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Photon Induced Photo-Acoustic Streaming- Conquering the Enemy within - A Review.

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Abstract: *The goal of endodontic treatment is to obtain effective cleaning and removal of the smear layer, bacteria and their by products within the root canal system. Endodontic techniques use mechanical instruments as well as ultrasonic and chemical irrigation in an attempt to shape, clean and completely decontaminate the endodontic system, but still fall short of elimination of the same. A recent advancement in the delivery of laser energy into the root canal system has been investigated, specifically the creation of a system of laser-activated irrigation (LAI) .In this work, a novel tapered and stripped tip of a laser-activated irrigation technique called photon induced Photo-acoustic streaming (PIPS) was used.*

PIPS is a unique laser application utilizing the Er 2,940 nm wavelength. The Er:YAG is used because of its high affinity, chromophore, for water, and its hydroxyl group with low energy levels of 20 mJ creates a significant and profound photo acoustic shock wave that allows for 3-dimensional (3-D) movement of the irrigants without the need to place the tip close to the apical terminus. PIPS has significantly demonstrated the ability to remove smear layer, debride canals, lateral tubules, delicate apical morphology, and eliminating bacteria.Unlike other laser systems, this application with these specific settings and the unique PIPS tip design yields a nonthermal subablative effect.

The purpose of this article is to introduce the experimental background of this laser technique in removing bacterial load in areas where traditional methods may fail to succeed and to introduce the clinical protocol.

Keywords *- Photon induced photoacoustic Streaming ,Er:YAG, Laser-activated irrigation, lower energy levels.*

I. Introduction

Lasers have been used in endodontics since the early '70s[1, 2] and a growing interest in its use was seen since the late '90s [1]. Schoop et al in 2004, stated that different wavelengths have been shown to be effective in significantly reducing the bacterial load within infected canals, and this has also been confirmed by studies in vitro,[3]. Miserendino et al in1989 reported that CO2 laser is not appropriate for endodontic treatment since it cannot be delivered through a suitable fibre optic system into the root canal system,[4]. Also when CO2 laser is irradiated on the tooth surfaces a high temperature elevation is seen. Dederich et al in 1984 used Nd: YAG laser to irradiate root canal wall dentin and obtained a melted, recrystallized surface [5]. .Furthermore, it may also cause closure of the exposed dentinal tubules without dentin surface cracking.[6, 7].

Studies reported that near infrared lasers are highly efficient in disinfecting the root canal surfaces and dentinal walls up to 750 microns with the 810 nm diode laser and up to 1 mm with the 1064 nm Nd:YAG laser. On the other hand, these wavelengths did not show effective results in debriding and cleansing the root canal surfaces and also caused characteristic morphological alterations of the dentinal wall. The smear layer was only partially removed and the dentinal tubules primarily closed as a result of the melting of inorganic dentinal structures [8,9]. Studies have reported the ability of medium-infrared lasers in debriding and cleaning the root canal walls [10,11]. The bacterial load reduction after erbium laser irradiation demonstrated high effectiveness on dentin surfaces, but low in depth of penetration because of the high absorption of the laser energy on the dentin surface [12]. Other studies reported that the laser activation of commonly used irrigants (LAI) resulted in a statistically more effective removal of debris and smear layer in root canals compared with traditional techniques (CI) and ultrasound (PUI) [13,14]. Additionally, the laser activation method resulted in a strong modulation in the reaction rate of NaOCl, significantly increasing the production and consumption of available chlorine and oxygen ions in comparison to ultrasound activation [15].

DiVito et al in 2011 has reported the use of an Er:YAG laser, along with a newly designed radial and stripped tip, in combination with 17% EDTA and 6% sodium hypochlorite solution using a low energy (20 mJ)and very low pulse duration (50 microseconds) which resulted in effective debris and smear layer removal and showed minimal or no thermal damage to the dentinal structure through a photoacoustic technique called Photon Induced Photoacoustic Streaming (PIPS).The purpose of this article is to introduce the experimental background of this laser technique in removing bacterial load in areas where traditional methods may fail to succeed and to introduce the clinical protocol.

II. Background

The microphotographic recording of the LAI studies suggested that the Erbium lasers used in irrigant filled root canals generate a streaming of fluids at high speed through a cavitation effect [16]. The laser thermal effect generates the expansion-implosion of the water molecules of the irrigant solution, generating a secondary cavitation effect on the intracanal fluids. To accomplish this streaming, it is suggested that the fiber be placed in the middle third of the canal, 5 mm from the apex and stationary [17]. This concept greatly simplifies the laser technique, without the need to reach the apex and to negotiate radicular curves.

Also the recorded video of the new Photon Induced Photoacoustic Streaming (PIPS™) technique showed a strong agitation of the liquids inside the canals. It differs from the already cited LAI technique by activating the irrigant solutions in the endodontic system through a profound photoacoustic and photomechanical phenomenon, which generates a faster streaming of fluids distant from the source in magnitudes three-fold greater in comparison with passive ultrasonic irrigation (PUI). The use of low-energy (20 mJ at 15 Hz, 0.3 W average power, or less) generates a minimal thermal effect. A study with thermocouples applied to the radicular apical third revealed only 1.2 degree C of thermal rise after 20 seconds and 1.5 degrees C after 40 seconds of continuous radiation [19].

When the Erbium laser energy is delivered at only a 50 microsecond pulse duration through a specially designed, tapered and stripped, 600 micron diameter, 9 mm long tip (LightWalker, Fotona, LjubljanaSlovenia), it produces a high peak power of 400 Watts when compared to a longer pulse duration. Each impulse, absorbed by the water molecules, creates a strong "shock wave" that leads to the formation of an effective streaming of fluids inside the canal while also avoiding side effects seen with other methodologies. The placement of the tip in only the coronal portion of the treated tooth allows for a more minimally enlarged canal preparation with no thermal damage as seen with those techniques requiring placement into the canal system(Fig-1). The root canal surfaces irrigated with 17% EDTA and laser activated for 20 seconds showed an exposed collagen matrix, opened tubules and the absence of a smear layer and debris.

The profound and distant effect of PIPS™ eliminates the need to introduce the tip into the root canal system. Unlike traditional laser techniques requiring placement of the tip 1 mm from the apex, or even 5 mm from the apex as proposed for LAI [18], the PIPS™ tip is placed only in the coronal portion of the pulpal chamber and left stationary, allowing the photoacoustic waves to spread into the openings of each canal.

A new tip design consisting of a 600 micron diameter, 9 millimeter long tapered end is used for this technique. The final 3 millimeters of coating is stripped from the end to allow for greater lateral emission of energy compared to the frontal tip (Fig. 2). This mode of energy emission allows for improved lateral diffusion of the low energy, enhanced photoacoustic waves.

III. Clinical Protocol

3.1 Laser Settings

An 2940 nm Er:YAG laser equipped with a tapered and stripped 600 micron tip (LightWalker AT, FOTONA, Ljubljana-Slovenia), is placed at the coronal orifice (not inserted into the canal), left stationary and activated for 30-second cycles (20 mJ, 15 Hz, 50 microseconds) during the irrigation between each instrumentation used (Fig. 3).

3.2 Operative Protocol

Access the pulp chamber creating a clear glide path as usual: #6 carbide round or cylindrical burr. The preparation of the canals with NiTi instruments is still the gold standard in endodontics today. This allows for a standardized shaping and obturation of the root canals. It is important to establish the correct working length using a #08 or #10 K hand file introduced in the canal with a gel (RC PREP). The working lengths are confirmed using both radiologic and electronic verification.

3.3 PIPS technique for debriding and decontamination of the endodontic system

During the canal preparation, the PIPS™ technique is used between each shaping file step to produce an improved streaming of fluids into the endodontic system. Because of the enhanced streaming activity of PIPS™ and its ability to move irrigants three dimensionally without needing to enlarge the canal size, an improved debridement and decontamination of the endodontic system is possible together with a minimally invasive canal preparation. In the authors' experience, an apex preparation of #20-25 in the apical third is currently performed for vital teeth. For necrotic or retreated teeth, the apical preparation is closely related to the previous condition of the tooth anatomy.

IV. Discussion

Laser irradiation is a common technique used in endodontics to improve the cleaning, debriding and disinfection of the root canal system. Many wavelengths and protocols are used. Near-infrared lasers are used for the three-dimensional decontamination of the endodontic system. Nd:YAG and diode lasers use thermal energy to kill bacteria. On the contrary, Erbium lasers are traditionally used for their effective smear layer removal, while their bactericidal activity is limited to the root surface. The placing of the tip close to the apex and its subsequent backward movement during the activation process is related to the risk of apical perforation, ledging and surface thermal damage due to the ablation ability of these wavelengths . Also, a traditional tips and fibers placed into the canal close to the apex (1 mm), perpetuating all of the disadvantages currently identified in the literature with long, narrow and curved canals.

DiVito et al (2012) demonstrated that laser activation irrigation using PIPS tips resulted in significantly better cleaning of the root canal walls in comparision with the conventional irrigation procedure.In a recent study,Lioyd et al (2013) also showed that laser-activated irrigation using PIPS tips eliminated organic debris from canal isthmus at significantly greater level compared with standard needle irrigation. Bubbles, the formation of an empty space in a liquid, are the basis of cavitation . Er/YAG laser irradiation is highly absorbed by hydroxyapatite and water. When Er:YAG laser irradiation is absorbed by water, the energy causes evaporation. The vapour bubble starts to expand and form a void in front of the laser light. Matsumoto et al.(2011) demonstrated that bubble increased in size and reached up to 1800microns in 220 microseconds when 300microns laser tip was used. They stated that when the laser tip was inserted 2 and 5mm short of the bottom of an artificial glass root canal model, the second cavitation bubbles were clearly observed at the bottom of an artificial root canal. Therefore,they suggested that it is not always necessary to insert the laser tip upto the terminus of the canal because the cavitation bubbles also assist in cleaning the apical region.

Photon-induced photoacoustic streaming tips have been used at subablative levels with specific models and settings and with a radial and stripped tip of novel design.Previous studies have shown that the use of erbium lasers in root canal may result in side effects.Matsuoka et al.(2015) observed carbonization and cracks on the root canal walls when laser tips were used for root canal preparations.Kimura et al.(2002) monitored a temperature increase of up to 6 degree Celsius.The subablative parameters in the PIPS technique result in a photochemical effect, which occurs when light energy is pulsed in a fluid, rather than thermal effect.

The traditional laser applications necessitate conventional preparation for atleast up to size 30 and the laser tip need to reach apical third of the root. However, the PIPS tip does not need to reach the canal terminus, and it is placed into the coronal reservoir only of the root canal. Therefore, this technique allows for minimally invasive preparation of the root canal(DiVito & Lloyd 2012a, DiVito et al. 2012b). The effect may be explained by the increased Naocl reaction kinetics with laser activation .

V. Figures

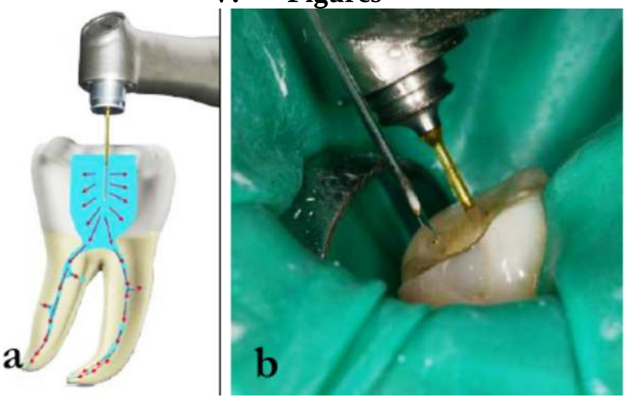

Fig.1 a&b - Laser activated irrigation using PIPS™ technique: the tip must be placed in the coronal chamber with open access to the canals .

Fig.2-PIPS™ tip : 9 mm long, 600 micron tapered and stripped tip.

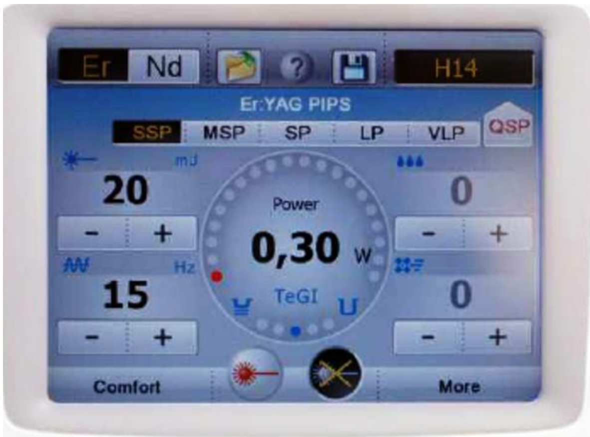

Fig.3-: Touch screen panel showing the PIPS setting, at 20 mJ, 15 Hz, no air / no water, 50 microsecond pulse duration.

VI. Conclusion

The PIPs technique when used helps in safe and effective debriding and decontamination of the root canal system,[20]. It has no thermal effect on the dentinal walls by the virtue of decreased energy settings, short pulse duration and placement of the tip in the orifice of the canal (away from the target site).The dentin surface and its collagen are undisturbed and clean.This technique allows the clinician to deliver treatments in less time and the need to enlarge the canal system is minimal and therefore allows a more biomimetic preparation which can be obturated three dimensionally

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Examples follow:

Journal Papers:

[1] M Ozaki, Y. Adachi, Y. Iwahori, and N. Ishii, Application of fuzzy theory to writer recognition of Chinese characters, International Journal of Modelling and Simulation, 18(2), 1998, 112-116 Note that the journal title, volume number and issue number are set in italics.

Books:

[2] R.E. Moore, Interval analysis (Englewood Cliffs, NJ: Prentice-Hall, 1966).

Note that the title of the book is in lower case letters and italicized. There is no comma following the title. Place of publication and publisher are given.

Chapters in Books:

[3] P.O. Bishop, Neurophysiology of binocular vision, in J.Houseman (Ed.), Handbook of physiology, 4 (New York: Springer-Verlag, 1970) 342-366. Note that the place of publication, publisher, and year of publication are enclosed in brackets. Editor of book is listed before book title.

Theses:

[4] D.S. Chan, Theory and implementation of multidimensional discrete systems for signal processing, doctoral diss., Massachusetts Institute of Technology, Cambridge, MA, 1978.

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Proceedings Papers:

[5] W.J. Book, Modelling design and control of flexible manipulator arms: A tutorial review, Proc. 29th IEEE Conf. on Decision and Control, San Francisco, CA, 1990, 500-506