The power of the bubble: comparing ultrasonic and laser activated irrigation

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The power of the bubble.
Comparing ultrasonic and laser activated irrigation

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ABSTRACT

The major problem of irrigation is the fluid motion within the confined geometry of the root canal: efficient dispersion of the liquid is difficult, conventional irrigation is limited due to the absence of turbulence over much of the canal volume, vapour lock may limit apical cleaning and disinfection, there is also a stagnation plane beyond the needle tip. The best way to improve irrigant penetration and biofilm removal is achieved by means of the agitation of the fluid.

Today ultrasonic activation appears to be the best way to activate and potentiate irrigants among the present-day used means and marketed systems. Another way to activate irrigation solutions is the use of lasers: laser activated irrigation or photon-initiated acoustic streaming have been investigated. Based on present-day research it appears that the efficacy of laser activation (especially with Erbium lasers) can be more efficient thanks to the induction of specific cavitation phenomena and acoustic streaming. Other wavelengths are now explored to be used for laser activated irrigation.

Keywords: endodontics, root canal cleaning, root canal disinfection, root canal treatment, laser activated irrigation, Er:YAG, ultrasonic irrigation, ultrasound

1. INTRODUCTION

The success of root canal treatment is estimated at 85% 1. Reasons for failures are:
   (1) the impact of the intrinsic nature (complexity) of the root canal anatomy with instruments only acting on the central body of the canal, but leaving isthmus, cul-de-sacs and fins untouched after completion of the preparation;
   (2) the presence of a biofilm which is not completely removed and the presence of therapy resistant micro-organisms;
   (3) the presence of an extra-radicular biofilm.

We rely on a chemomechanical approach for the cleaning and the shaping of the root canal system. Both mechanical and chemical cleaning are needed. During mechanical preparation not the whole surface of the root canal wall is efficiently exposed to instrument blades 2. Preparation with instruments (also NiTi) results in the accumulation of debris, blocking isthmus, fins, accessory canals and lateral canals 3. Traditional chemomechanical preparation often fails due to insufficient elimination of bacteria 4.

Irrigation is an essential part of root canal debridement because it allows for cleaning and disinfection in these areas that are not touched or reached by the root canal instruments 5.

Endodontic irrigants have to meet the following conditions:
   (1) wetting and removal of debris;
   (2) destruction of micro-organisms;
   (3) dissolution of organic matter;
   (4) removal of the smear layer and softening of the dentine;
   (5) cleaning in areas, inaccessible to mechanical cleaning methods.
Today there is no unique irrigant that can meet all these requirements. Combination of irrigant solutions is recommended, in fact also to complement the short-comings associated with these of a single irrigant. Another problem is that the irrigants have the come in contact with the entire root canal surface, also there where no action of endodontic instruments was possible. This means that a thorough three-dimensional spreading of the solution is needed especially in isthmi and in the apical part of the root canal especially small root canals. Manual agitation techniques did not result in satisfactory improvement of the cleanliness of the root canal wall and root canal system:

1. The mechanical flushing action created by hand-held syringe irrigation with needles and cannulas (side-venting and end-venting) is weak and the irrigant cannot be brought further than 1-2 mm beyond the tip of the needle. Also size and rigidity of the needle do not allow insertion deep enough in the apical third in fine root canals resulting in insufficient apical cleaning.
2. The use of brushes (e.g. Endobrush, NaviTip FX) was proposed. The friction created by an up and downward or rotational movement of the brush bristles might result in the dislodgement of particles, trapped tissue and debris in the areas of the noninstrumented root canal walls and into the fins, cul-de-sacs, and isthmi. However, brushes cannot be used to full working length because of their size (leading to packing of debris into the apical portion of the canal after brushing. An active scrubbing action failed in demonstrating improved cleanliness of the middle and apical portion.
3. Manual-dynamic agitation (hand-activated well-fitting gutta-percha) within an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent. The laborious nature of this hand-activated procedure (i.e. 100 strokes per 30 seconds) hinders its application in clinical practice.

To overcome these shortcomings a number of automated devices designed for the agitation of root canal irrigants are used nowadays. These systems can be subdivided in the following groups: (1) machine-assisted agitation systems, (2) sonic irrigation, (3) ultrasonic irrigation, (4) pressure alternation devices and (5) laser activated irrigation.

The objective is this presentation is to make a comparison between the use of ultrasound (ultrasonic irrigation) and laser (laser activated irrigation) for the agitation of endodontic irrigants on the hand of an investigation comparing.

2. MATERIALS AND METHODS

2.1. Study Model

The experimental setup was based on the model described by Lee et al. and modified by De Moor et al. Straight roots (n=25) from extracted human maxillary canines were selected. The canals were prepared to an ISO size 30 at working length (1 mm short of the apical foramen) with a 6% taper using Profile series (Dentsply Maillefer, Ballaigues, Switzerland), under irrigation with 2.5% NaOCl (University Hospital Pharmacy, Ghent, Belgium) using a 27-gauge endodontic needle (Monoject; Sherwood Medical, St. Louis, MO, USA). The roots were imbedded in acrylic resin (Orthocryl, Dentaurum GmbH & Co, Germany) and sliced longitudinally in the root's mesio-distal plane using an Isomet low-speed saw (Buehler, Dusseldorf, Germany). The two obtained halves were reassembled and fixated with the help of metal bolts through holes that were made in the resin block prior to slicing. Using a customized ultrasonic tip (Dentsply Maillefer), a groove of 4 mm in length, 0.5 mm deep, and 0.2 mm wide, was cut in the wall of one half of each root canal. The 6% taper ISO 30 Profile (Dentsply Maillefer), was then re-inserted to remove accumulated debris and refine the preparation. The groove started 1 mm short of working length.

and was filled with a mixture of dentin debris and 2.5% NaOCl solution. The models were reassembled and canals were filled to the brim with 2.5% NaOCl. Pilot tests had shown that a single model could be reused up to 6 times without any visible damage to the canal wall at microscopic level. Therefore, the 25 models were used repeatedly in the 6 experimental groups, which are shown in Table 1.

2.2. Irrigation protocols

Six irrigation methods were studied, each repeated 20 times.

In **group 1 (conventional irrigation, CI)**, syringe irrigation with 4 ml of 2.5% NaOCl was performed using a 27 gauge endodontic needle (Monject; Sherwood Medical) placed 1 mm short of the working length. The needle was moved up and down the apical half of the canal, with a flow rate of approximately 0.3 mL/s. The canal was dried using paper points ISO 30, 02 taper.

In **group 2, manual-dynamic irrigation (MDI)** was used. A well fitting ISO 30 taper 0.06 gutta percha cone (Henry Schein, Vilvoorde, Belgium) was inserted to working length. A total of 100 push-pull strokes were performed manually in one minute.

In **group 3 (Passive Ultrasonic Irrigation, PUI)**, a non-cutting #20 file (Irrisafe, Satelec Acteon, Mérignac, France) driven by an ultrasonic device (Suprasson Pmax Newton, Satelec) at power setting ‘blue 4’ was used in the canal for 20 seconds. The tip of the Irrisafe was kept 1 mm short of working length.

In **group 4 (Laser activated irrigation with Er:YAG laser, Er-conventional)**, a 2.940 nm Er:YAG laser (AT Fidelis, Fotona, Ljubljana, Slovenia) equipped with a hand piece (R14, Fotona) holding a flat 300 μm diameter fiber tip (Preciso 300/14, Fotona) was used to activate the irrigant. The tip was inserted to 5 mm from the working length and held still during the 4 times 5 seconds of laser activation (with an intermezzo of 5 seconds). The pulse energy was set at 60 mJ, the frequency was 20 Hz and the pulse lengths 50 μs.

The same Er:YAG laser was used in **group 5 (Laser activated irrigation with PIPS-tips, Er-PIPS)** with a conical fiber tip (PIPS 300/14, Fotona). The laser tip was introduced no further than 4 mm in the canal. The laser was operated with a hand piece (R14 PIPS, Fotona) at 40 mJ and 20 Hz with pulse lengths of 50 μs for 5 seconds and this was repeated 4 times as described in group 4.

In **group 6 (laser activated irrigation with a diode laser, diode)**, a 980 nm diode laser (Fox diode laser, A.R.C. laser GmbH, Nürnberg, Germany) was used to activate the irrigant. The 200 μm plain ended fiber was inserted in the root canal no further than 2 mm from working length and moved in an up and downwards motion along the groove. The fiber was activated for 18 seconds at an output power of 7.5 W and 25 Hz. This particular setting was based on pilot investigations where it was observed that activity remained limited to the fiber tip and the effects as described by Hmud et al. (22) did not occur below 7.5 W.

At the end of the procedures, roots in groups 2 - 6 were rinsed with 2 ml NaOCl (2.5%) and dried with paper points ISO 30, 02 taper (Dentsply Maillefer).

2.3. Evaluation of Dentin Debris Removal

Pictures of each groove were taken before and after each irrigation procedure using a digital camera mounted on an operating microscope (Opmi Pico, Carl Zeiss, Göttingen, Germany). The sequence of all the pictures was randomized, and 2 calibrated examiners blinded to the irrigation protocol scored each picture twice, with a two-week interval. The following scoring system was used to quantify the debris; 0 - the groove was empty, 1 - less than half the groove was filled with debris, 2 - more than half of the groove was filled with debris and 3 - the groove was completely filled with debris. In case the scores amongst the two examiners differed, the picture was discussed until a consensus was reached.
2.4. Statistical Analysis

The inter- and intrarater agreement was determined (Cohen kappa). The differences in debris scores between the groups were analyzed by means of the Kruskal-Wallis test and the Mann-Whitney test. The significance level was set at 0.05.

3. RESULTS

The debris scores after irrigation with the six different techniques are displayed in Table 1.

The Cohen kappa coefficient of interrater agreement was 0.74, whilst the intra-observer reliability scores were 0.9 and 0.92. Conventional irrigation removed significantly less debris from the groove than the laser groups, MDI and PUI (P < 0.001). The erbium laser with the flat fiber tip removed significantly more debris than the diode laser (P = 0.007), the MDI (P = 0.02) and the erbium laser using the PIPS tip (P = 0.004).

Table 1: Distribution for debris scores for each irrigant activation technique

<table>
<thead>
<tr>
<th>Group</th>
<th>Irrigation technique</th>
<th>Debris scores (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1*</td>
<td>Conventional</td>
<td>0</td>
</tr>
<tr>
<td>2*</td>
<td>MDI</td>
<td>10 (50)</td>
</tr>
<tr>
<td>3</td>
<td>PUI</td>
<td>14 (70)</td>
</tr>
<tr>
<td>4*</td>
<td>LAI (Er conventional, flat tip)</td>
<td>17 (85)</td>
</tr>
<tr>
<td>5*</td>
<td>LAI (Er-PIPS, conical tip)</td>
<td>8 (40)</td>
</tr>
<tr>
<td>6*</td>
<td>LAI (diode)</td>
<td>9 (45)</td>
</tr>
</tbody>
</table>

* Statistically significantly different from CI  l Statistically significantly different from Er-flat tip

4. DISCUSSION

4.1. Activation of irrigants: Sonic versus Ultrasonic

Ultrasonic irrigation is based on the oscillation of files or smooth wires. This will result in an acoustic stream around the file and a rapid movement of fluid in circular or vortex-like motion.

Two generations can be described for the ultrasonic activation of irrigants. During the first generation files with cutting tips were used, this generation can be referred to as the period of “Endosonics” i.e. simultaneous irrigation and instrumentation 10. An important disadvantage of the approach was the risk for iatrogenic
perforations. The second generation refers to the use of on cutting tips and smooth wires for the activation of the irrigant.

The efficiency of ultrasonic activation is considered to be higher than sonic activation of the irrigant. The streaming velocity of the irrigant has an effect on the cleaning efficacy. The streaming velocity is related to the frequency and the frequency of sonic equipment is between 1000 and 6000 Hz and ultrasonic is at least between 20,000 to 30,000Hz (Table 2).

Table 2: comparing Sonic versus Ultrasonic activation

<table>
<thead>
<tr>
<th></th>
<th>Sonic</th>
<th>Ultrasonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1000 – 6000 Hz</td>
<td>20,000 – 30,000 Hz</td>
</tr>
<tr>
<td>Amplitude</td>
<td>Large: +/- 1 mm</td>
<td>Small: ≤ 0.1 mm</td>
</tr>
<tr>
<td>Pattern</td>
<td>1 node</td>
<td>Multiple nodes and antinodes</td>
</tr>
<tr>
<td>Cavitation</td>
<td>No</td>
<td>Yes (but only recently demonstrated)</td>
</tr>
</tbody>
</table>

Effective ultrasonic activation of irrigants refers to the passive ultrasonic activation (PUI): after the root canal has been shaped until the master apical file the irrigant will be activated by an ultrasonically activated small non cutting wire without preparing the root canal. Most effective is the intermittent flush technique 3 times 20 seconds of ultrasonic activation alternating with a 2 ml flush of sodium hypochlorite from the syringe (hand irrigation). The root canal walls are cleaned by the streaming of the irrigant, hereafter the irrigant is refreshed by fresh sodium hypochlorite.

In fact the amplitude is not doing the work in a root canal, but the frequency is. The working area is a very restricted area so that no improvement of the system by increasing the amplitude is possible. Hence, the streaming velocity of the irrigant is related to the cleaning efficiency, the higher the streaming velocity the higher the cleaning efficiency.

Ultrasonic irrigation:

1. will increase the NaOCl reactivity
2. will heat the irrigant
3. smooth wires are as effective as files
4. is more efficient with greater apical taper
5. is more efficient in straight canals
6. oscillation of the instrument in the direction of a groove is possible – high velocity jets will result in better cleaning.

4.2. Cavitation with ultrasound in endodontic irrigants

Cavitation can be roughly described as the violent nonlinear collapse of a tiny gas or vapour bubble immersed in a liquid.

Two types of cavitation are described: (1) transient cavitation being responsible for the creation of jets, shock waves and oxy radicals; (2) stable cavitation referring to the injection of air bubbles, and being responsible for mixing and shear stresses.

Acoustic cavitation occurs whenever a liquid is subjected to sufficiently intense sound or ultrasound (that is, sound with frequencies of roughly 20 kHz to 10 kHz). When sound passes through a liquid, it consists of expansion waves (negative pressure) and compression waves (positive pressure). If the intensity of the sound field is high enough, it can cause the formation, growth, and rapid compression of vapour bubbles in the liquid. Macedo et al. (2013) demonstrated the creation of cavitation bubbles generated by an ultrasonically oscillating dental file in root canals models by means of sonochemoluminescence. Cavitation even occurred at low power settings, the bubbles however were not visible for the human eye.
4.3. What about the bubble?

The occurrence and/or the effect of cavitation with ultrasonic activation in the root canal has been questioned for long. Today there is evidence that cavitation bubbles are created during ultrasonic activation of sodium hypochlorite. Another way to induce cavitation effects is the creation of high pressure vapour due to instant heating. Expansion is reverted to implosion, and shock waves are created in the fluid at the point of the collapse. The latter is possible with Erbium lasers (Er:YAG 2940 nm, Er,Cr:YSGG 2780 nm).

4.4. Laser activated irrigation with Erbium lasers

The irrigant solution during the exposure time of the laser pulse is turned instantly into vapour. The root canal prevents the vapour from expanding freely laterally, pushing the irrigant both forward and backward in the canal. Since the irrigant solution 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. This process delays the dynamics of expansion and implosion. During implosion of the vapour bubble, the formation of new bubbles can be observed near the apex attributed to cavitation effects due to low pressure as a secondary effect of the imploding vapour bubble. Fluid turbulence remains for a longer time after the actual laser pulses up to several milliseconds.

The fluid velocity can be calculated based on the measurement of bubble growth and collapse versus time. For a 200 µm fibre used at 20 Hz and an exposure time of 130 microseconds, used at 75 mJ fluid velocities of 21 m/second were derived.

4.5. Efficiency of Erbium Laser Activated Irrigation

4.5.1. Conventional Laser Activated Irrigation

De Moor et al. (2009, 2010) demonstrated that laser activated irrigation (LAI) with an Er,Cr:YSGG and an Er:YAG laser (4x 5 sec stationary at 5 mm from the working length) was more efficient than passive ultrasonic irrigation (PUI) during 20 seconds for the removal of artificially placed dentin debris plugs. Using a laser fibre in the root canal stationary is referred to as conventional Laser Activated Irrigation. When PUI was performed 3x 20 seconds there was no statistically significant difference. The data in Table 1 are confirmed by both studies. Other LAI in vitro studies showed LAI to be more effective than PUI for the removal of debris in simulated canal irregularities, for the removal of apical smear layer.

4.5.2. PIPS - Photon Induced Photoacoustic Streaming

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) resulting in effective debris and smear layer removal. Minimal to no thermal damage to the dentinal structure through a photoacoustic technique called Photon Induced Photoacoustic Streaming (PIPS) was shown. The PIPS technique showed a strong agitation of the liquids inside the canals. This phenomenon was explained as a result of irrigant solution activation through a profound photoacoustic and photomechanical phenomenon in the endodontic system, which generates a faster streaming of fluids distant from the source in comparison with passive ultrasonic irrigation (PUI). Root canal surfaces irrigated with 2 ml of 5.5% sodium hypochlorite solution, and 2 ml of 17% EDTA irradiated for 20 seconds showed clean, open tubules with essentially no smear layer or debris remaining. According to Peters et al., PIPS showed greater reduction in bacterial contamination and less bacterial mass contained in apical canals cross sections compared with ultrasonic activation and syringe irrigation. In laser activated irrigation the laser tip has to placed 1mm from the apex for some and other traditional techniques requires the placement of the tip 5mm from the apex. The PIPS technique eliminates the need to introduce the tip into the root canal system due to its profound and distant effect. The tip has to be placed in the coronal portion of the pulp chamber and left stationary. A 2940-nm Er:YAG laser with a specifically designed, 14-mm-long, 400-micron diameter tapered tip is used. The final 4mm of the fibre is stripped from the back to allow for greater lateral emission of energy.
compared to the frontal tip. This should allow for improved lateral diffusion of low energy and enhanced photoacoustic waves.

4.5.3. Conventional Laser Activated Irrigation versus PIPS

According to Table 1 significantly more debris is removed with the conventional LAI technique than with PIPS used at the entrance of the root canal. In this investigation an Er:YAG Preciso 300/14 tip (Fotona) was used at 60 mJ - 20 Hz - 50 µs and a R14 PIPS tip (Fotona) was used at 40 mJ – 20 Hz – 50 µs, both at a stationary position. An explanation for the lower efficacy of the PIPS may be the high pulse energy also resulting in ejection of the irrigant solution out of the root canal. The combination of continuous irrigation and simultaneous laser activation is advocated by the inventors of the PIPS. In this respect the cleaning protocol used in this study differs from the other PIPS studies. Further investigation of the fluid dynamics with PIPS tips is needed.

4.6. Laser Activated Irrigation with Diode laser

The 980 nm diode laser with its current power settings was significantly more effective at removing debris from the groove than conventional irrigation performed with a syringe, but significantly less effective than the Er:YAG laser with conventional fiber (Table 1). Hmud et al. (2010) observed formation of cavitations at the end of fiber tip using a microscope with 940 and 980 nm diode lasers. Depending on the output power, these cavitations developed after several seconds and were visible to the enhanced human eye. This clearly differs from Erbium lasers, where the bubble forms instantly (microseconds) at the fiber tip and is invisible to the human eye because it exists for only a few hundred microseconds. For the 980 nm diode bubble formation was only observed starting at 7.5 W. The latter is a very high power and serious concerns about thermal safety in the clinical situation are appropriate. The fluid movement induced by the diode laser was limited to the tip of the fiber and hence the fiber tip was constantly moved up and down in the canal along the groove. Given the limited cleaning action for a high output power, the 980nm diode laser does not seem not to be an efficient tool for the activation of NaOCl.

5. CONCLUSION

Laser activated irrigation (LAI) with Erbium lasers (Er:YAG and Er,Cr:YSGG) helps in effective debriding of the root canal system, and can be considered as a decent alternative for passive ultrasonic irrigation. Studies on antibacterial efficiency are limited, though are in favour of erbium LAI when compared to passive ultrasonic irrigation.

More investigations, however, are needed to analyse the process of Erbium LAI cavitation and its impact on fluid dynamics within the confines of a root canal system.

6. REFERENCES


