Introduction

Endodontic success is determined by the removal of remnants of vital and necrotic tissues, microorganisms and their microbial toxins from the root canal system. Today, cleaning and shaping of the root canal is based on a sodium hypochlorite (NaOCl) supported root canal preparation followed by final rinsing with EDTA. It is important that these irrigants come into contact with the root canal wall and biofilm (if present), especially in the apical third of the root canal system. Therefore, a number of mechanical devices have been introduced to improve the penetration and effectiveness of irrigation.

Laser fibre in dry root canal

In endodontics three types of investigations were performed with fibre lasers on the effect of direct irradiation of the root canal wall:

– Type I: Water absorption increases significantly at 1,450 nm. With the potential of near-IR lasers with wavelengths larger than 1,450 nm in removal of dental hard tissues, investigations were conducted on their use in the instrumentation of root canals.

– Type II: Investigations were also performed with wavelengths below 1,450 nm such as Nd:YAG (1,032 nm), diodes (810, 830, 940, 980 nm) and KTP (532 nm) for the modification and cleaning of the root canal wall.

– Type III: Investigations examining the effect of direct irradiation with a laser fibre of the root canal wall on the eradication of bacteria.

Up to 2006/2007, all these studies with high power lasers were performed with flat ending fibres. The studies had in common that a spiral motion of the laser fibre was needed in order to expose the root canal wall to the laser light. The findings were not always encouraging:

– In the type I studies, canals treated with Erbium lasers resulted in significantly more debris than canals that were prepared with NiTi-rotaries, laser instrumentation required twice as much time, and there was also a risk for creation of ledges and root canal wall irregularities. At the end, these type of lasers were considered to be adjuncts to mechanical instrumentation.

– The Nd:YAG laser is one of the most extensively investigated lasers in endodontics. Up to the end of the 1990s, it was also the most widely used laser in endodontics. Studies have demonstrated that the smear layer could be modified and typical aspects of glazing were described in these Type II studies.

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interacting with the smear layer, the need for the use of this wavelength for this type of laser-target interaction disappeared.6

In type III studies, much of the work has been conducted with the Nd:YAG followed by the diodes. A study in 2010 by Hibst et al. demonstrated that high-power NIR laser bacterial killing is not caused by the light itself (photochemical effect).7 The exception are black pigmented bacteria when irradiation is performed with Nd:YAG. They found that the most important parameter was the maximum temperature, meaning that killing was the result of a photo thermal process. Hence, irradiation of the bacteria at low temperature does not result in killing.9 Furthermore, the spiral motion of the fibre did not allow for complete exposure of the root canal wall to the laser light.

Erbium lasers have also been investigated for this purpose (Type III studies). In general, when relying on a spiral motion of the fibre, the Nd:YAG proved to be more effective at reducing the number of CFU and at eradicating the bacteria in a biofilm when compared to Erbium lasers.10 However, when it was possible to expose the biofilm directly to the laser light, Er:YAG was significantly more effective in bacterial killing.9 With the introduction of radial firing tips, a better coverage of the root canal was expected.10 An increase of the disinfection effectiveness of the root canal with the Er,Cr:YSGG laser remained limited.10,11

The era of the bubble

Limitations of the Erbium laser fibres

One of the problems with the Erbium lasers during disinfection of the root canal was the need to achieve a balance between sufficient power output for effective sterilization and avoidance of excessive morphological alterations or damage to root canal dentine. The use of both Er:YAG and Er,Cr:YSGG may result in the creation of ledges due to their ablative nature. Effective sterilization could not be obtained at the lower power outputs.10-12 Although Nd:YAG has a lower penetration depth in dentine and dentinal tubules than NaOCl,13 and taking into account that a direct exposure of the root canal wall to Erbium lasers for root canal disinfection is not possible yet, the 3-D sterilization of the root canal system with its anatomic aberrations remains impossible.

Free liquid environment

Of all IR lasers, the Er:YAG has the highest absorption in water.14 As the laser light can be delivered through a small-diameter fibre tip, this wavelength has already been used in a wide range of laser-assisted medical applications since the beginning of the century.15,16 The Erbium radiation delivered into liquid water through a submerged fibre tip is completely absorbed right beside the fibre tip due to the high absorption coefficient.17-20

At the beginning of the laser pulse (0 to 50 µs), the energy is absorbed in a 2 µm layer that instantly heats over the boiling point and is turned into vapour. The time of the vapour formation depends on the pulse energy and the pulse duration.17 This vapour at high pressure starts expanding at high speed and provides an opening for the Erbium light in front of the fibre. As the laser continues to emit energy, the light passes through the bubble and evaporates the water surface at the front of the bubble. In this way, it drills a channel through the liquid until the pulse ends.18 This mechanism has been referred to as “the Moses effect in the microsecond region.”20

From the moment the emission of energy stops, the vapour cools and starts condensing. The internal pressure decreases and becomes lower than the pressure in the surrounding liquid. The result is the implosion of the bubble. The collapse of the bubble follows immediately. The implosion occurs near the tip of the fibre and results in the separation of the bubble from the fibre. During the collapse, a portion of energy stored in the bubble is converted into acoustic energy. This results in the emission of acoustic transients and shock waves.17 The cavitation generated pressure waves travel at supersonic speed (shock waves) in the beginning and at sonic speed (acoustic waves) later.21,22 Also a high-speed liquid jet is formed23 and fluid surrounding the bubble quickly flows inside the decompressed vapour gap.

After the first large vapour bubble disappears, the shock wave abruptly and extensively changes
Fig. 1. Frames captured at the beginning (a and b) and at the maximum size (c and d) of a vapour bubble. With the flat tip (BioLase MZ4 Ziptip) an elongated bubble is created (a and c). The radiation with the conical tip (BioLase MZ4 tip) results in a spherical bubble (b and d). Irradiation was performed with an Er,Cr:YSGG laser (Biolase) at 0.5 W – 20 Hz – 400 µm fibre.

Fig. 2. The frames are captured in three different liquids: Distilled water (H₂O), Sodium hypochlorite (NaOCl) and Ethylenediaminetetraacetic acid (EDTA). Radiation is performed with a flat tip (BioLase MZ4 Ziptip) (a, b and c) and with a conical tip (BioLase MZ4 tip) (d, e and f). Irradiation was performed with an Er,Cr:YSGG laser (Biolase) at 0.5 W – 20 Hz – 400 µm fibre.

Important parameters that influence the bubble formation are pulse energy, pulse duration and pulse frequency (the latter more from the perspective that the pulse duration cannot always be changed). There is also the effect of tip design which may influence the shape of the laser-induced bubble and the direction of the energy emission. The conventional laser tips are flat and end-firing generating a channel-like bubble, whereas conical fibre tips induce spherical bubbles (Fig. 1). There is also the optodynamic energy-conversion efficiency which refers to the ratio between the mechanical energy of the liquid medium and the pulse energy. When a conical tip is used, the efficiency is significantly larger and it increases with increasing pulse energy and decreasing pulse duration.¹⁷

Conventional laser-activated irrigation (C-LAI)

High-speed recordings of laser generated cavitation bubbles in glass models demonstrated that vapour bubbles were created at the end of the fibre. During these experiments, the fibre was positioned in the root canal. The form of the cavitation bubbles was identical to the ones in free liquid environment: the flat tip resulted in a cavitation bubble appearing as an elongated bubble with diffuse surface or the previously described channel-like bubble. The conical tip resulted in the formation of a spherical bubble.¹⁸

In the study of de Groot et al., using an Er:YAG laser with a flat-ending fibre, the bubble grew with a velocity of the order of 1 m/s during the pulse duration. When the laser pulse ended, the bubble collapsed with a velocity of the order of 1 m/s.²⁵ When the bubble collapsed, secondary cavitation was seen with a relatively large bubble near the collapse site. The cycle of expansion and collapse of the cavitation bubble repeated for a number of times, until it was damped out within a few milliseconds. The laser bubble also grew predominantly in the coronal direction. For laser energy exceeding 120 mJ per pulse it was observed that some fluid was ejected from the root canal, leaving less irrigant in the root canal.²⁵

In the study of Blanken et al., using an Er,Cr:YSGG laser with a flat-ending fibre, bubbles up to a length of 3 to 3.5 mm were observed.¹⁸ The small canal prevented the vapour from expanding freely laterally, pushing the water both forward and backward in the canal. Since the water obstructs the expansion of vapour in the forward direction, the bubble also grows backwards along the fibre. The pressure inside the bubble remains high for a long time, since it has to fight against the resistance of the irrigant which has to be displaced in the small canal. The presence of secondary cavitation bubbles was also noted. In this study, it was emphasized that the creation of cavitation bubbles of this size in a root canal may result in the absence of irrigation solution between fibre and canal wall. Hence, there is a risk that the emitted energy can be absorbed by hydroxyapatite in the canal wall and may result in the damage of the root canal wall.
In the study of Matsumoto et al., using an Er:YAG laser with a conical tip with top angle degree of 84 degrees, large vapour bubbles were created. The maximum bubble length was 4.5 mm and the bubble expanded in vertical direction. The registrations were in line with the study of de Groot et al. and Blanken et al. The three studies also had in common that there were considerations with regards to safety to the patient and it was recommended not to position the fibre end too close to the apex (Blanken et al. recommend 5 mm from the most apical point of the preparation, Matsumoto et al. also used the fibre 5 mm short of the most apical end).

George and Walsh examined the extrusion of fluid through the apex following laser activation of irrigant with the Er:YAG and the Er,Cr:YSGG, and with an end-firing and a radial firing tip placed 5 mm or 10 mm short from the most apical end. Neither laser type nor tip design appeared to be significant variables. The amount of dye extrusion was higher in the laser groups than in the group with manual syringe irrigation. Also the position of the laser tip did not result in significantly different extrusion distances (the 5 mm group, however, had a generally greater amount of extrusion). One important parameter that was not taken into account was the presence of an intact periodontal ligament. Nevertheless, the risk of apical extrusion was brought to attention. The studies in the glass models also demonstrated that the form of the cavitation bubbles was identical to the ones in water. In this respect, Meire et al. demonstrated that the transmission spectra of endodontic irrigation solutions (a.o. NaOCl and EDTA) proved to follow the spectrum of pure water to a large extent. A pilot study performed by the authors on the influence of fibre tip design and endodontic irrigant solutions on laser-activated cavitation with Er,Cr:YSGG demonstrated that there was no influence of the form of the cavitation bubble (Fig. 2).

Conventional LAI was reported to result in a significantly better debridement of artificial root canal wall grooves filled with artificially prepared dentin debris when comparing the use of PUI during 20 seconds with the use of C-LAI during 20 seconds (Er:YAG25 – Er,Cr:YSGG29). When comparing C-LAI during 20 seconds with PUI for 3 x 20 seconds, there was no statistically significant difference (however, there was a trend for better debridement scores for C-LAI with both Er:YAG and Er,Cr:YSGG). A comparison between C-LAI (Er:YAG flat tip) during 20 seconds with LAI performed with the tip hovering over the entrance of the canal (H-LAI) (Er:YAG conical) and PUI during 20 seconds demonstrated significantly higher debridement scores for both C-LAI and PUI than for H-LAI. There were no statistically significant differences between PUI and C-LAI.

In vitro studies investigating the bactericidal effect of C-LAI with the two types of fibre tips have not been published. At present, there is only a blind randomized controlled clinical trial with six month evaluation, where Er,Cr:YSGG was used with a radial firing tip combining C-LAI in distilled water (two times) and the spiral motion of the fibre in the dried canal (two times) in necrotic teeth with chronic apical periodontitis. This protocol was compared with the concomitant use of 3% NaOCl and interim calcium hydroxide paste. There were no significant differences in terms of periapical healing between the two groups, however, they exhibited statistically significant decreases in PAI scores in favour of the laser protocol.

A comparison between the use of lasers for laser-activated irrigation with the fibre in the canal (C-LAI) versus fibre in the pulp chamber (H-LAI) will be made in Part II of this article in laser 3/2014.

**Conclusion**

Conventional Laser Activated Irrigation (C-LAI) with Erbium lasers, i.e. placement of the fibre tip in the proximity of the most apical end of the prepared root canal, used stationary or retracting until reaching the most coronal part of the root canal has the potential of better debridement of dentinal plugs along the root canal wall when compared to Passive Ultrasonic Irrigation. Investigations of the bactericidal effect of C-LAI have not yet been performed.

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