Evolution of the role of phototherapy during endodontic decontamination

Omid Heidar Muhammad ¹, Jean-Paul ROCCA ^{1,2}, Carlo Fornaini ³, Etienne Medioni ^{1,2}

1: MICORALIS Laboratory (EA 7354), Faculté d'Odontologie, Université de Nice-Sophia Antipolis

2: Pôle Odontologie, CHU NICE

3: Dental school, Faculty of Medicine, University of Parma

A microbe free root canal space before obturation leads to higher success rate and conventional chemo-mechanical debridement might not achieve this goal completely.

First trials of laser in dentistry started from surgical intervention on caries and bones of oral cavity and extended to prepare cavities and even shaping root canals. Afterward lasers were implicated soon into direct debridement of root canal space.

Anyhow failure of laser to remove debris totally from root canal space is demonstrated recently, additionally it might lead to damages to surrounding tissues or inorganic material of root canal if be used without precaution. Nowadays the theory of light assisted protocols became another start point for laser in endodontics. Laser has been introduced as an adjuvant to conventional debridement of root canals. We used Medline search engine to collect scientific publications to edit this review article in purpose of revealing the evolution of laser position from an ultimate cleaning methodology to an adjuvant to conventional root canal disinfection protocols.

Key words: Decontamination · Diode · Endodontics · Er:YAG · LASER, PDT

Introduction

The conventional endodontic treatment has high success rate. ¹⁾ Nevertheless, this treatment may fail. A great part of failures occur when treatment procedures have not reached an acceptable measure for the control and elimination of infection. ²⁻⁴⁾ It is well-established that the mechanical debridement followed by chemical irrigation removes the bulk of the infecting microorganisms, but because the infection of root canal system is three dimensional, the residual bacteria are still detectable in an important area of the teeth just before filling the root canal. ⁵⁻⁷⁾ Certain operative problems such as insufficient instrumentation, missed canals or inadequate coronal restoration might lead to peri-apical pathologies. ⁷⁾ The complexity of root canal anatomy is another obstacle to obtain an ultimate bac-

terial free root canal system, which makes chemo-mechanical debridement ineffective. ⁸⁾ This complexity incorporates small accessory canals, isthmuses and dentinal tubules that do not allow direct access during the biomechanical preparation because of their location and/ or their small diameters. ⁹⁾

The success rate of endodontic treatments is higher when the canal is bacterial free at the time of obturation. ¹⁰⁾ This was reported to reach 68 – 85% when so-called rigorous radiographic standards were used. The success rates were approximately 66%, 75%, 77%, and 85% for interventions carried out by general dental practitioners, undergraduate students, graduate students, and specialists, respectively. ¹¹⁾ Previous studies have shown that in a microorganism free root canal environment just before filling- treatment may achieve a success rate up to 94%. However, because the presence of the bacteria, this rate can be diminished to 68%. ⁴⁾ The antimicrobial sensitivity or resistance of the polymorphous micro flora, which includes anaerobic, facultative anaerobic and aerobic bacteria, may deter-

Addressee for Correspondence:

Prof. Etienne Medioni

Address : MICORALIS Laboratory (EA 7354), Faculté d'Odontologie, Université de Nice-Sophia Antipolis, 24, Avenue des Diables Bleus 06357 NICE, France

E-mail : medioni@unice.fr

Tel : +33614489437 Fax : +33492001263

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mine the outcome.⁹⁾

A decade after laser invention by Maiman,¹²⁾ Weichman introduced laser, for the first time, for endodontic therapy using a 10.6 μm CO₂ laser and then a 1064 nm Nd:YAG laser;¹³⁾ although the results were not encouraging but the original idea brought the bravery for future studies.

After one decade of academic silence, during 1980s, Melcer, using laser in endodontics contributed lots about laser knowledge to dental sciences.¹⁴⁻¹⁷⁾ These studies were continued by other researchers like Miserandino *et al.*¹⁸⁾ Likewise, other wavelengths such as 308 nm,¹⁹⁾ 488 nm,²⁰⁾ 1064 nm²¹⁾ adopted in endodontical treatment studies.

This review throws a glance at evolution of application of different kind of lasers used with different wavelengths in the field of endodontic disinfection and aims to answer whether laser is just a “dreaming star wars” in dentistry or it is real future of the field.²²⁾

Scientific publications concerning “Endodontics” and “Laser assisted disinfection” in PubMed database could be found from 1971. Using (Endodontics OR

Root canal) AND Laser MeSH terms, 1047 articles in English language were found until end of 2014. This search could be narrowed down for defined period of time by using publication date filter of search engine (**Table 1**).

A huge wave of scientific reports raised in last 5 years. In addition, this search could be restrained for articles that targeted root canal disinfection. The search should be formulated as (Endodontics OR Root Canal) AND Laser AND (Disinfection OR decontamination OR antimicrobial OR Bactericidal), which narrows down the results to 306 published articles in the selected timespan (**Table 1**). The antimicrobial characteristic of laser was known for many years, but in last 10 years the attention of researchers was specially brought to utilize this device to eliminate root canal bacteria (**Fig. 1**).

Diode lasers comes to the top of the list of the lasers when their possible ability to decontaminate root canal system is evaluated by publications indexed in PubMed. Anyhow, by a manual revision in suggested articles we found out the search results was included

Table1: Number of publications related to Endodontics and Laser and disinfection from 01.01.1971 to 31.12.2014.

	Total	1971-1981	1982-1992	1993-2003	2004-2009	2010-2014
All Articles about Endodontics and Laser	1047	4	55	314	285	403
Articles about Endodontic disinfection and Laser	306	0	4	44	89	174

Figure 1: Distribution of scientific publications about “Endodontics” and “Laser” according to specific wavelength and PDT from 01.01.1971 to 31.12.2014.

Figure 2: Distribution of scientific publications about “Endodontic Disinfection” and “Laser” according to specific wavelength and PDT from 01.01.1971 to 31.12.2014.

many articles for photodynamic therapy in which diode laser is used as activator of photosensitizer (**Fig. 2**). It is important to note that the lack of homogeneity in keywords and MeSH terms used in articles may result in many unrelated articles among PubMed search results. Therefore, a manual review of results is compulsory. However, photodynamic therapy came along to be an interesting subject in terms of root canal decontamination in the last 5 years (**Fig. 2**).

Nd:YAG laser is still hired as machine of choice in certain endodontic protocols, however, the golden period of this laser was in 1990s and beginning of 2000s when the majority of published scientific reports in this field contributed to this wavelength. KTP laser is used anyhow to clean root canal space, but as the first application of 532 nm laser is treatment of vascular lesions, the capability of this device to decontaminate root canal pathogens was ignored (**Fig. 2**).

Erbium doped lasers are wavelengths which brought attention of researchers from their emergence till now. Er:YAG was the first laser system cleared by FDA in 1997 to treat dental decay and subsequently implicated to endodontic disinfection, thanks to its physical properties specially its affinity to H₂O molecules and superficially limited activity.

Er:YAG

Erbium doped lasers are machines with wide range of application; the laser beam arrives easily in most distal region of oral cavity using sapphire tips. Erbium doped yttrium aluminum garnet (Er:YAG) laser hand pieces are equipped with specially designed fiber to bring the efficiency of this laser light inside root canal space.^{23,24)} Er:YAG laser has been used more than any other wavelengths to study the dentin-laser interaction in the field of endodontics (**Fig. 1**). Topçuoğlu using inductively coupled plasma-atomic emission spectrometry (ICP-AES), demonstrated that there is no change in mineral content of dentin inside the root canal after irradiation with Er:YAG laser.²⁵⁾ Application of Er:YAG laser for intra radicular disinfection, presents optimal results in microbial infection reduction from endodontic space which has been confirmed by Mehl *et al.*²⁴⁾ These properties are dose-dependent and not selective to any bacterial species. Er:YAG with a wavelength of 2940 nm has highest absorption rate in water and hydroxyapatite.²⁶⁾ Thus, Er:YAG is able to disrupt organized biofilms and explode the bacterial cells through a well-established mechanism of action by production of explosive vapor.

Er:YAG laser could reduce bacterial load from

infected root canal²⁷⁾ and it is an efficient tool for removing the smear layer.²⁸⁾ This laser could clean root canal dentin from smear layer and leaves the dentinal tubules open without any harm to the inorganic structure of root canal wall and/ or surrounding periodontal tissue. Although, this result needs a direct contact of optic fiber with root canal walls; it might be a source of thermal damage if it is not controlled.²⁹⁾ When root canal irradiation is coupled with a chemical antimicrobial agent like NaOCl, it leads to a total eradication of microbes from root canal space. Such an activation with an output power of 0.3 W, 15 Hz for 3 period of 20 seconds could ensure an ideal result in terms of endodontic decontamination.³⁰⁾ Erbium doped lasers initiate by their explosive nature of action, a cavitation effect inside irrigation solutions passing the root canal;³¹⁾ this is the principle of laser activated irrigation (LAI). Matsumoto suggested that a successful root canal treatment, especially in narrow curved root canals, might be achieved when laser activated irrigation is used for disinfection.³²⁾ Likewise, considerable reduction of output power of laser to activate irrigants is another important advantage of LAI. Nowadays, researchers are looking for getting benefits from sub-ablative energy of Er:YAG laser to activate other irrigation solutions inside the root canal. For example erbium doped laser might increase the efficiency of EDTA to remove smear layer.^{33, 34)} Interestingly it is reported in the literature that ultrasonic irrigation could not encourage chelating character of EDTA.³⁵⁾

De Moor evidenced that LAI using an erbium doped laser with low energies (75 mJ) and an intermittent flushing technique (4 times 5 seconds) is as efficient as passive ultrasonic irrigation (PUI) to remove debris from root canal space.³⁶⁾ Recent innovation in this field is PIPS or photon induced photoacoustic streaming. The mechanism of action is nearly the same than in passive ultrasonic irrigation. The laser produces acoustic waves by low energy pulses and could help irrigants to distribute inside root canal space. Furthermore, DiVito demonstrated that a stationary positioning of the fiber at the canal orifice during PIPS is enough to excite the irrigant even in apical region.³⁷⁻³⁹⁾ Recently, eradication ability of PIPS against mono-species bacterial contamination was confirmed,⁴⁰⁾ and this would be a promising technique for future application in the clinical trials.

Er,Cr:YSGG

Erbium, chromium yttrium scandium gallium garnet

(Er,Cr:YSGG) is another member of the erbium doped lasers family. Er,Cr:YSGG with a wavelength of 2780 nm is better absorbed in hydroxyapatite and like Er:YAG, it has a great affinity for H₂O molecules.²⁶⁾ Identical to Er:YAG, Er,Cr:YSGG laser does not cause thermal damages to dentin that makes this device suitable for root canal smear layer and debris removal.⁴¹⁾

Eldeniz demonstrated the bactericidal effects of Er,Cr:YSGG laser.⁴²⁾ This is a time and dose dependent procedure. For instance, 60 seconds irradiation of canal with a 2 W power is as effective as 5% NaOCl irrigation in terms of bacterial load reduction.⁴³⁾ An ultimate bacterial free canal is not achievable using Er,Cr:YSGG alone, hence it brings the attention of the researchers to test its ability to enhance the effect of other cleansing agents. De Moor *et al.* showed the Er,Cr:YSGG laser is as effective as Er:YAG laser or passive ultrasonic irrigation to activate NaOCl.^{36, 44)} They demonstrated how a 2780 nm laser is efficient to remove debris from root canal space when the irrigant is triggered with energy of 75 mJ and for 20 seconds (4x5 seconds). Likewise, Bago Jurič showed this activation of NaOCl is efficient in terms of total bacterial charge reduction.⁴⁵⁾ They demonstrated the LAI granted more bacterial free sample at the end of treatment than any other test groups. A clinical trial by Martins revealed that Er,Cr:YSGG assisted irrigation of teeth with periapical periodontitis is as effective as conventional irrigation protocols.⁴⁶⁾ A follow up of 12 months showed a considerable reduction in peri-apical index (PAI) scores.

Nd:YAG

Nd:YAG is a near infrared laser with a wavelength of 1064 nm and widely used in soft tissue surgery. It is highly absorbed by hemoglobin and dark-colored tissue.²⁶⁾ Antimicrobial efficacy of Nd:YAG was investigated first by Levy, Rooney and Hardee.⁴⁷⁻⁴⁹⁾ They all demonstrated a direct relation between dose of irradiation and the bacterial load reduction. Later on, Moshonov and Rahimi demonstrated that Nd:YAG laser could partially clean smear layer and remove bacterial colonies.^{50, 51)} They proposed a totally cleaned root canal space from bacterial infection could be achieved when Nd:YAG laser and NaOCl are used in synergy.

Hence, Nd:YAG laser is a thermic laser and all bacteria present in root canal microbial biofilm are not pigmented; and Nd:YAG laser is able to inactivate bacteria by local rise of temperature leading to denaturation of enzymes and boiling the liquid presented in canal.⁵²⁾ Confirming Mehl's study,⁵³⁾ Meire evaluated

the efficiency of 1064 nm laser in terms of bacterial decontamination. They used low parameters (total 80 J) to kill *Enterococcus faecalis*.^{54, 55)} As the microorganism is not pigmented so the light will pass through the bacterial cytoplasm, therefore the possible mechanism of action is photo-thermic effect of laser on the environment around bacteria. However, the desired effect was not obtained because of inefficiency of laser parameter. Only by increasing the power of Nd:YAG laser beyond clinically allowed dosage, bacterial reduction was observed. Nevertheless, Pirnat demonstrated the near infra-red lasers like Nd:YAG and high power diode lasers could destroy pigmented bacteria presented in the endodontic biofilm.⁵⁶⁾

It is well established in literature that thermal elevation produced by Nd:YAG laser is more than 5.5°C which is physiologically acceptable⁵⁷⁾ and could cause unrecoverable response by surrounding tissue.^{49, 58, 59)}

In addition, Cox and Türkmen^{60, 61)} showed uncontrolled Nd:YAG laser irradiation may cause many undesirable effects on root canal walls. Smear layer could be formed and occlusion of some dentinal tubules linked with structural modification of dentin (recrystallization, melting and carbonization) may also be observed. Another study indicated that a direct application of Nd:YAG laser could alter structure of dentin even with lower energies (25-50 J/cm²).⁶²⁾

Nd:YAP

Another neodymium doped laser is neodymium doped yttrium aluminum perovskite (Nd:YAP) with a wavelength of 1340 nm. Blum was the first to propose that Nd:YAP inhibits growth of *Streptococcus mitis* with a frequency of 30 Hz and an energy of 300 mJ.⁶³⁾ Same authors in a further study suggested that the combination of subsonic irrigation and Nd:YAP laser irradiation give better results.⁶⁴⁾ Moreover, Moshonov showed Nd:YAP laser could be implicated in root canal cleansing protocol.⁶⁵⁾ They observed a cleaner root canal when Nd:YAP laser was involved as an adjuvant to conventional endodontic preparation methods without changing molecular composition of dentin.

Rather than a better absorption in water, Nd:YAP laser has the same photo-thermic mechanism of action when compared with Nd:YAG laser. The temperature elevation during Nd:YAP laser irradiation may become considerable and lead to damages identical to Nd:YAG laser,⁶⁶⁾ as use of cooling water and an adapted protocol inside the root canal is required.

KTP

The effect of potassium titanyl phosphate or KTP laser on dentin structure has been studied from its very first emergence in market. Tewfik evidenced that KTP laser is able to make changes on dentin inside the root canal. The parameters were adjusted to 1 W for 1 second or 0.5 W for 0.5 second, because thermal elevation is about 5°C and could not damage periradicular tissues.⁶⁷⁾ However, KTP laser resulted in crack formation in dentinal tubules even when using a safe range of energy. In contrast, Machida reported KTP laser is able to remove smear layer and debris from apical dentin using safe parameters (1 W × 6 s, 5 Hz, repeated 5 times and at 2 W × 3 s, 5 Hz, repeated 5 times).⁶⁸⁾ This clarified that power and working time influence the outcome of laser treatment on root canal walls. In addition, it is important to consider resting time to avoid any cumulative thermal damage.⁶⁹⁾

KTP is capable to reduce bacterial load, but its efficiency is inferior to the results from NaOCl alone.⁷⁰⁾ Since we know that total eradication of bacteria from root canal space is not possible, the ideal protocol seems to be the conjunction of both chemo-mechanical debridement and laser irradiation.⁷¹⁾

Diodes

Another group of lasers are semiconductor or diode lasers. Diodes rapidly found their way into laser-assisted dentistry thanks to their small size, ease of use and affordable price. Diode lasers with a big range of different wavelengths from visible to infrared contributed a lot to the field of endodontics especially endodontic disinfection.

For the first time in 1997, Moritz examined an 810 nm diode laser ability to kill root canal bacteria in *in vitro* and *in vivo* studies.^{72, 73)} Furthermore it was verified that this wavelength is able to decontaminate deep layers of radicular dentin which is an important point to overcome the 3-dimensional aspect of root canal space.⁷⁴⁾ It could be explained by the phenomenon that diode laser is not absorbed in water or inorganic material which leads to scattering of laser beam into deeper layer of dentin.⁷⁵⁾ Same results were obtained by 830 nm,⁷⁶⁾ 940 nm⁷⁷⁾ and 980 nm⁷⁸⁾ diode lasers. These findings demonstrated different wavelengths of diode laser are all effective in terms of reduction of bacterial load.

da Costa Ribeiro showed photo-thermic damage of diode laser is negligible when reasonable parameters are used.⁷⁹⁾ They showed thermal elevation

caused by this laser is up to 8.6°C in continuous mode and between 1.2 to 3.3°C in pulsed mode which is crucial to prevent any harm to periodontal tissue. However, still this little thermal change could result in closure of dentinal tubules. To prevent any cumulative thermal effect, it is mandatory to consider recovery time during diode laser irradiation interval. Respecting this rule, diode laser could be counted as a safe laser with different power level⁸⁰⁾ which could raise up to 3 W if it has been used in pulsed mode.⁸¹⁾ Stationary contact of fiber tip with dentin leads to overheating and melting the dentin and further thermal damage to surrounding tissues. For this reason constant moving of fiber during irradiation is fundamental.⁸⁰⁻⁸²⁾

The morphological changes caused by diode lasers in root canal dentin are power dependent. Diode lasers removes smear layer at 1.5 W, but increasing power leads to extreme changes in dentin like melting of surface dentin.⁸³⁻⁸⁵⁾ Nevertheless, despite any morphological alteration initiated, diode lasers have no adverse effect on structural characteristic of mineral matrix of root canal.⁸⁵⁾ Smear layer elimination could be achieved using diode laser in conjunction with some irrigation solutions. However, the kind of irrigation solutions determine the outcome of treatment.⁸⁴⁾ For example, synergy of diode laser and NaOCl produces smear layer, but combination of diode laser and EDTA results in smear layer elimination.⁸⁶⁾ In another study, activation of EDTAC[®] by a 940 nm diode laser seems to be an ideal protocol to remove smear layer, but irradiation of hydrogen peroxide with same parameters develops no significant effects on smear layer.⁸⁷⁾

Diode lasers might contribute to activation of irrigation solutions thanks to their high frequency that reaches to 20-50 KHz. This property of diode laser could promote cavitation effect inside root canal irrigants and subsequent better debridement.⁸⁸⁾ Neelakantan demonstrated the diode laser is as efficient as Er:YAG laser to activate irrigants in the root canal and disturb microbial biofilm.³⁴⁾ However, in another study it has been indicated that there are some differences in quality of explosive vapor initiated by diode and Er:YAG lasers. The peak of cavitation and bubbles formation with diode laser happens with a delay after irradiation starts. Due to slower fluid movement during irradiation by diode laser, the possibility of irrigants extrusion beyond dental apex is less than that of Er:YAG laser.⁸⁹⁾ However, there is a proportional relationship between irrigant volume in root canal spaces and the power needed to activate it. The form of the fiber may enhance the outcome. George introduced a modified

light delivery fiber called honeycomb tip to enhance the agitation and cavitation properties of diode laser. Using this fiber, diode laser makes more bubbles toward root canal walls and less in apical direction. As well the time needed to achieve peak cavitation is inferior to that of plain fiber. However, the factor of power is playing an important role. The cavitation occurs always in a power level more than 2 W.⁸⁹⁾

PDT

Photodynamic therapy (PDT) is a medical treatment which utilizes light to activate an agent called photosensitizer in presence of oxygen. Many Photosensitizers and different from chemical photosensitizing agents like toluidine blue,^{90, 91)} methylene blue^{92, 93)} to natural photosensitizers like curcumin⁹⁴⁾ have been examined. The outcome of PDT in different protocol with different activating lights has been tested. However, using different types of laser does not improve the outshot of PDT.⁹⁵⁾

As a pioneer, Wilson mentioned bactericidal effects of PDT in dental diseases.^{96, 97)} Afterward, the potential role of PDT in total eradication of root canal infection was outlined in many researches.⁹⁸⁻¹⁰¹⁾ The number of scientific publication on this topic is increasing in recent years (**Fig. 2**). A high degree of safety of PDT could be a reason for such significant progress.¹⁰²⁾

The results of studies are controversial. It is demonstrated conventional photo-activated disinfection (PAD) could not disrupt polybacterial plaque but it might reduce a mono-species biofilm made of *Enterococcus faecalis*.¹⁰³⁾ Anyhow, Yao suggested that PDT is more effective on planktonic form of bacteria than their biofilm state inside root canals.¹⁰⁴⁾ Thus, the conventional disruption of intracanal biofilm before PDT is critical for success of treatment.⁹²⁾ Clinical trials of Jurič very well demonstrated application of PDT after conventional debridement of root canal space to obtain a bacterial free canal.¹⁰⁵⁾

Concerning biofilm – PDT interaction, it is evidenced that different PDT protocols could not be effective without pretreatment of biofilm with conventional decontaminating agents like NaOCl.^{106, 107)} Anyhow, promising results are reported especially when more incubation time with Photosensitizer and longer irradiation is applied.^{99, 108)} An *in vitro* study by Komine and Tsujimoto exhibited that the highest amount of singlet oxygen generated through photodynamic therapy could be achieved after longest time of irradiation.⁹³⁾ Regarding working time, these conditions seem to

be difficult to apply in daily clinical procedures particularly when treating multi rooted teeth. To overcome this problem, PDT in 2 visits could be beneficial.^{109, 110)} However, there are controversies about irradiation time; interestingly, Yildirim reported that there is no difference between 1 minute and 4 minutes irradiation of photosensitizers.¹¹¹⁾

The quality of activating light may also influence the outcome. For example, emitters or light diffuser optic fiber could scatter unidirectional light of diode laser to ensure maximum reach even in the most distal zones of root canal.^{99, 112)} Light emitting diodes (LED) showed to be promising in terms of activating the photosensitizers.¹¹³⁾ LED light travels easily in all direction with no need to move the optic fiber. This may lead to better results in terms of bacterial load reduction rather than PDT utilizing a unidirectional diode laser (**Fig. 3**).¹⁰⁷⁾

Recently, another study by Sabino demonstrated different effect of a same light source on a bioluminescent species of *Candida albicans*.¹¹⁴⁾ When micro-organisms are irradiated with laser using a light diffuser fiber, the reduction in bacterial load is 100 times more than using a normal optic fiber.

CO₂

Zakariasen was the first to propose an exposure of 1 second to a 10 W CO₂ laser beam leads to bacterial death,¹¹⁵⁾ but later on its effects on root canal dentin were studied.¹¹⁶⁾ Takeda demonstrated that by placing a conical tip inside the root canal and using 3 W, CO₂ laser could remove smear layer partially.²⁸⁾ However, in some regions some undesired effects like burning, melting, recrystallization and glazing of dentine were observed too and confirmed by other studies.⁶¹⁾ Likewise, an *in vitro* studies proposed that irradiation of root canal space by CO₂ laser using a hollow fiber at 30 J energy in either pulsed or super-pulsed mode may lead to damage to tissues beyond the apex.¹¹⁷⁾ Additionally, CO₂ laser light could not be transferred via an optic fiber¹¹⁸⁾ and trials to deliver the energy of a defocused laser beam inside root canal space also failed.¹¹⁹⁾ Regarding difficulties in irradiation of CO₂ laser and subsequent undesirable effects, logically and at the present time, there is no more interest to deploy such wavelength in terms of root canal disinfection.

Conclusion

If we look to the milestone of laser in endodontics, the beginning of the way is marked with issues regarding

energy leading to undesirable effects on dentin and periradicular environment. Thanks to constant evolution of laser technology and progressive scientific experiments, nowadays it is well documented that lower energies could provoke the intended objectives.

Laser assisted endodontic decontamination in conjugation with conventional chemical solutions activated by laser should be favored over direct use of laser to remove bacterial biofilm from root canal space. Both erbium doped lasers through explosive vapor and diode lasers with short pulses and high frequencies could produce cavitation effect inside irrigation solutions and result in a 3-dimensionally clean root canal walls, free from smear layer and debris even in apical region. This does not need high energies and could prevent unwanted thermal and physical side effects to root canal dentin or other surrounding tissues.

It is known that common root canal irrigation solutions could absorb light in different wavelengths

from 513 nm for chlorhexidine (CHX) to 2200 nm for citric acid. In addition, different irrigants have high absorption rate for wavelengths higher than 2500 nm. These optical properties make all tested irrigants qualified for LAI.¹²⁰⁾ The important point is to match the right irrigant with available wavelength or vice versa.

Mechanism of photodynamic therapy is quite different from physical interaction of LAI which is based on wave production in irrigants or direct root canal decontamination by near infra-red lasers which work by thermal elevation. PDT is a pure chemical reaction and it could not clean totally the root canal space from microbial biofilm, alone. It should be kept in mind that photodynamic therapy is an adjuvant and not a substitute to conventional chemo-mechanical debridement. Thus, there is no resistance or selectivity toward PDT, it might be helpful removing bacteria from root canal space especially microbial flora of chronic endodontic disease or/ and those resistant to antibiotics.

Figure 3: Quality of light may be effective on the outcome of PDT. A, B: Non-collimated, intense LED light could travel in all direction and does not need to be moved to excite photosensitive agent. C, D: Collimated 650 nm diode laser light needs to be moved through the canal to activate photosensitizer.¹⁰⁷⁾

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