to 6 mm), with diameters between 600 and 800 µm, made of quartz to allow the use of higher energy and power. The importance of this technique should not be underestimated.

Owing to its affinity to tissues richest in water (pulp and carious tissue), the laser allows for a minimally invasive access (because it is selective) into the pulp chamber and, at the same time, allows for the decontamination and removal of bacterial debris and pulp tissue. Access to the canal orifices can be accomplished effectively after the number of bacteria has been minimized, thereby avoiding the transposition of bacteria, toxins and debris in the apical direction during the procedure. Chen et al. demonstrated that bacteria are killed during cavity preparation up to a depth of 300 to 400 µm below the radiated surface.[20] Moreover, Erbium lasers are useful in the removal of pulp stones and in the search for calcified canals.

Preparation and shaping of canals

The preparation of the canals with NiTi instruments is still the gold standard in endodontics today. In fact, despite the recognized ablative effect of Erbium lasers (2,780 and 2,940 nm) on hard tissue, their effectiveness in the preparation of root canals appears to be limited at the moment and does not correspond to the endodontic standards reached with NiTi technology.[21–23] However, the Erbium,Chromium:YSGG (Er,Cr:YSGG) and the Erbium:YAG (Er:YAG) lasers have received FDA approval for cleaning, shaping and enlarging canals. A few studies have reported positive re-

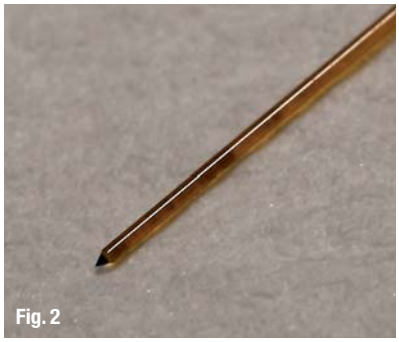


Fig. 2

Fig. 3

Fig. 4

sults for the efficacy of these systems in shaping and enlarging radicular canals.

Shoji et al. used an Er:YAG laser system with a conical tip with 80 per cent lateral emission and 20 per cent emission at the tip to enlarge and clean the canals using 10 to 40 mJ energy at 10 Hz, obtaining cleaner dentinal surfaces compared with traditional rotary techniques.[24]

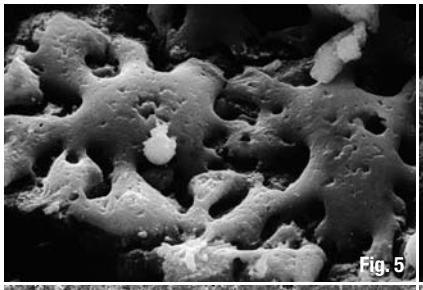
In a preliminary study on the effects of the Er:YAG laser equipped with a microprobe with radial emission of 200 to 400 µm, Kesler et al. found the laser to have good capability for enlarging and shaping in a faster and improved manner compared with the traditional method. The SEM observations demonstrated a uniformly cleaned dentinal surface at the apex of the coronal portion, with an absence of pulp residue and well-cleaned dentinal tubules.[25]

Chen presented clinical studies prepared entirely with the Er,Cr:YSGG laser, the first laser to obtain the FDA patent for the entire endodontic procedure (enlarging, clearing and decontaminating), using tips of 400, 320 and 200 µm in succession and the crown-down technique at 1.5 W and 20 Hz (with air/water spray 35/25 per cent).[26,27]

Stabholz et al. presented positive results of treatment performed entirely using a Er:YAG laser and endodontic lateral emission microprobes.[28,29] Ali et al., Matsuoka et al. and Jahan et al. used the Er,Cr:YSGG laser to prepare straight and curved canals, but in these cases, the results of the experimental group were worse than those of the control group. Using the Er,Cr:YSGG laser with 200 to 320 µm tips at 2 W and 20 Hz on straight and curved canals, they concluded that the laser radiation is able to prepare straight and curved (less than 10 degree) canals, while more severely curved canals demonstrated side effects, such as perforations, burns and canal transportation.[21–23]

Inamoto et al. investigated the cutting ability and the morphological effects of radiation of the Er:YAG laser *in vitro*, using 30 mJ at 10 and 25 Hz with a velocity of extraction of the fibre at 1 and 2 mm/seconds, again with positive results.[30] Minas et al. reported positive results using the Er,Cr:YSGG laser at 1.5, 1.75 and 2.0 W and 20 Hz, with water spray.[31]

The surfaces prepared with the Erbium laser are well cleaned and without smear layer, but often contain l edges, irregularities and charring with the risk of perforations or apical transportation. In effect, canal shaping performed by Erbium laser is still a complicated procedure today that can be performed only in large and straight canals, without any particular advantages.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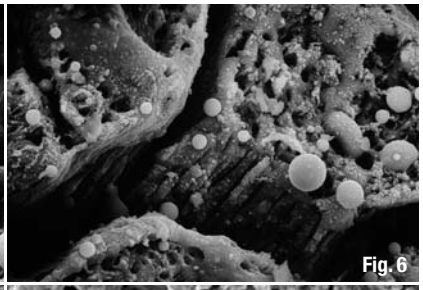
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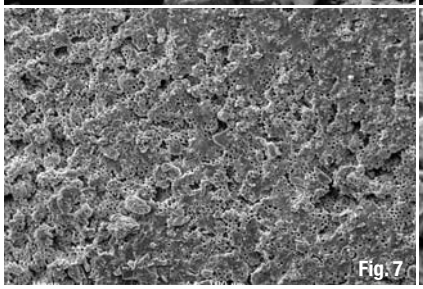
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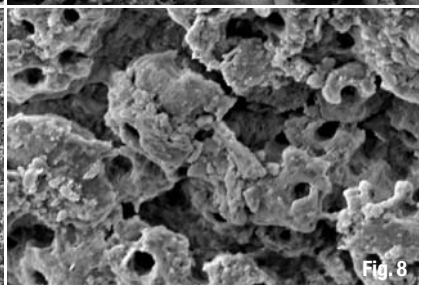


Fig. 8

Decontamination of the endodontic system

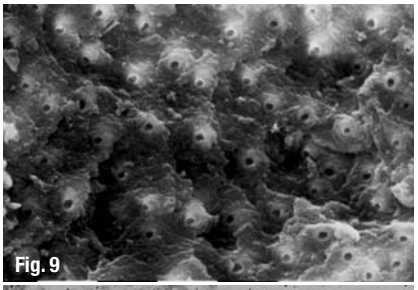
Studies on canal decontamination refer to the action of chemical irrigants (NaClO) commonly used in endodontics, in combination with chelating substances for better cleaning of the dentinal tubules (citric acid and EDTA). One such study is that of Berutti et al., who reported the decontaminating power of NaClO up to a depth of 130 µm on the radicular wall.[32] Lasers were initially introduced in endodontics in an attempt to increase the decontamination of the endodontic system.[2–7]

All the wavelengths have a high bactericidal power because of their thermal effect, which, at different powers and with differing ability to penetrate the dentinal walls, generates important structural modifications in bacteria cells. The initial damage takes place in the cell wall, causing an alteration of the osmotic gradient, leading to swelling and cellular death.[16,34]

Decontamination with near infrared laser

Laser-assisted canal decontamination performed with the near infrared laser requires the canals to be prepared in the traditional way (apical preparation with ISO 25/30), as this wavelength has no affinity and therefore no ablative effect on hard tissue.

The radiation is performed at the end of the traditional endodontic preparation as a final means of decontaminating the endodontic system before obturation. An optical fibre of 200 µm diameter is placed 1 mm from the apex and retracted with a helical movement, moving coronally (in five to 10 seconds according to the different procedures). Today, it is advisable to perform this procedure in a canal filled with endodontic irrigant (preferably, EDTA or citric acid; alternatively, NaClO) to reduce the undesirable thermal morphological effects.[9,35–38]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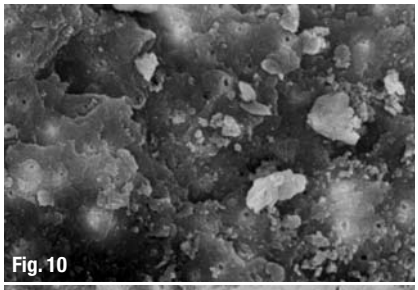
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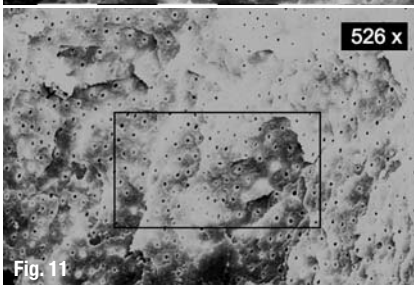

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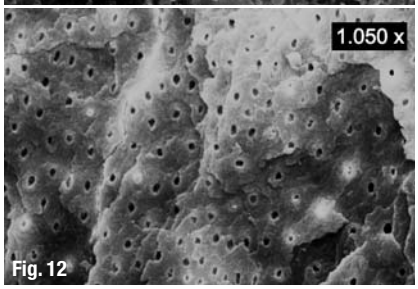

Fig. 12

Using an experimental model, Schoop et al. demonstrated the manner in which lasers spread their energy and penetrate into the dentinal wall, showing them to be physically more efficient than traditional chemical irrigating systems in decontaminating the dentinal walls.[8] The Neodymium:YAG (Nd:YAG; 1,064 nm) laser demonstrated a bacterial reduction of 85 per cent at 1 mm, compared with the diode laser (810 nm) with 63 per cent at 750 µm or less. This marked difference in penetration is due to the low and varying affinity of these wavelengths for hard tissue. The diffusion capacity, which is not uniform, allows the light to reach and destroy bacteria by penetration via the thermal effects (Fig. 1).

Many other microbiological studies have confirmed the strong bactericidal action of the diode and Nd:YAG lasers, with up to 100 per cent decontamination of the bacterial load in the principal canal.[39–43] An *in vitro* study by Benedicenti et al. reported that the use of the diode 810 nm laser in combination with chemical chelating irrigants, such as citric acid and EDTA, brought about a more or less absolute reduction of the bacterial load (99.9 per cent) of *E. faecalis* in the endodontic system.[9]

Decontamination with medium infrared laser

Considering its low efficacy in canal preparation and shaping, using the Erbium laser for decontamination in endodontics requires the use of traditional techniques in canal preparation, with the canals prepared at the apex with ISO 25/30 instruments. The final passage with the laser is possible thanks to the use of long, thin tips (200 and 320 µm), available with various Erbium instruments, allowing for easier reach to the working length (1 mm from apex). In this methodology, the traditional technique is to use a helical movement when retracting the tip (over a 5- to 10-second interval), repeating three to four times depending on the procedure and alternating radiation with irrigation using common chemical irrigants, keeping the canal wet, while performing the procedure (NaClO and/or EDTA) with the integrated spray closed.

The 3-D decontamination of the endodontic system with Erbium lasers is not yet comparable to that of near infrared lasers. The thermal energy created by these lasers is in fact absorbed primarily on the surface (high affinity to dentinal tissue rich in water), where they have the highest bactericidal effect on *E. coli* (Gram-negative bacteria), and *E. faecalis* (Gram-positive bacteria). At 1.5 W, Moritz et al. obtained an almost total eradication (99.64 per cent) of these bacteria.[44] However, these systems do not have a bactericidal effect at depth in the lateral canals, as they only reach 300 µm in depth when tested in the width of the radicular wall.[8]

Further studies have investigated the ability of the Er,Cr:YSGG laser in the decontamination of traditionally prepared canals. Using low power (0.5 W, 10 Hz, 50 mJ with 20 per cent air/water spray), complete eradication of bacteria was not obtained. However, better results for the Er,Cr:YSGG laser were obtained with a 77 per cent reduction at 1 W and of 96 per cent at 1.5 W.[42]

A new area of research has investigated the Erbium laser's ability to remove bacterial biofilm from the apical third,[46] and a recent *in vitro* study has further validated the ability of the Er:YAG laser to remove endodontic biofilm of numerous bacterial species (e.g. *A. naeslundii, E. faecalis, L. casei, P. acnes, F. nucleatum, P. gingivalis* or *P. nigrescens*), with considerable reduction of bacterial cells and disintegration of biofilm. The exception to this is the biofilm formed by *L. casei*.[47]

Ongoing studies are evaluating the efficacy of a new laser technique that uses a newly designed both radial and tapered stripped tip for removal of not only the smear layer, but also bacterial biofilm.[13] The results are very promising.

The Erbium lasers with "end firing" tips—frontal emission at the end of the tip—have little lateral penetration of the dentinal wall. The radial tip was proposed in 2007 for the Er,Cr:YSGG, and Gordon et al. and Schoop et al. have studied the morphological and decontaminating effects of this laser system (Fig. 2).[48–50]

The first study used a tip of 200 µm with radial emission at 20 Hz with air/water spray (34 and 28 per cent) and dry at 10 and 20 mJ and 20 Hz (0.2 and 0.4 W, respectively). The radiation times varied from 15 seconds to two minutes. The maximum bactericidal power was reached at maximum power (0.4 W), with a longer exposure time, without water in dry mode and with a

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99.71 per cent bacterial eradication. The minimum time of radiation (15 seconds) with minimum power (0.2 W) and water obtained 94.7 per cent bacterial reduction.[48] The second study used a tip of 300 µm diameter with two different parameters of emission (1 and 1.5 W, 20 Hz), radiating five times for five seconds, with a cooling time of 20 seconds for each passage. The level of decontamination obtained was significantly high, with important differences between 1 and 1.5 W, with a thermal increase contained between 2.7 and 3.2 °C.[49] The same group from Vienna studied other parameters (0.6 and 0.9 W) that produced a very contained thermal rise of 1.3 and 1.6 °C, respectively, showing a high bactericidal effect on *E. coli* and *E. faecalis*.[50]

The need to take advantage of the thermal effect to destroy bacterial cells, however, results in changes at the dentinal and periodontal level. It is important to evaluate the best parameters and explore new techniques that reduce the undesirable thermal effects that lasers have on hard- and soft-tissue structures to a minimum.

Morphological effects on the dentinal surface Numerous studies have investigated the morphological effects of laser radiation on the radicular walls as collateral effects of root-canal decontamination and cleaning performed with different lasers. When they are used dry, both the near and medium infrared lasers produce characteristic thermal effects (Figs. 3 & 4).[51] Near infrared lasers cause characteristic morphological changes to the dentinal wall: the smear layer is only partially removed and the dentinal tubules are primarily closed as a result of melting of the inorganic dentinal structures. Re-crystallisation bubbles and cracks are evident (Figs. 5–8).[52–55]

Water present in the irrigation solutions limits the thermal interaction of the laser beam on the dentinal wall and, at the same time, works thermally activated by a near infrared laser or directly vaporized by a medium infrared laser (target chromophore) with its specific action (disinfecting or chelating). The radiation with the near infrared laser—diode (2.5 W, 15 Hz) and Nd:YAG (1.5 W, 100 mJ, 15 Hz)—performed after using an irrigating solution, produces a better dentinal pattern, similar to that obtained with only an irrigant.

Radiation with NaClO or chlorhexidine produces a morphology with closed dentinal tubules and presence of a smear layer, but with a reduced area of melting, compared with the carbonization seen with dry radiation. The best results were obtained when radiation followed irrigation with EDTA, with surfaces cleaned of the smear layer, with open dentinal tubules and less evidence of thermal damage.[35–38] In the conclusion of their studies on the Erbium laser, Yamazaki et al. and Kimura et al. affirmed that water is necessary to avoid the undesirable morphological aspects markedly present when radiation with the Erbium lasers is performed dry.[56,57] The Erbium lasers used in this way result in signs of ablation and thermal damage as a result of the power used. There is evidence of ledge cracks, areas of superficial melting and vaporisation of the smear layer. A typical pattern arises when dentine is irradiated with the Erbium laser in the presence of water. The thermal damage is reduced and the dentinal tubules are open at the top of the peri-tubular more calcified and less ablated areas. The inter-tubular dentine, which is richer in water however, is more ablated. The smear layer is vaporized by radiation with Erbium lasers and is mostly absent.[58–64] Shoop et al., investigating the

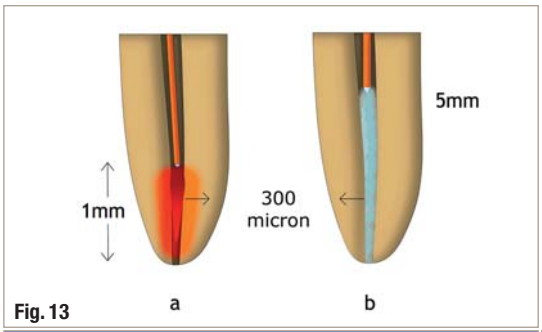

Fig. 13

Fig. 14

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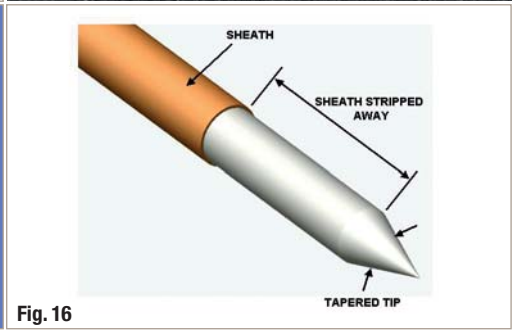

Fig. 16

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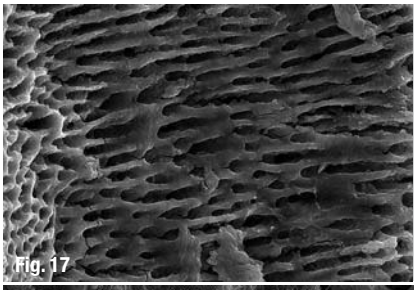
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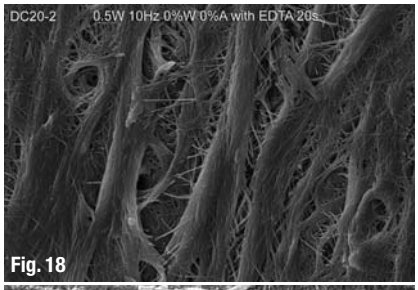

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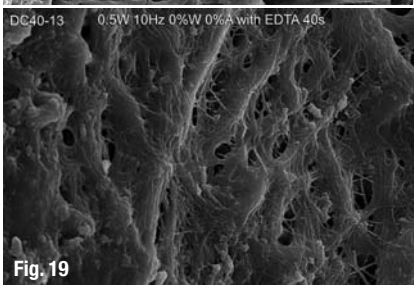

Fig. 19

Fig. 20

variations of temperature on the radicular surface *in vitro*, found that the standardised energies (100 mJ, 15 Hz, 1.5 W) produced a measured thermal increase of only 3.5 °C on the periodontal surface. Moritz proposed these parameters as the international standard of use for the Erbium laser in endodontics, claiming it as an efficient means of canal cleaning and decontamination (Figs. 9–12).[14,16]

Even with Erbium lasers, it is advisable to use irrigating solutions. Alternatively, NaClO and EDTA can be utilized during the terminal phase of laser assisted endodontic therapy with a resulting dentinal pattern, with fewer thermal effects. This represents a new area of research in laser-assisted endodontics. Various techniques have been proposed, such as laser-activated irrigation (LAI) and photon-initiated photoacoustic streaming (PIPS).

Photo-thermal and photomechanical phenomena for the removal of smear layer George et al. published the first study that examined the ability of lasers to activate the irrigating liquid inside the root canal to increase its action. In this study, the tips of two laser systems – Er:YAG and Er,Cr:YSGG (400 µm diameter, both flat and conical tips) with the external coating chemically removed – were used to increase the lateral diffusion of energy.

The study was designed to irradiate the root canals that were prepared internally with a dense smear layer grown experimentally. Comparing the results of the groups that were laser radiated with the groups that were not, the study concluded that the laser activation of irrigants (EDTAC, in particular) brought about better cleaning and removal of the smear layer from the dentinal surfaces.[65] In a later study, the authors reported that this procedure, using power of 1 and 0.75 W, produces an increase in temperature of only 2.5 °C without causing damage to the periodontal structures.[66]

Blanken and De Moor also studied the effects of laser activation of irrigants comparing it with conventional irrigation (CI) and passive ultrasound irrigation (PUI). In this study, 2.5 per cent NaClO and the Er,Cr:YSGG laser were used four times for five seconds at 75 mJ, 20 Hz, 1.5 W, with an endodontic tip (200 µm diameter, with flat tip) held steady 5 mm from the apex.

The removal of the smear layer with this procedure led to significantly better results with respect to the other two methods.[67] The photomicrographic study of the experiment suggests that the laser generates a movement of fluids at high speed through a cavitation effect. The expansion and successive implosion of irrigants (by thermal effect) generates a secondary cavitation effect on the intra-canal fluids. It was not necessary to move the fiber up and down in the canal, but sufficient to keep it steady in the middle third, 5 mm from the apex.[68] This concept greatly simplifies the laser technique, without the need to reach the apex and negotiate radicular curves (Fig. 13).

De Moor et al. compared the LAI technique with PUI and they concluded that the laser technique, using lower irrigation times (four times for five seconds), gives results comparable to the ultrasound technique that uses longer irrigation times (three times for 20 seconds).[69] De Groot et al. also confirmed the efficacy of the LAI technique and the improved results obtained in comparison with the PUI. The authors underlined the concept of streaming due to the collapse of the molecules of water in the irrigating solutions used.[70]

Hmud et al. investigated the possibility of using near infrared lasers (940 and 980 nm) with 200 µm fibre to activate the irrigants at powers of 4 W and 10 Hz, and 2.5 W and 25 Hz, respectively. Considering the lack of affinity between these wavelengths and water, higher powers were needed which, via thermal effect and cavitation, produced movement of fluids in the root canal, leading to an increased ability to remove debris and the smear layer.[71] In a later study, the authors also verified the safety of using these higher powers, which caused a rise in temperature of 30 °C in the intra-canal irrigant solution but of only 4 °C on the external radicular surface. The study concluded that irrigation activated by near infrared lasers is highly effective in minimizing the thermal effects on the dentine and the radicular cement.[72]

In a recent study, Macedo et al. referred to the main role of activation as a strong modulator of the reaction rate of NaOCl. During a rest interval of three minutes, the consumption of available chlorine increased significantly after LAI compared with PUI or CI.[73]

Photon initiated photoacoustic streaming (PIPS)

The PIPS technique uses the Erbium laser (Powerlase AT/HT and LightWalker AT, both Fotona) and its interaction with irrigating solutions (EDTA NaOCl or distilled water).[13] The technique uses a different mechanism from the preceding LAI. It exploits exclusively the photoacoustic and photomechanical phenomena, which result from the use of subablative energy of 20 mJ at 15 Hz, with impulses of only 50 microseconds. With an average power of only 0.3 W, each impulse interacts with the water molecules with a peak power of 400 W creating expansion and successive "shock waves" leading to the formation of a powerful streaming of fluids inside the canal, without generating the undesirable thermal effects seen with other methodologies.

The study with thermocouples applied to the radicular apical third revealed only 1.2 °C of thermal rise after 20 seconds and 1.5 °C after 40 seconds of continuous radiation. Another considerable advantage is derived from the insertion of the tip in the pulp chamber at the entrance to the root canal only without the problematic insertion of the tip into the canal or at 1 mm from the apex required by the other techniques (LAI and CI). Newly designed tips—9 mm in length, 600 µm in diameter and with "radial and stripped" tip—are used. The final 3 mm are without coating to allow a greater lateral emission of energy compared to the frontal tip. This mode of energy emission makes better use of the laser energy when, at subablative levels, delivery with very high peak power for each single pulse of 50 microseconds (400 W) produces powerful "shock waves" in the irrigants, leading to a demonstrable and significant mechanical effect on the dentinal wall (Figs. 14–16). The resultant acoustic streaming allows for a three dimensional movement throughout the root canal system allowing the clinician to easier access the complex anatomy often seen in the apical one third.

The studies show the removal of the smear layer to be superior to the control groups with only EDTA or distilled water. The samples treated with laser and EDTA for 20 and 40 seconds show a complete removal of the smear layer with open dentinal tubules (score 1 according to Hulsmann) and the absence of undesirable thermal phenomena, which is characteristic in the dentinal walls treated with traditional laser techniques. With high magnification, the collagen structure is maintained intact, suggesting the ability for minimally invasive endodontic treatment (Figs. 17–19).

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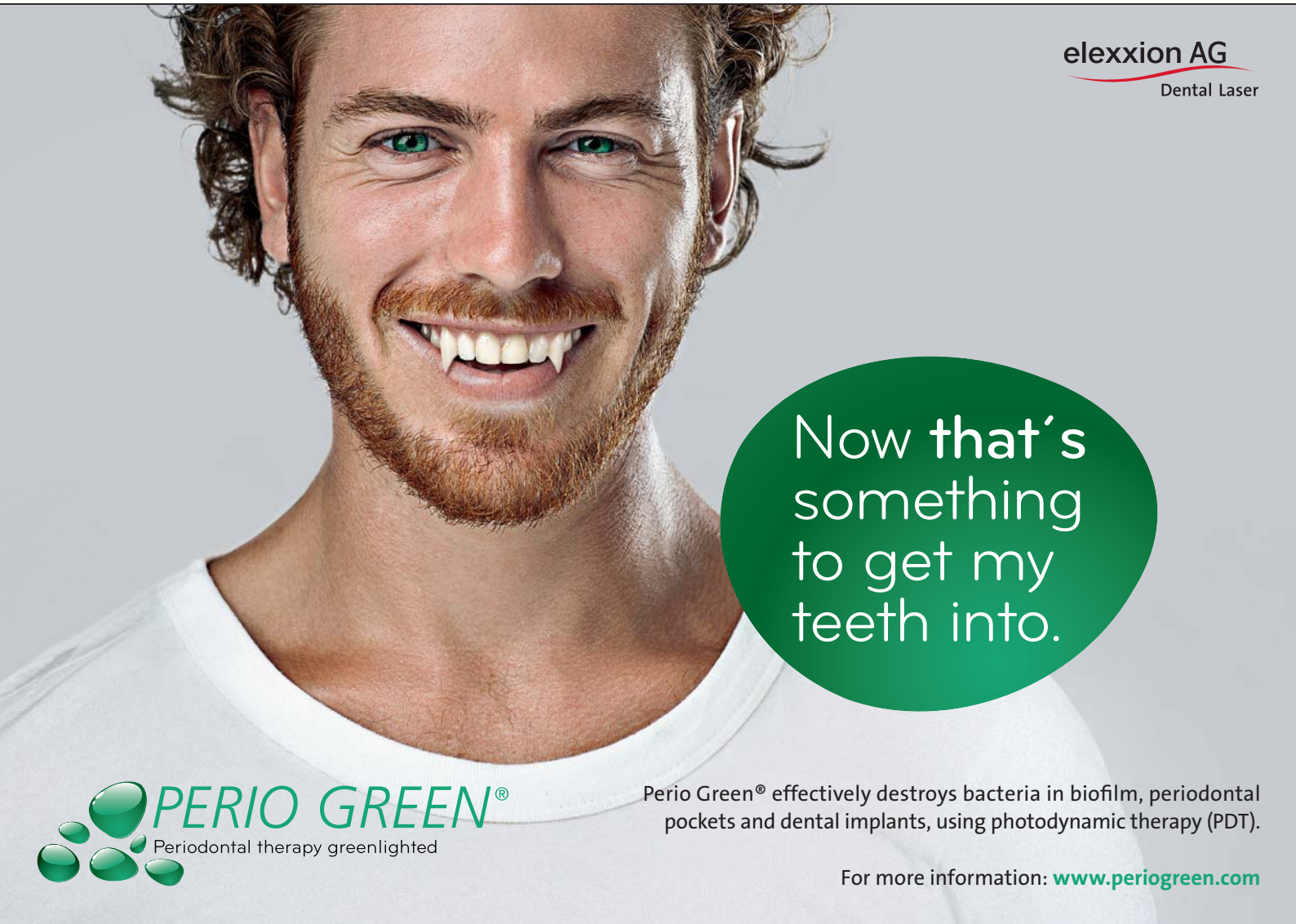

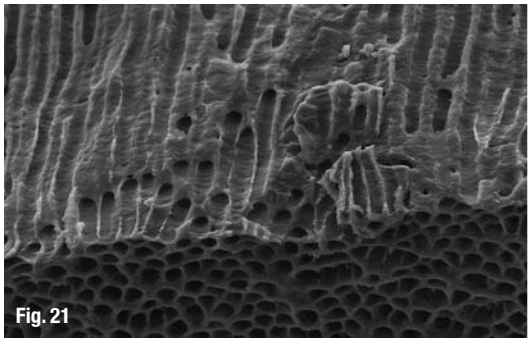
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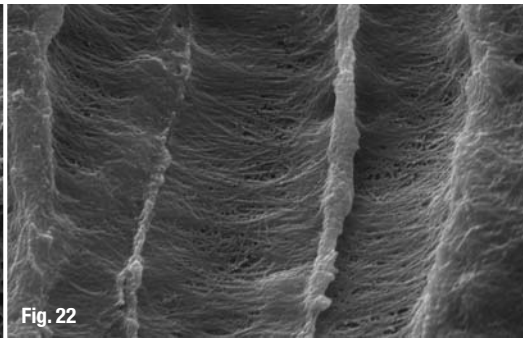
Fig. 22

The Medical Dental Advanced Technologies Group, in affiliation with the University of the Pacific Arthur A. Dugoni School of Dentistry, the University of Genoa and the University of Loma Linda School of Dentistry, University of Tennessee, Boston University, Louisiana State University and the Arizona School of Dentistry and Oral Health, are currently investigating the effects of this technique of root-canal decontamination and the removal of bacterial biofilm in the radicular canal. The results which are about to be published are very promising (Figs. 20–25).

_Discussion and conclusion

Laser technology used in endodontics in the past 20 years has undergone an important evolution. The improved technology has introduced endodontic fibers and tips of a caliber and flexibility that permit insertion up to 1 mm from the apex. Research in recent years has been directed toward producing technologies (impulses of reduced length, "radial firing and stripped" tips) and techniques (LAI and PIPS) that are able to simplify its use in endodontics and minimize the undesirable thermal effects on the dentinal walls, using lower energies in the presence of chemical irrigants. EDTA has proved to be the best solution for LAI technique that activates the liquid and increments its chelating capacity and cleaning of the smear layer. The use of NaClO increases its decontamination activity. Finally, the PIPS technique reduces the thermal effects and exerts a potent cleaning and bactericidal action thanks to its three dimensional streaming of fluids initiated by the photonic energy of the laser. Further studies are currently under way to validate these techniques (LAI and PIPS) as innovative technologies available to endodontics._

Editorial note: An earlier version of this article was published in the international edition of roots, issue 2/2011. A complete list of references is available from the publisher.

_about the author

laser

Enrico DiVito, DDS, the lead author of this article, founded his dental practice in Scottsdale, Ariz., in 1980. He is also the founder and director of the state-accredited Arizona School of Dental Assisting. In addition to teaching at the school, DiVito is also a clinical instructor at the Arizona School of Dentistry and Oral Health and is responsible for helping create the Department of Laser Dentistry. He earned his undergraduate degree from Arizona State University and graduated with honors from the Dental School at the University of the Pacific in San Francisco, receiving several Clinical Excellence Awards. He can be contacted at: edivito@azcld.com.

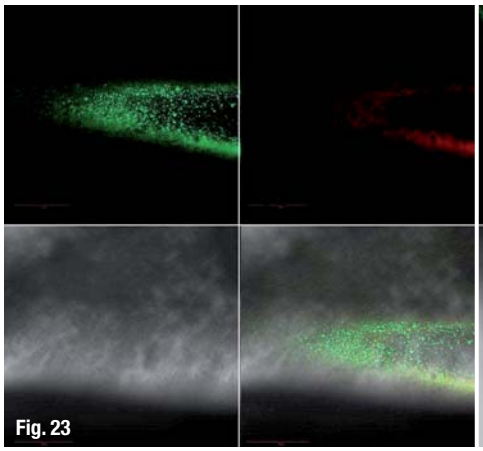
Fig. 23

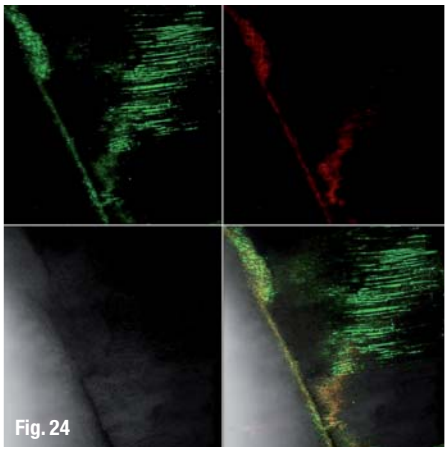
Fig. 24

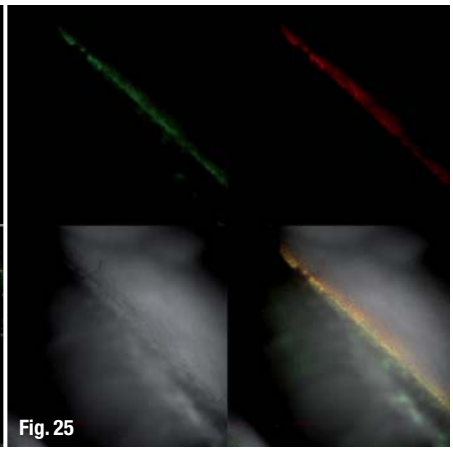
Fig. 25

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