Laser Assisted Root Canal Disinfection-A Review

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Abstract: Laser assisted procedures evoked the field of endodontics almost 3-4 decades ago by means of using appropriate energy produced by light for alteration of various hard and soft tissues. During the initial years, the cumbersome laser delivery systems and handling limited its use, despite the purported advantages. However, the last few years, have seen tremendous advancements in terms of tip designs, disinfection agents, photoacoustic streaming etc. This paper has been compiled in an attempt to discuss the effects of photo-activated technology on the root canal system.

Keywords: Laser irradiation, photodynamic therapy, root canal disinfection, smear layer.

1. INTRODUCTION

The sequel of endodontic treatment is acutely linked to the subsistence of microorganisms in the root canal anatomy. It is well established that microorganisms play a central role in the pathogenesis of pulpo-periapical disease. Endodontic therapy aims to adequately outline the root canal system to achieve disinfection by eliminating bacteria, their toxins, and removing smear layer. In pursuance of achieving a reduction of the microbial count in the root canals, diversified approaches have been suggested involving endodontic preparation techniques, irrigation protocols and use of disinfecting medicaments. Paque *et al.* [1] have reported that in post mechanical instrumentation, large areas of root canal remain untouched, regardless of whether manual or rotary technique was used. Oguntebi *et al.* [2] in addition showed that the ability of intracanal medicaments to penetrate into the dentinal tubules is limited and also some of them do not possess a wide spectrum of action against endodontic pathogens. Thus, elimination of microorganisms from the root canals using traditional instrumentation and decontamination techniques remains uncertain. Off late, the use of lasers is increasingly being suggested to attain disinfection of the root canal system and removal of smear layer. The complexities within the root canal harbours locales like secondary canals, anastomoses and deep dentinal tubules which are inaccessible to the conventional disinfecting irrigants and intracanal medicaments. Laser therapy have provided access to these elusive areas and effectively eradicated microorganisms from the deeper reaches of the endodontic reticulation.

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2. SMEAR LAYER REMOVAL

A residual layered reservoir that contains organic and inorganic debris which is often formed after root canal preparation, with a penetrability of 40μ in dentin [3]. The elimination of this smear layer has resulted in improved periapical healing.

Various methods have be improvised for its effective elimination and the recent approach rely on laser light when irradiated inside a root canal results in formation of bubbles inside a fluid. This is followed by a phenomenon known as acoustic streaming caused by generation of shock waves due to rapid changes in pressure/amplitude. A forced collapse of bubbles causes implosions that impact on surfaces causing shear forces. In the closed environment of the root canal system these shear forces clear away the smear layer, herniate bacterial cells and disrupt the endodontic surface biofilm thus enhancing their disinfecting and debriding ability [4, 5]. The photothermal and photomechanical actions of laser facilitate smear layer removal. However, since the actions are based on thermal effects, heat generation

E-ISSN: 2311-8695/16

and its associated undesirable effects are always a matter of concern. In this regard, it is essential that the appropriate parameters for the selected operation are validated and their safety documented. A quantum of studies has been done to study the various parameters that can be safely employed.

George *et al.* [6] studied the smear layer removing ability of modified flat and conical tips, with Er:YAG and Er,Cr:YSGG (400µm diameter) laser. Laser activation of irrigants (EDTAC) resulted in sanitised dentinal walls devoid of smear layer. Also, only a 2.5^{o}C increase in temperature was seen when a power of 1 and 0.75W was used. Arslan *et al.* [7] evaluated the efficacy of 808-nm diode laser agitation of 15% ethylene diaminetetraacetic acid (EDTA) and its effectiveness in smear layer removal. Effective smear layer removal was noted in the apical thirds of root canal following 20 seconds agitation of the irrigant with the diode laser. Hulsman *et al.* [8] exhibited complete smear layer removal with open dentinal tubules with laser activation of EDTA irrigant without any undesirable phenomena. Intact collagen structure was seen under scanning electron microscope (SEM) in the root dentin suggesting the conservative nature of this treatment modality. De Moor *et al.* [9] studied the effect of laser activation of irrigants (LAI). They activated 2.5% sodium hypochlorite (NaOCl) with Er,Cr:YSGG laser at 75mJ, 20Hz, 1.5W for 5 seconds with an endodontic (flat end) tip of 200µm diameter. The laser energy energised the irrigants producing photoacoustic streaming. Thermal expansion causing subsequent implosion generated secondary cavitation effect on intracanal fluids. The tip was held stationary 5mm from the apex in the middle third of the canal, without being retracted or moved up and down thus greatly simplifying the procedure. De Moor *et al.* [4] also compared the efficacy of LAI technique with PUI (Passive ultrasonic irrigation) and CI (Conventional Irrigation) and concluded that laser technique provided superior results with lower irrigation times. Studies by De Groot *et al.* [5] and Hmud *et al.* [10] also supported the results by De Moor *et al.* Macedo *et al*. [11] stated that laser activation increased potency of NaOCl and increased the consumption of chlorine significantly more compared to PUI or CI.

3. DISINFECTION OF ROOT CANAL SYSTEM

Conventionally irrigants have been used to achieve disinfection of root canals with or without mechanical agitation. Laser can be considered as a suitable alternative to achieve endodontic disinfection [12]. Though the bactericidal effects of lasers have been well established but the exact mechanism has not been fully decoded. The antibacterial action depends on the type of laser used. Anti-bacterial effect of Nd:YAG lasers mainly results from its thermal effects, whereas strong water absorption has been suggested for the bactericidal mechanism of action for Er:YAG lasers [13]. Lasers are reported to destroy deeply located bacteria in radicular dentin than traditional chemo-mechanical methods [14]. A substantial reduction of the bacterial load has been observed when laser is used an adjunct to conventional endodontic treatment [15]. Both near infrared lasers or medium infrared lasers can be used to achieve endodontic disinfection [12, 16].

Lasers of near infrared wavelength have no affinity to hard tissues and thus have no ablative action and are thus is safely employed intraradicularly for disinfection. The root canals are prepared in the conventional way employing mechanical instrumentation until ISO 25/30 apical preparation. Laser irradiation is done at the conclusion of endodontic shaping just prior to obturation as a final means of decontamination. Clinically a fine 200µm diameter endodontic tip is positioned 1mm short of the apical terminus and using a helical movement the tip is retracted coronally at a steady pace in 5 to 10 seconds. The lasing procedure is done in canal filled with an irrigant such as EDTA or NaOCl to avoid undesirable thermal effects. Schoop *et al.* [13] demonstrated superior efficacy of lasers in disinfection compared to traditional chemical irrigation, *in vitro* owing to the energy spread of laser irradiation and penetrability into the dentinal wall. The diffusion capacity varied with the wavelength used. A bacterial reduction of 85% at 1mm was demonstrated using Nd:YAG (1064nm) when compared with diode laser(810nm) which exhibited a reduction of 63% at 750µm or less. Diode laser (810nm) when used in combination with endodontic irrigants, EDTA and citric acid brought about a more or less absolute reduction of the bacterial load (99.9%) of *E. faecalis* in the endodontic system [17].

Erbium lasers possess high affinity to water. They are absorbed primarily on the surface of root canals and exert high bactericidal activity against gram positive *(E. faecalis)* and gram negative *E. coli* bacteria [12]. Lasers possess high bactericidal action owing to their thermal effect and can penetrate deep into the dentinal tubules. Er:YAG laser exerts bactericidal action against *A. naeslundii, E. faecalis, L caesei, P. acnes, F. nucleatum, P. gingivalis* and has been shown to be able to disrupt endodontic biofilm even in the apical third [18]. Moritz *et al.* [19] obtained an almost total eradication (99.64%) of *E. faecalis* using Er:YAG laser following root canal preparation.

Following preparation of the root canal with conventional instrumentation long, thin (200 and 320μm) Erbium laser tip is placed till the working length and retracted using a helical movement over 5 to 10 second interval. The procedure is repeated 3 or 4 times alternating with irrigation with chemical irrigants (NaOCl and/or EDTA) keeping the canal wet while irradiating with laser.

Conventionally mechanical or ultrasonic agitation of endodontic irrigants (NaOCl in combination with chelating agents such as EDTA and citric acid) is carried out to achieve disinfection and cleaning of the endodontic system. Berutti *et al*. [20] have reported action of NaOCl upto 130μ depth on the root canal walls. Chen *et al*. [21] have exhibited bactericidal action upto a depth of 300 to 400μm below the lased surface. Bactericidal action results from structural modifications in bacterial cell wall which alters the osmotic gradient, causing cellular distension and finally death.

3.1. Dry vs Wet Laser Irradiation

Thermal effects of lasers help kill bacterial cells but also manifests as detrimental changes in the root canal dentinal and adjacent periodontal ligament. Collateral effects of root canal decontamination are seen with both near and medium infrared lasers when used dry. Melting of inorganic dentinal structures seals off tubules. Also recrystallisation bubbles and cracks are evident with partially removed smear layer. To minimize the undesirable thermal effects of laser beam on the dentinal wall laser activation is done in wet canals. The water limits the diffusion of heat onto the dentinal walls and it gets thermally activated either directly by near infrared laser irradiation or indirectly by vaporisation with a medium infrared laser [22, 23, 24].

Yamazaki *et al*. [24] and Kimura *et al.* [25] studied effects of erbium laser and concluded that water is necessary to avoid undesirable morphologic side effects when dry canals are irradiated. Thermal damage and ablation result at the power used for decontamination. Crazing, ledges, zones of superficial melting and smear layer ablation are evident. However, when Erbium laser is irradiated in a wet canal, the thermal damage is minimised and establishes patency of dentinal tubules. Less ablated areas are seen in the more calcified peritubular dentin than inter tubular dentin which is rich in water. Also, following irradiation with erbium laser the smear layer is ablated and mostly eradicated. Moritz *et al.* [19] observed a temperature rise only 3.5^{o}C on the periodontal surface when standardised energy of 100mJ, 15Hz and 1.5W which is safely tolerated.

4. PHOTOACTIVATED DISINFECTION (PAD)

Anti-bacterial effect of the laser used is dependent on its pulse length, fluence, irradiance apart from its wave length [26]. Lasers commonly are used in isolation but can also be used with photosensitizers in a technique called photoactivated disinfection. The mode of action varies completely from that described for lasers used alone. Photodynamic therapy originally was developed as an anticancer therapy. But thereon its application has also been expanded to eradicate bacteria and viruses. The core of this therapy is based on three basic elements: a photosensitizer, a light source and tissue oxygen form. The mechanism of action suggested is due to generation of free radicals. In photoactivated disinfection a photosensitizing compound is topically applied to the hard tissue site to be disinfected and then irradiated with a laser light of a suitable wavelength absorbed by the photosensitizing compound. When a laser of a suitable wavelength (diode) is used, the photosensitizer gets excited, highly cytotoxic singlet oxygen is generated. Localised exposure to light eliminates bacteria whereas the reactive oxygen species act on bacteria and tissue that have selectively taken up the photosensitizer leading to their destruction [27]. A nontoxic photosensitizer is used that is selectively absorbed in a target tissue that responds to a low-intensity light source. In the presence of oxygen, following photo-induced activation, the photosensitizer, produces singlet oxygen and free radicals which damage the bacterial membrane and DNA. The extent of tissue/cell damage depends on the type, dose, incubation time, localization of the photosensitizer, availability of oxygen and also the wavelength of light (nm). A photosensitizer should absorb laser light in the red portion of the visible spectrum or at longer wavelengths in the near infrared region [28].

Bonsor *et al*. [29] have shown PAD and citric acid to be as effective as sodium hypochlorite in disinfection of root canals. PAD also provides a broad-spectrum effect, against some difficult to eradicate organisms [30]. Rovaldi *et al.* [31] have also shown that it is effective even in the presence of blood. Because of its high antibacterial potential PAD has been suggested as an adjunct to conventional endodontic disinfection protocols [32].

Commonly photosensitizer / laser combinations are:

a) Tolonium chloride with a 635nm diode laser or 632.8nm helium –neon laser.

b) Methylene blue with 670nm diode laser.

c) Aluminum disulfonatedphthalocyanine with a 660nm diode laser.

5. PHOTON INDUCED PHOTOACOUSTIC STREAMING (PIPS)

PIPS technique is based upon the interaction of erbium laser and irrigating solutions. It utilises the photoacoustic and photomechanical phenomena exclusively and is not reliant on the thermal action of the laser. PIPS is carried out at subablative intensity with parameters of 20mJ at 15Hz, with 50 microsecond impulses. Each impulse (peak power of 400W) interacts the water molecules with creating successive “shock waves” without the undesirable thermal effects seen with traditional laser techniques. The photo-acoustic shockwave generated courses irrigants powerfully throughout the entire root canal system (lateral canals, dentinal tubules and canal anastomoses to the apex) results in high level endodontic debridement and disinfection.

A new tip design with a stripped end is employed in PIPS technique to allow for greater lateral emission of energy compared to the frontal tip. A 600 micron diameter, 9 millimeter long tapered tip with a 3 millimeter stripped end is used. The tip is placed inside the pulp chamber or extended till the coronal 1/3 of root canal and left stationary unlike the LAI technique which the laser needs tip to be placed to within mm from the apical terminus thus greatly simplifying the procedure.

5.1. Advantages of Pips

- Effective cleaning and debridement of the root canal system minimising the risk of reinfection.
- Preservation of tooth structure owing to the minimally invasive nature of PIPS.
- Elimination of the risks associated with conventional endodontic preparation techniques like lodging or canal transportation etc.
- Avoidance of unwanted apical extrusion of chemical irrigants since the PIPS tip is only inserted into the pulp chamber or coronal 1/3 of the canal, also there is no risk of tip breakage from curved canals.
- Time efficient - Laser activation of chemical agents reduces holding time and saves 20-30 minutes per canal for patient and clinician.

6. NEWER TIP DESIGNS

Lasers have a lot of purported advantages, however, there are also several limitations associated with the intracanal use of lasers. Conventionally laser energy is emitted from the end of the optical fiber or the laser guide tip (“end firing tips”) and is directed along the root canal and does not necessary spread laterally along the root canal walls [33]. With the conventional end firing tips it is highly improbable to uniformly irradiate the complete root canal surface using a laser [34]. Also there is a potential for thermal damage to the periapical tissues associated with intracanal use of laser [35]. In order to irradiate all areas of the root canal walls and at the same time to ensure the safety of such intracanal usage of lasers various tips were developed.

- Endolase side-firing spiral tip- designed specifically to allow for lateral irradiation of root canal walls. Spiral slit located all along the tip emits the Er:YAG laser irradiation laterally throughout the length of the tip. The tip is sealed at its far end preventing apical irradiation of laser.
- Radial firing tip-passage of laser energy from the tip end towards and through the apical foramen of the tooth causes periodontal damage. A patented 200µm RADIAL FIRING TIPS (Water Lase MD) has been designed for use with an Er:Cr:YSGG laser having a unique beam pattern that does not fire directly into the apex of the root.
- A conical tip which has a fan-shaped emission profile, delivers 80 percent of the energy laterally, and only 20 percent in the forward direction.
- Honeycomb tips with safe ends can activate fluids placed in the root canal and generate shockwaves that are directed onto the walls of the root canals and also into the intricacies of the root canal system. There is very little apical emission, which serves to eliminate the problem of driving fluids beyond the apical foramen. While studying the fluid movements association with laser activation, honeycomb tip design produced agitation driving fluid onto the root

canal walls. In comparison, the conventional plain optical fibers and the conical tips created fluid movement predominantly directed in apical direction [36]. A further advantage of these tip designs is that they are simpler to use in practice because it is no longer necessary for the operator to follow complex sequences of moving and withdrawing the fiber in order to achieve even irradiation of the canal walls.

- Spherical and cylindrical tips with a near-360-degree emission profile (isotropic tips) have been used for photoactivated disinfection of root canals using low-intensity visible red light, but the designs are not suited to delivering high-intensity pulses in the near (780-1400nm) and mid-infrared (1400-3000nm) range.

CONCLUSION

With the advancements in laser properties, it has been possible to invade the obscure apical zone of the root canal system thus providing synergistic gains to conventional endodontic therapy. The use of photo-induced disinfection techniques and contemporary tip designs have paved channels to eliminate pathogens and expedite periapical tissue repair, hence creating promising multifaceted applicability.

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Received on 30-10-2016 Accepted on 01-12-2016 Published on 20-12-2016

DOI: http://dx.doi.org/10.12974/2311-8695.2016.04.02.1