Laser activated irrigation

Part II: Does the position of the fibre matter?

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[PICTURE: ©VECTOR ILLUSTRATION]

_Introduction

The endodontic cleaning and shaping procedures are based on the use of instruments to shape the central body of the root canal system hereby creating a reservoir for the rinsing solutions.[1] Irrigants are needed to clean those areas that cannot be touched and reached by endodontic instruments. At present, a combination of irrigants i.e. Sodium hypochlorite (NaOCl) and Ethylenediaminetatraacetic acid (EDTA) is favoured as initial and final rinse. Both are complementary.[2, 3] The root canal system is geometrically very complex, including curvatures in multiple directions, isthmuses, fins, cul de sacs, lateral branches, the apical delta and also the dentinal tubules. These areas remain untouched during instrumentation and even get blocked with debris and smear layer as a result of root canal preparation. These locations are also excellent hiding places for bacteria.[4] Therefore, chemical modifications of the compounds of irrigants and agitation systems for root canal irrigation have been developed to improve the penetration and effectiveness of irrigation solutions.[5, 6]

_Ultrasound and the increase of efficiency of irrigants

It was already known that heating NaOCl solutions from 20 to 45 °C improved their antimicrobial and tissue-dissolution capacity.[7] The effect of agitation of irrigants on tissue dissolution, however, was more efficient than that of temperature.[8] Continuous agitation of sodium hypochlorite resulted in the fastest dissolution.[8]

Previous investigations had already demonstrated the very important impact of mechanical agitation of the hypochlorite solutions on tissue dissolution referring to the great impact of violent fluid flow and shear forces caused by ultrasound on the ability of hypochlorite to dissolve tissue.[9]

At that time (2005), it was concluded that acoustic micro-streaming and cavitation were to play an important role during ultrasonic activation of irrigants.[10] The occurrence of cavitation, however, has been a matter of debate during the last two decades. Cavitation had been demonstrated to occur around ultrasonically driven instruments oscil-

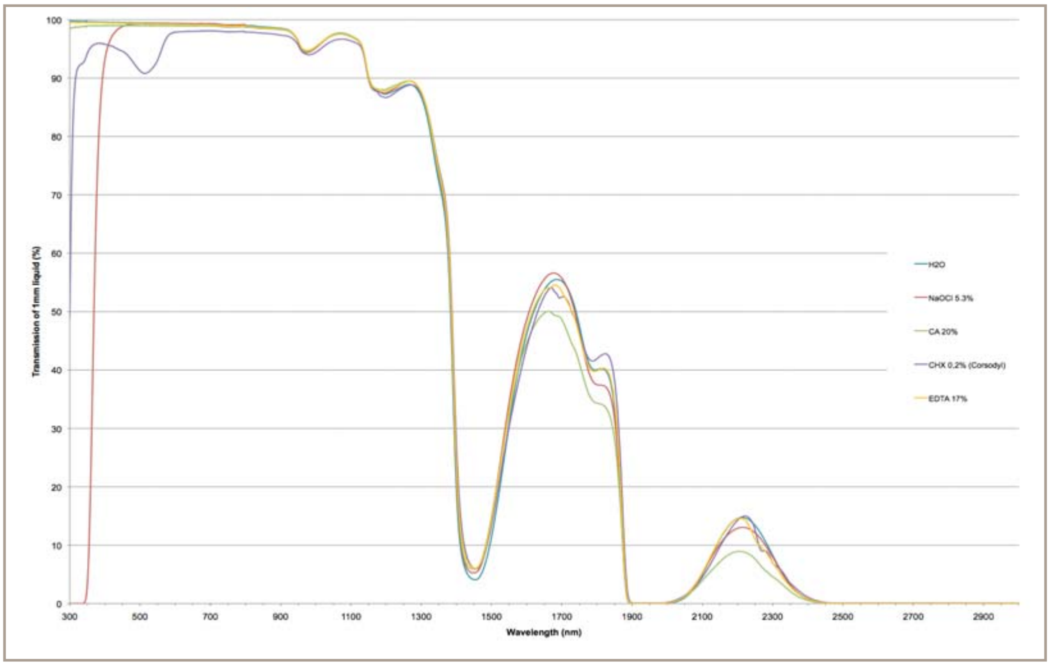


Fig. 1_Transmission spectra of distilled water, NaOCl 5.5 %, citric acid 20 %, Chlorhexidine 0.2 % (Corsodyl), EDTA 17 % (path length = 1 mm, according to Meire et al. 2013).

lating freely in a liquid medium.[11-13] It was argued that cavitation was unlikely to occur inside the root canal due to space restrictions and hence limiting the oscillation amplitude of the file.[12]

It was only until recently that the occurrence of cavitation with ultrasonically driven instruments has been demonstrated.[13, 14] The oscillation of endodontic files may result in the generation of cavitation even at low power settings. Transient cavitation (i.e. the process where a void or bubble in a liquid rapidly collapses, producing a shock wave) is generated by most of the files, in the form of a large bubble cloud at the tip of a file and smaller bubbles at subsequent antinodes. The bubble cloud collapses predominantly on the file itself and not on the root canal wall, but its collapse can pull material off a neighbouring wall. At the air-liquid interface at the coronal part of the root canal, air entrainment leads to the entrapment of stable cavitation (i.e. the process in which a bubble in a fluid is forced to oscillate in size and shape due to some form of energy input) bubbles in the root canal.[21]

The amount of cavitation differs between the files. Influencing parameters are file length, diameter, cross-sectional shape, twisting of the file and the oscillation characteristics. Larger file diameters increase the cavitation activity. There is an increased cavitation activity (increase in number and size of the bubbles) within the confines of a root canal as compared to a free liquid environment.[21]

_Laser activated irrigation

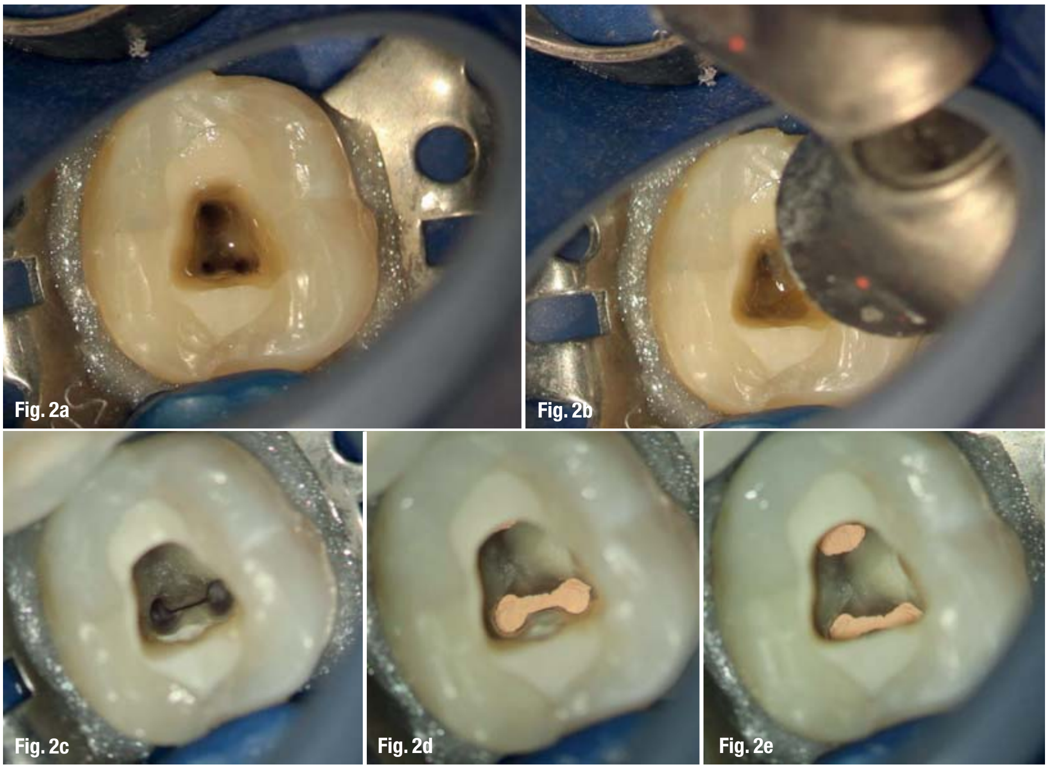
Activation of irrigants can also be performed with lasers. A number of researchers have investigated the ability of some laser wavelengths to activate the present-day favoured endodontic irrigants within the confines of the root canal.[16-19]

Expansion and implosion of the vapour bubble

The technique for activation of an irrigant is called "Laser Activated Irrigation—LAI". The cleaning effect of this method is based on cavitation. Laser operation results in the formation of vapour bubbles at the tip of the fibre, which expand during the pulse and then implode or collapse quickly

Laser	Wavelength	Water	NaOCl 5.3 %	EDTA 17 %
Diode	810	0.0438	0.0511	0.0512
	830	0.0486	0.0559	0.0560
	940	0.118	0.123	0.116
	980	0.243	0.250	0.234
Nd:YAG	1,064	0.101	0.108	0.105
Er,Cr:YSGG	2,790	>40	>40	36.3
Er:YAG	2,940	>40	>40	33.5

Tab. 1_Alpha values of pure water, sodium hypochlorite 5.3 % and EDTA 17 % at wavelengths corresponding to lasers used in root canal treatment (according to Meire et al. 2013).



Figs. 2a–e_Root canal treatment on a mandibular first molar and the use of H-LAI with the X-Pulse tip demonstrating its cleaning efficiency (a. Access cavity, b.Root canal cleaning using X-Pulse H-LAI, c. The cleaned pulp chamber and root canals, d and e. Root canals filled with gutta-percha and Top Seal).

after termination of the laser pulse. The effect within the confines of a root canal is threefold:

1) The volumetric changes of the bubbles are accompanied by considerable fluid movement inside the canal.[20]
2) The cavitation bubble implosion, which is a vigorous process, generates localised, large-amplitude shock waves and micro jets in the irrigant at the point of the implosion.[21] Localized and transient surface stresses can also be generated when the bubble collapses close to solid faces.
3) Besides to primary cavitation, smaller secondary cavitation bubbles occur that are also activated by subsequent laser pulses resulting in acoustic streaming.[22]

Absorption characteristics of the endodontic irrigants

The effect of the laser beam is dependent on the target chromophore. Knowledge of the absorption characteristics of a given irrigant permits a better estimation of the energy required to induce cavitation with a certain laser. The spectral properties of water and irrigating solutions were determined by Meire et al.[23] (Table 1). They demonstrated that NaOCl 5.3 % and EDTA 17 % displayed roughly the same transmission spectrum as that of pure water.

Spatial and temporal energy concentration

As previously mentioned, the mechanism behind the cleaning action of LAI is cavitation, i.e. the formation and subsequent collapse of vapour bubbles in the irrigation solution. For this purpose, a high concentration of energy is needed to heat and to vaporise a small volume of the irrigant. The energy concentration can be obtained temporal (distributing the energy within a very small time frame) or spatial (by directing the energy onto a very small surface).

An example of temporal energy concentration is given by Lauterborn and Ohl[24], and Lauterborn et al.[25] In their studies of single bubble dynamics, they have used (1) a ruby laser with a pulse duration between 30 and 50 ns, a wavelength of 694.3 nm (hence low absorption in water), and an energy per pulse of several 10 mJ, and (2) a Nd:YAG laser with a pulse duration of 8 ns, a wavelength of 1,064 nm and similar energies per pulse. It was possible to register the collapse times of the generated bubbles: they range from 9 ns for bubbles starting to collapse from a radius of about 1.5 mm down to 4 ns for bubbles of a maximum radius of about 0.75 mm. Shock wave pressure measurement series were also obtained with different bubble sizes: About 10 kbar is reached for a bubble collapsing from a radius of 500 µm and about 25 kbar when collapsing from a radius of 3 mm.

An example of spatial energy concentration is given by Jansen et al.[26] Cavitation was demonstrated in water at the tip of a Ho:YAG laser (λ = 2,120 nm, α in water is 11.3 cm^{-1}, transmission through 1 mm water is 7.4 %) using 200 mJ pulses

Figs. 3a–f_Root canal treatment on a mandibular first molar with apical periodontitis and the use of H-LAI with the PIPS tip demonstrating its cleaning efficiency, and the six month follow-up (a. Diagnostic radiograph, b. Cleaning of the root canal using PIPS H-LAI, c. The cleaned pulp chamber and root canals, d. Root canals filled with gutta-percha and Top Seal, e,f. Control radiograph of the root fillings.

and a fibre tip diameter of 400 µm. The occurrence of cavitation bubbles was demonstrated for pulse lengths in the microsecond range. The latter is the case for most of the dental laser systems.

The parameters that influence cavitation

Both examples demonstrate that cavitation does not necessarily depend on the absorption coefficient of the liquid per se. Power density and energy density (determined by pulse length, pulse energy, fibre diameter and design) are also important parameters. These parameters have to be taken into account for the amount of energy that is delivered to the tooth and in the root canal. In the situation of the root canal this means that non-absorbed radiation by the irrigant can result in unwanted side effects and consequences. For wavelengths that are well absorbed into the dentine, this will imply damage to the root canal and the root canal wall. For wavelengths that penetrate deeper into the dentine thermal damage to the dentine and even the periodontal ligament can be expected. Consequently, high α-values for the irrigation solutions are recommended. For as far as LAI is considered, a critical borderline for α-values is fixed at 10 cm^{-1}.

Hence, candidates for the induction of cavitation are both Erbium wavelengths. The absorption coefficients for water at 2,790 nm (Er,Cr:YSGG) and 2,940 nm (Er:YAG) are around 6,000 and 12,000, which is very high (Table 1). In this respect, considering a number of fixed parameters such as the minimal and maximal diameter sizes of commercially available endodontic laser fibres, pulse duration, pulse energy and fibre design, and for same lasers also the fixed pulse frequency, become the influencing parameters for the induction of cavitation.

Fibre tip design

Fibre tips with plain ends result in the formation of cavitation bubbles appearing as channel like, elongated or elliptical bubbles with a diffuse surface. The conical tip results in the formation of a spherical bubble.[20, 21, 26]

The ability of laser-generated shock waves to debride root canals depends upon the efficiency of the energy absorption within the fluid, the energy, shape and duration of the laser pulse and the power density achieved at the fibre tip.[27] The direction of the shockwaves is influenced by the shape of the fibre tip. It is expected that plain fibre tips deliver laser energy primarily in forward direction, resulting in a forward direction of the laser shock waves and largely parallel to the walls of the root canal surface.

Laser activated irrigation with the fibre in the root canal or in the region of the orifice

We make a distinction between the use of the fibre in the canal (conventional laser activated irrigation—C-LAI) and the fibre hovering over the orifice (hovering laser activated irrigation—H-LAI).

At present, our studies together with the one of de Groot et al. have demonstrated that C-LAI with the plain fibre tip ends resulted in the efficient removal of artificial dentinal debris out of an artificial root canal wall groove.[17,18, 28]

These studies appear to be the only ones that are using a fibre in the root canal for the evaluation of debridement efficiency. The study of De Moor et al. in 2010 was the only one to compare the debridement efficiency of both Er:YAG and Er,Cr:YSGG laser.[18] In a study of Macedo et al. it was demonstrated that Er:YAG C-LAI increased the reactivity of NaOCl.[29]

PIPS-tips (Photon-Induced Photoacoustic Streaming) were presented by its developers at the World Congress of Minimally Invasive Dentistry meeting in San Francisco in August 2009. The parameter settings differ from the ones used for C-LAI, the pulse energy has been decreased to 20 to 50 mJ, and pulses of only 50 microseconds of duration are used. The pulse frequency remains in line with the previously used C-LAI frequencies of 10 to 20 Hz. With an average power of only 0.2–0.5 W, each pulse interacts with the water molecules with a nominal peak power of 400–1,000 Watts, creating a shock wave-like phenomenon leading to the formation of a powerful streaming of fluids inside the canal.[30] The temperature rise after 20 and 40 seconds did not exceed 1.5 °C.[31]

At present, there are contradicting findings for H-LAI with PIPS. Deleu et al. found a better debridement of dentine plugs in artificial root canal wall grooves with C-LAI than with H-LAI PIPS.[19] Removal of intracanal tissue and debris, based on high-resolution micro-computed tomography, was 2.5 times higher than with conventional needle irrigation in mesial roots of mandibular molars.[32] Data from the authors yet submitted for publication demonstrate that H-LAI with PIPS tips 400/14 (Fotona, Ljubljana, Slovenia) and H-LAI with XPulse tips 400/14 (Fotona, Ljubljana, Slovenia) both with the recommended PIPS power settings and exposure time result in the same amount of debris removed from artificial root canal wall grooves (Figs. 2 and 3 are examples for the use of PIPS and X-Pulse tips). It was also found that continuous irrigation was necessary, especially when the tips are placed in root canal chambers with small dimensions. This in order to avoid depletion of irrigant through splattering.

The antibacterial effect was higher with H-LAI PIPS used in conjunction with NaOCl than syringe irrigation with NaOCl in the study of Al Shahrani et al.[33] and also higher than syringe irrigation with NaOCl and ultrasonic irrigation in NaOCl in the study of Peters et al.[34], comparable with syringe irrigation with NaOCl and EDTA in a study of Zhu et al.[35] and with syringe irrigation with NaOCl in the study of Pedulla et al.[36]

In Part I the risk of apical extrusion with C-LAI was addressed on the basis of published data. Investigations are needed for H-LAI in order to evaluate the safety of this technique. Patients feel the action of H-LAI and describe it as gentle knocking at the top of the root. Hence, it is not unrealistic that with high peak power also high pressure can be generated.

_Conclusion

Laser and fiber technology for root canal debridement and disinfection has evolved enormously during the last two decades. Fibre tip design has become important with a focus on radial firing tips, as well as the use of Erbium fibres in root canal irrigants for laser activated irrigation. At present, there is laser-activated irrigation with the fibres in the root canal (C-LAI) and fibres hovering over the root canal orifice (H-LAI). Comparison in efficiency between both has been minimally investigated. The few data available demonstrate (1) that hovering over the canal orifice with radial firing tips with pulses of reduced length and high peak powers helps in removing debris and minimises thermal effects on the dentinal walls; and (2) that the use of fibres in the root canal still is superior regarding the removal of compacted dentine debris. More research is needed for the determination and evaluation of the antibacterial effectiveness of both, preferably in the same study._

Editorial note: A list of references is available from the publisher.

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