Innovative endodontics using SWEEPS technology

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The ultimate goal of endodontic treatment is the eradication of microorganisms responsible for endodontic disease.[1,2] Enlarging and shaping the root canals to a size sufficient for delivery of irrigants into the endodontic space allows for pulp tissue dissolution and antibacterial activity in the full space.[3] A stable and hermetic sealing of the endodontic space permits long-lasting success of the therapy. Present-day endodontic research is more focused on instrumentation than on irrigation to improve the success rate of root canal therapy. The newest high-performance nickel-titanium alloys reduced the stiffness and increased the elasticity of endodontic instruments, permitting simplified and faster root canal preparation with reduced diameter and taper and greater preservation of the dental structure. However, Peters et al.,[4] more recently confirmed by other researchers,[5,6] demonstrated the incomplete action of the tested instrument systems, which left 35 % or more of the canal's surface area unchanged. Furthermore, the reduced operating time arising from using new mechanical rotary systems reduces the contact time of decontaminating agents (chemical and mechanical cleansing) with the root canal surfaces, and from this perspective, improving the fluid dynamics of irrigants in the endodontic space appears to play an important role.[7]

Irrigation techniques

The fluid dynamics of the irrigants in the confined canal space is one of the main problems in endodontics and very few innovations have been introduced in this regard. Many techniques are currently used to deliver and activate the irrigants in the endodontic space. A constant flow of irrigants helps to dissolve inflamed and necrotic tissue, to disinfect the canal walls by removing bacteria and biofilm, and to flush out debris and the smear layer from the root canal, and hence is essential for the success of endodontic therapy. The complex macro- and micro-anatomy of the root canal system limits the access, flow and turbulence of irrigants in the endodontic space and finally the deep penetration of antibacterial agents into the dentinal walls, thus limiting their 3D cleaning and disinfecting ability.[8,9] Ricucci and Siqueira reported that chemomechanical preparation partially removed vital and necrotic tissue from the entrance of lateral canals and apical ramifications, leaving adjacent tissue inflamed and infected, and associated with periradicular disease.[10] Sodium hypochlorite (NaOCl) is the most commonly used endodontic irrigant because of its antimicrobial and tissue-dissolving activity. Many factors influence its effectiveness. Optimisation of surface tension, concentration, temperature, agitation and flow can improve tissue-dissolving effectiveness by as much as 50-fold.[11] When the NaOCl was modified with the adjunct of a surface active agent, it showed lower contact angle on dentine, resulting in more effective tissue dissolution compared with conventional NaOCl solutions.[11] Also, agitation and higher temperatures considerably enhanced the efficacy of NaOCl. However, the effect of agitation on efficacy was greater than that of temperature, and continuous agitation resulted in the fastest tissue dissolution.[11]

Comparing the efficacy of different agitation systems on the activity of NaOCl, De Gregorio et al. found limited penetration of the irrigant into lateral canals using an apical negative pressure irrigation system—it was however the most effective in reaching the working length—in comparison with the other tested systems (sonic irrigation; passive ultrasonic irrigation; F-file; and positive pressure irrigation).[12] In contrast, passive ultrasonic irrigation demonstrated significantly greater penetration of irrigant into lateral canals.[12] The efficacy of NaOCl depends on the quantity and reactivity of its free-chlorine form. Macedo et al. verified that Er:YAG laser activation of the irrigant produced a greater reaction rate of NaOCl, producing more active chlorine ions in three times less time than with passive ultrasonic irrigation.[13] In the last ten years, the use of laser in promoting the activity of intra-canal irrigants (laser-activated irrigation) has been investigated and successfully introduced in endodontics.

Laser in endodontics

Lasers are used with different techniques in endodontics (Table 1, Fig. 1). They can be used to directly irradiate the canal walls or to irradiate and activate fluids introduced into the canal (photosensitisers or irrigants), thus performing their clinical action on the endodontic system indirectly.

Wavelength	Laser technique	Target chromophore	Laser–tissue interaction	Laser effects
Near infrared	Conventional direct irradiation	Bacteria pigment	Diffusion	Photothermal
Medium infrared	Conventional direct irradiation	Water content of dentine Bacteria	Absorption	Photothermal
Visible near infrared	PAD indirect irradiation	Photosensitisers	Absorption	Photochemical
Medium infrared	LAI indirect irradiation	Water content of irrigants	Absorption	Photothermal cavitation
Medium infrared	SWEEPS indirect irradiation	Water content of irrigants	Absorption	Photothermal Photoacoustic cavitation Shock wave

PAD = photoactivated disinfection; **LAI** = laser-activated irrigation; **SWEEPS** = shock wave enhanced emission photoacoustic streaming.

Table 1: Classification of laser techniques used in endodontics (modified from Olivi[14]).

Conventional laser endodontics

The term "conventional laser endodontics" was coined by Olivi in 2013 to describe the conventional use of laser fibre inserted inside the canal, up to the working length (–1 mm), to directly irradiate the dentinal walls.[14] The laser fibre inserted inside the canal is activated during the withdrawing movement. Laser irradiation interacts with the canal surface according to the various modalities typical of the wavelength used. The primary effect produced is a photothermal one, followed by a secondary bactericidal effect, but undesired morphological modification of dentinal walls is also generated. The main problems associated with conventional laser endodontics are the irregular fluence supplied along the canal and the inability of laser fibres to passively negotiate the canal without interference with the dentinal walls. Contact of laser fibre with dentinal walls can create thermal damage varying from ablation to melting, and bubbles of recrystallisation of the hydroxyapatite and microcracks.[15]

Photoactivated disinfection

Photoactivated disinfection involves the use of a photosensitiser that is introduced into the root canal and selectively activated by an affine wavelength. The visible wavelengths (from 635 nm to 675 nm) activate toloudine and methylene blue, while the near-infrared (810 nm) wavelength activates indocyanine green. The laser irradiation produces a photochemical effect that activates the photosensitiser solution with release of reactive radicals and singlet oxygen. There is no direct laser interaction with the dentinal surface, eliminating any undesired collateral effect. Owing to the low oxygen concentration inside the dentinal tubules and the prevalence of anaerobic/aerobic facultative bacteria in the root canal system, the use of photoactivated disinfection is considered only an adjunct procedure to the conventional one.[16]

Laser-activated irrigation

Laser-activated irrigation (LAI) involves the irradiation of commonly used irrigant solutions in the canal by a laser. The minimum common denominator of different LAI techniques is the wavelength that can be used: the wavelengths of erbium lasers (Er,Cr:YSGG [2,780 nm] and Er:YAG [2,940 nm]) are the only ones absorbed by water, the main component of common irrigant solutions (17 % EDTA and 5 % NaOCl). The greater the absorption coefficient of the molecule for a wavelength, the lower the

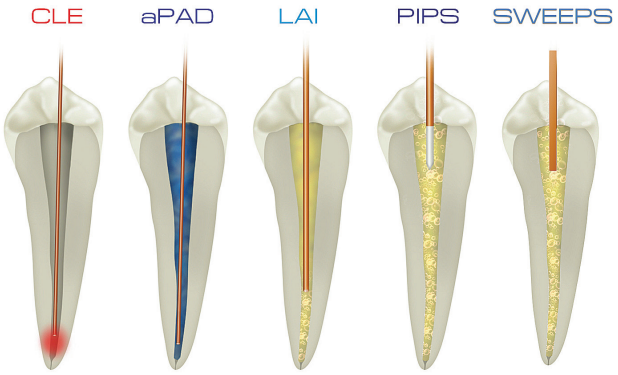


Fig. 1: Graphic representation of various laser techniques used in endodontics: CLE = conventional laser endodontics; aPAD = antibacterial photoactivated disinfection; LAI = laser-activated irrigation; PIPS = photon-induced photoacoustic streaming; SWEEPS = shock wave enhanced emission photoacoustic streaming.

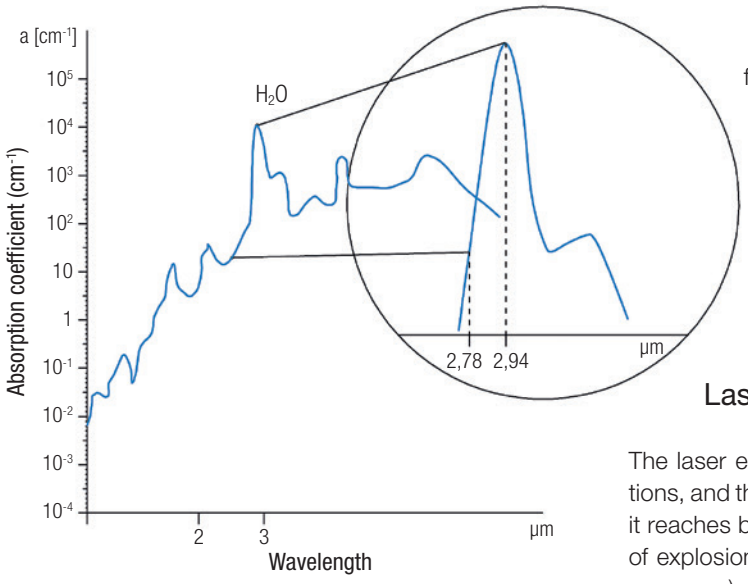
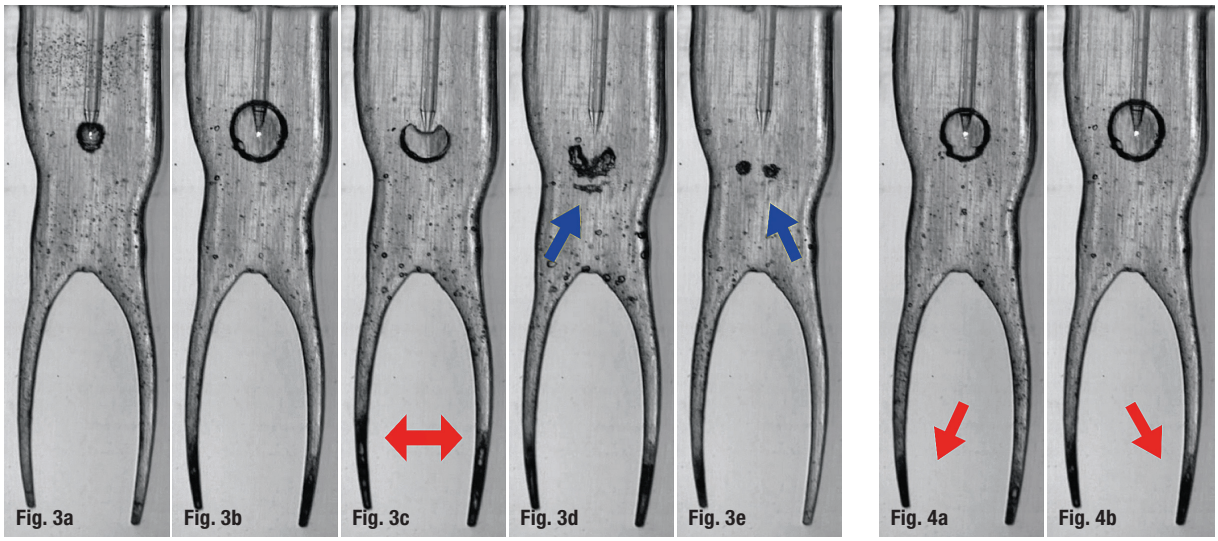


Fig. 2: Different water absorption coefficients in the medium electromagnetic spectrum for 2,780 nm and 2,940 nm. The absorption of Er:YAG laser radiation at 2,940 nm by water is three times greater than that of Er,Cr:YSGG laser radiation at 2,780 nm.

energy required to obtain its absorption (Fig. 2). Specifically, the absorption of Er:YAG laser radiation by water is three times greater than that of Er,Cr:YSGG laser radiation and requires less energy to obtain the same effect.[17] To thoroughly understand the mechanism of LAI, the various devices and settings used, and consequently the proposed protocols in recent years, it is important to consider all the parameters that determine the difference between one laser system and another. Indeed, regardless of the positive results achieved in various LAI investigations, the use of the different protocols can confuse readers. Besides the wavelength specificity (2,940 nm and 2,780 nm) for the target (water), it is important to consider the laser setting used, including energy, pulse repetition rate, fluency, pulse duration and peak power. Also important is to choose the correct laser fibre or tip and position inside the tooth, including tip end design and diameter.

Laser setting

The laser energy is absorbed by the water of the solutions, and the water rapidly increases in temperature until it reaches boiling point (100 °C), forming typical bubbles of explosion (photothermal/photoacoustic primary phenomenon) and thus generating immediate cavitation in the canal (secondary phenomenon; Figs. 3a–e).[18–21] The higher the energy applied, the bigger the bubble size and the more efficient the cavitation produced. However, the application of high energy with the tip inserted inside a canal can have obvious contra-indications owing to rapid vaporisation of liquid from the canal, dry irradiation and consequent undesirable thermal effects on the dentinal walls. A fundamental concept, which explains the efficiency of one system over another, is the peak power emitted by the laser pulse as a function of the energy applied in the time, according to the formula: *peak power = energy/pulse duration*. The goal is to reach a high peak power (400 W) with very low energy applied at subablative levels (20 mJ), to avoid any thermal or ablative effects. This is possible when the pulse duration is very short (50 microseconds), to produce an efficient photoacoustic effect. The higher the peak power of each



Figs. 3a–e: Premolar model showing an Er:YAG laser (LightWalker) equipped with a SWEEPS conical-end tip of 400 µ firing a single 25-microsecond pulse at 20 mJ in water: bubble explosion **(a & b)**, bubble implosion and primary cavitation (blue arrows) **(c–e)**, red arrows show secondary cavitation in the apical third **(c)**. **Figs. 4a & b:** Premolar model showing an Er:YAG laser (LightWalker) equipped with a SWEEPS conical-end tip of 400 µ: single 50-microsecond pulse at 20 mJ in water: bubble explosion at the tip end **(a)**, single 25-microsecond pulse at 20 mJ in water: bigger bubble explosion at the tip end **(b)**.

pulse, the greater the pressure wave generated by the primary bubble explosion (Figs. 4a & b). The pulse duration and the peak power of a laser depend on the technology utilised by the various laser devices. Also, the efficiency of the irrigant streaming depends on the tip used and its position in the endodontic space.

Laser tip

A high peak power, closely related to the pulse duration, of the various erbium lasers used explains the different energy settings used and the different positions of the tip, as reported in the various techniques. During LAI, the tip may be used in motion, up and down, in the canal and withdrawn slowly towards the pulp chamber or may be used in stationary position or with small movements in the apical third or middle third of the canal.[22,23] In contrast, when using PIPS (photon-induced photoacoustic streaming), the laser pulse (of 20 mJ emitted at 50-microsecond pulses [super-short pulse], with the Er:YAG laser LightWalker, Fotona) generates a high peak power (400 W) and creates primary phenomena of explosion and secondary cavitation even at a relevant distance from the area of activation (access cavity), at an average speed of about ten times higher than that measured for passive ultrasonic irrigation.[24] Accordingly, the PIPS technique requires the specific and easy positioning of the laser tip, not inserted into the canal, but held stationary in the pulp chamber, where the irrigant solution is supplied by a syringe.[17] Today, the PIPS technology has been updated, improved and presented as SWEEPS (shock wave enhanced emission photoacoustic streaming) technology (Fig. 5).[25]

SWEEPS technology

SWEEPS represents the technological evolution of PIPS. The laser is the same Er:YAG laser (2,940 nm), now produced in two models (LightWalker and SkyPulse, Fotona). The endo-mode permits emission of energy in two modalities: single pulse and dual pulse. The single super-short pulse modality (50 microseconds; the same as for PIPS) is today accompanied by the ultra-short single pulse modality (25 microseconds, USP) that allows better modulation of the emitted energy, maintaining the same peak power (i.e. 400 W peak power using only 10 mJ) or a more powerful peak power (800 W) using the same energy (20 mJ) as PIPS. In addition, the emission of the dual-pulse modality is now available, firing a second laser pulse after the first in rapid succession. The emission interval between one pulse and another varies randomly from 250 to 600 microseconds (SWEEPS-Auto; Figs. 6a–d). More sophisticated is the emission of the second pulse in resonance with the first (X-SWEEPS); this can happen when the delay of the second pulse permits exact firing when the first bubble is still in the implosion phase, thus implementing the primary cavitation produced. This technology makes it possible to optimise the pressure waves produced depending on the internal volume of the tooth to be treated (molar, premolar, incisor).[25] Also the possibility of modulating the peak power of the single pulse and consequently of the intracanal irrigant pressure wave allows better management of the irrigation in the case of particularly wide canals and resorbed apices of large dimensions.

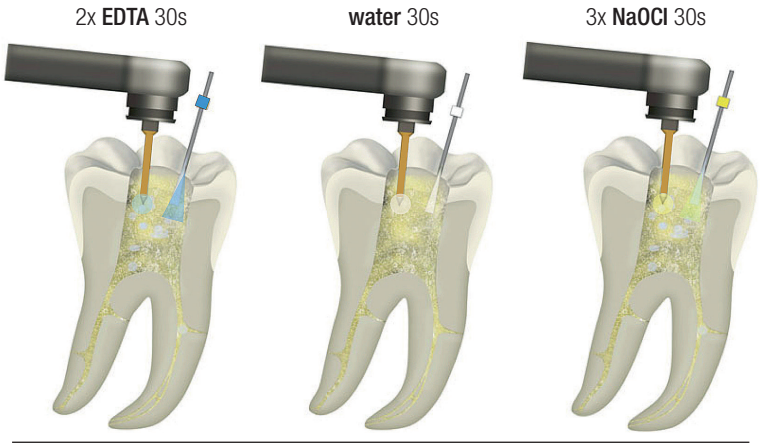
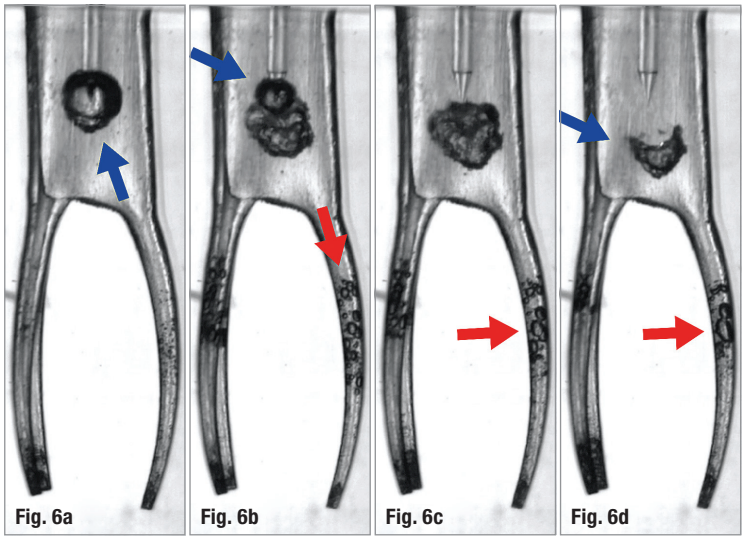


Fig. 5: SWEEPS final irrigation protocol: at the end of therapy, a final irrigation protocol entails two cycles of 17 % EDTA activated by SWEEPS for 30 seconds each, followed by rinsing with distilled water activated by SWEEPS for 30 seconds, then three cycles of 5 % NaOCl activated by SWEEPS for 30 seconds each and a resting time of at least 30 seconds.

Advantages of LAI (SWEEPS)

Laser activation and agitation of irrigants introduced a new standard among the several irrigation methods.



Figs. 6a–d: Molar model showing an Er:YAG laser (LightWalker) equipped with a SWEEPS conical-end tip of 400 µ. Dual-pulse modality at 20 mJ in water: blue arrows show the first bubble **(a)**, the second bubble **(b)** and the induced shock waves **(d)**; red arrows show the secondary cavitation in the middle and apical thirds of the canal **(b, c & d)**.

Fig. 7: SWEEPS tips: conical end and 9–14 mm flat.

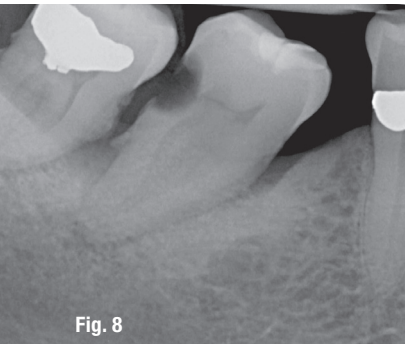
Er:YAG laser activation offers various advantages over the other methods and has been validated by several peer-reviewed papers:

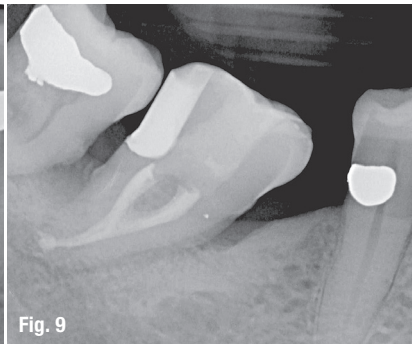
- It provides superior chemical activation of NaOCl.[13]
- It produces superior chemical dissolution of pulp remnants by NaOCl.[26]
- It provides superior physical disruptive action on biofilm.[27]
- It provides a superior smear layer cleaning ability to that of EDTA.[28–30]
- It produces a superior bactericidal effect.[31–33]

In addition, the easy positioning of the tip in the access cavity offers new clinical possibilities in endodontics (Fig. 7). LAI in the access cavity can start just after the opening of the access cavity, allowing progressive reduction of the bacterial load, even before scouting and preparation of the canals. Moreover, using NaOCl, it dissolves the pulp tissue, reducing the possibility of irreversible dislodging of pulp remnants laterally and apically in the endodontic space during instrumentation. In addition, it allows irrigation of narrow and/or long canals with the same simplicity as irrigation of wider canals. Furthermore, it produces, in narrow canals, a more effective and faster flow of fluids in the apical direction, but with reduced pressure (hydrodynamic paradox or Venturi effect). Also, it provides irrigation throughout the entire endodontic space, one or more canals, at the same time. Clinically, it greatly helps in calcified canals, in case of a separated instrument, as well as in endodontic retreatment (Figs. 8 & 9).

Conclusion

The Er:YAG laser, at low energy and with ultra-short pulse duration, has been found to perform very well for activation of intra-canal endodontic irrigants. Owing to the lack of uniformity of parameters used in the various studies (including wavelength, pulse duration, energy, frequency and tip design and diameter) confusion still remains in LAI procedures regarding how to achieve the best results. However, there is now an overwhelming published evidence of the benefits of Er:YAG laser-supported root canal irrigation. Of course, in-depth study of advantages and possible complications of the LAI technique is advisable before *in vivo* clinical application.





Figs. 8 & 9: Tooth #47 with deep decay on the distal proximal wall. One-visit therapy was performed with SS White and ProTaper Next X2 rotary instruments. The SWEEPS irrigation technique allowed good decontamination and cleaning prior to the final sealing (EndoSequence BC Sealer, Brasseler).

about the authors

Dr Giovanni Olivi is an Italy-based dentist and internationally published author. He graduated cum laude in Medicine and Surgery (MD) and in Dentistry (DDS) in Rome. He obtained the postgraduate diploma in "Laser Dentistry" from the University of Florence and the Master status from the Academy of Laser Dentistry. In 2007, Dr Olivi was awarded the "Leon Goldman Award" for clinical excellence by the Academy of Laser Dentistry.

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Literature

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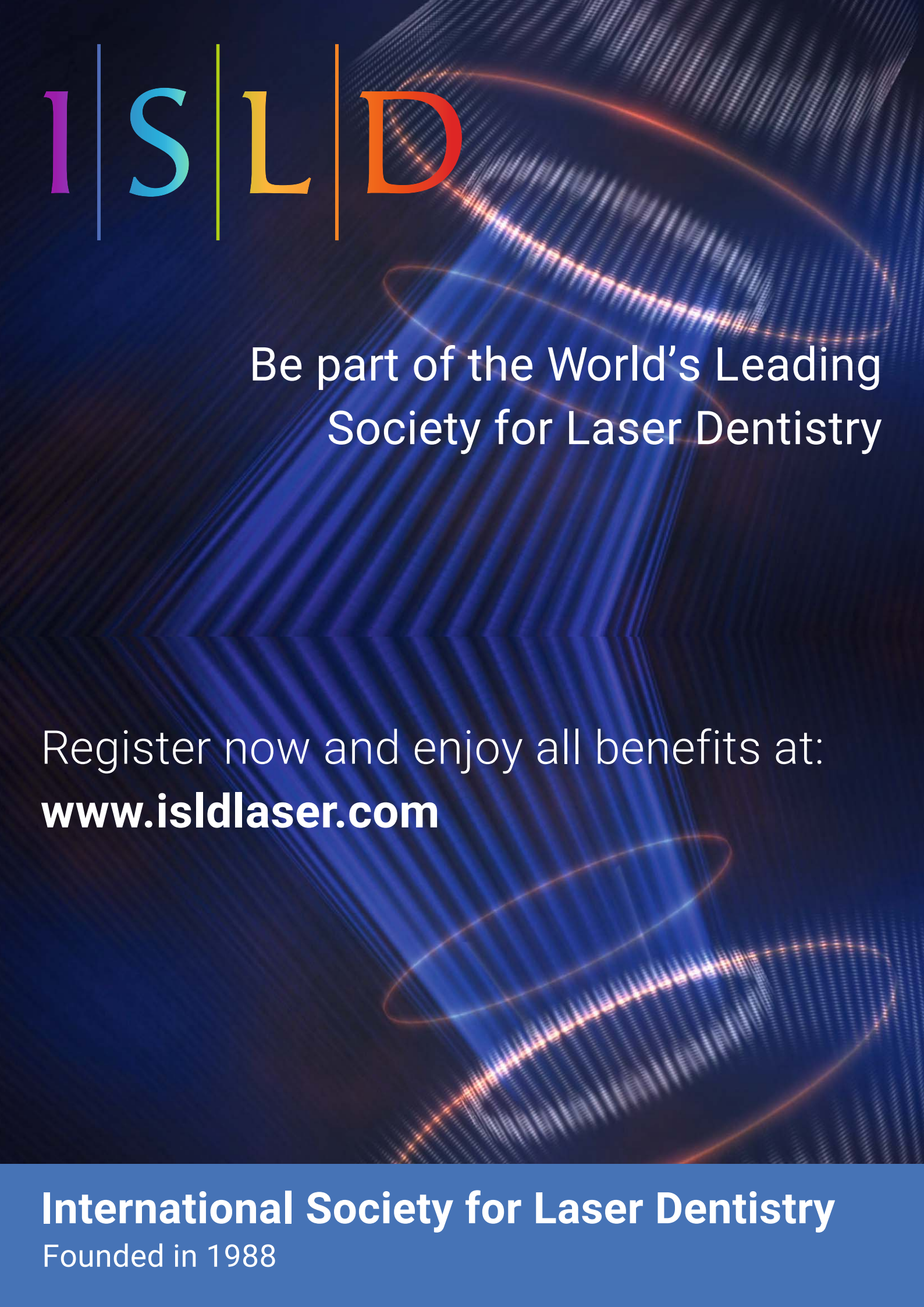
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