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REVIEW
Photoacoustic Endodontics using PIPS™: experimental background and clinical protocol

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ABSTRACT

The goal of endodontic treatment is to obtain effective cleaning and decontamination of the smear layer, bacteria and their byproducts within the root canal system. Clinically, traditional 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 successfully removing all of the infective microorganisms and debris. This is because of the complex root canal anatomy and the inability of common irrigants to penetrate into the lateral canals and the apical ramifications. It seems, therefore, appropriate to search for new materials, techniques and technologies that can improve the cleaning and decontamination of these anatomical areas.

Key words: endodontics, laser treatment, Er:YAG PIPS.

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I. INTRODUCTION

Among new technologies, lasers have been studied in endodontics since the early '70s [1-3] and have become more widely used since the '90s [4-6].

Different wavelengths have been shown to be effective in significantly reducing the bacteria within infected canals, and important studies have confirmed these results in vitro [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 [5,8]. Studies have reported the ability of medium-infrared lasers in debriding and cleaning the root canal walls [9,10]. 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 [7]. 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) [11,12]. 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 [13].

Recent studies have reported how the use of an Er:YAG laser, equipped with the newly designed radial and stripped tip, in combination with 17% EDTA solution, using a very low pulse duration (50 microseconds) and low energy (20 mJ) resulted in effective debris and smear layer removal with minimal or no thermal damage to the organic dentinal structure through a photoacoustic technique called Photon Induced Photoacoustic Streaming or "PIPS™" [14,15]. Also the same PIPS™ protocol in combination with 6% sodium hypochlorite solution has been investigated and shown to reduce the bacterial load and its associated biofilm in the root canal system three dimensionally [16]. Other similar studies are in progress for publication and the results are promising and suggest a three-dimensional positive effect of this laser-activated decontamination method.

The purpose of this article is to briefly present the experimental background of this laser technique 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 [17]. 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 [18]. 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 [14]. 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, Ljubljana-Slovenia), 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. 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 (Fig. 1a, b).

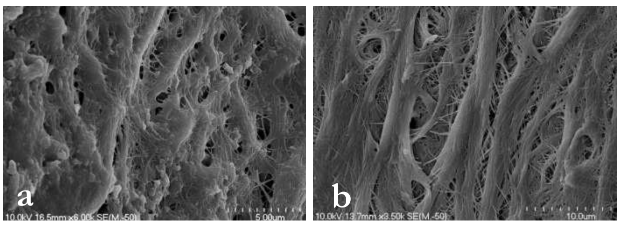

Fig. 1a, b: Representative sample images of root canal dentinal walls irrigated with 17% EDTA and PIPS™ for 20 seconds.

Rinsing with 6% sodium hypochlorite and laser irradiation for 30 seconds produced a strong activation of the solution, as also reported by Macedo [13], improving the disinfecting action of the sodium hypochlorite [16]. The disinfecting action of PIPS™ is very effective both on the root surface, lateral canals and the dentinal tubules, as confirmed with bactericidal studies as well as SEM and confocal studies (Fig. 2a,b).

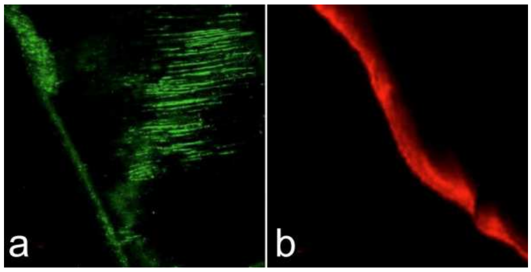

Fig. 2: Confocal microscope images of E. Facaelis penetrating into the dentinal tubules: a) before PIPS™ treatment; b) post PIPS™ treatment, showing no sign of dead bacteria, only auto fluorescence. (Images courtesy of Drs. Enrico DiVito and David Jaramillo, USA).

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 (Fig. 3a, b).

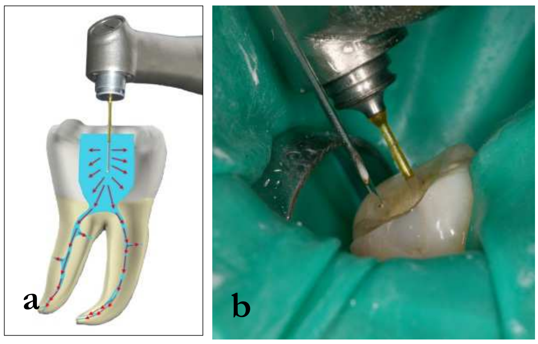

Fig. 3a, b: PIPS™ technique: the tip must be placed in the coronal chamber with open access to the canals

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. 4).

This mode of energy emission allows for improved lateral diffusion of the low energy, enhanced photoacoustic waves.

Fig. 4: PIPS™ tip for Fotona LightWalker: 9 mm long, 600 micron tapered and stripped tip.

III. CLINICAL PROTOCOL

a) 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. 5).

Fig. 5: Touch screen panel showing the PIPS™ setting, at 20 mJ, 15 Hz, no air / no water, 50 microsecond pulse duration.

b) 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.

c) 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 re-treated 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. Observations reveal a certain grade of thermal injury to the root canal surface and a typical morphological damage. Moreover they are not able to thoroughly remove the smear layer (Fig. 6).

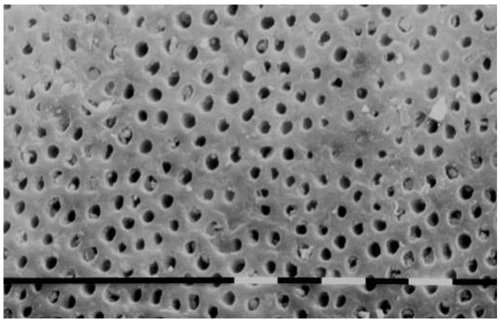

Fig. 6: Representative sample SEM image at the medium third, from 810 nm diode laser irradiation at 1.5 W in cw in sodium hypoclorite wet canal – 5 sec x three times. Image shows evidence of laser irradiation with complete superficial vaporization of the organic matrix; root canal surfaces exhibit partially opened tubules, some residual debris and smear layer still present.

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 (Fig. 7). Also, a combination of the near and medium infrared lasers has been proposed [19]. All of these techniques utilize 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.

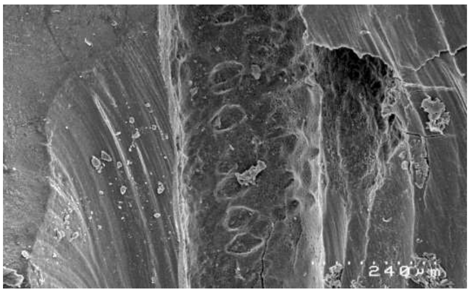

Fig. 7: Representative sample SEM image at the medium third from 2780 nm Er,Cr:YSGG laser irradiation at 75 mJ, 10 Hz with a traditional tip, placed at 1 mm to the apex and withdrawn with backward movement in 5 seconds. Spots of ablation are evident among the areas of non-irradiated dentin.

Erbium lasers are also used as a medium of activation of commonly used irrigants (LAI), avoiding the risk of thermal damage, while increasing the cleaning and disinfecting activity of the fluids. PIPS™ in particular reduces all these risks and disadvantages, thanks to the positioning of the tip in the coronal orifice only and using minimally ablative energy levels of 20 mJ or less. The high decontaminating effect as reported in studies [16] shows its effectiveness not only in the primary canal and the laterals, but also in the dentinal tubules, eliminating the need for near-infrared application (Fig. 2a, b).

V. CONCLUSIONS

The findings of our studies demonstrated that the PIPS™ technique resulted in safe and effective debriding and decontamination of the root canal system. Our clinical trials showed that the PIPS™ technique greatly simplifies root canal therapy while facilitating the search for the apical terminus, debriding and maintaining patency. The ability of PIPS™ to three-dimensionally debride and decontaminate dentinal tubules allows the clinician the possibility to effectively deliver treatments in less time and with less need to enlarge the canal system, allowing for a more minimally invasive and biomimetic preparation which can then be obturated three dimensionally.

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