Laser-activated irrigation with PIPS®

The power of better irrigation

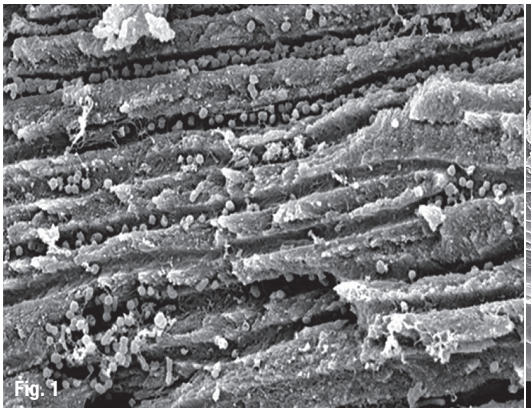
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Why endodontics?

Bacterial infections of the root canal system are one of the main causes of apical periodontitis.[1] The infection usually enters through the dentinal tubules. Carious lesions, leaky fillings, leaky dental implants, hairlines, traumas, or erosion may be the cause of canal system infections.[2] For the primary and for the secondary infection as well, an intra-radicular mixed bacterial flora was proven.[3] The median bacterial count for the primary infection was 4.6×10^7 colony forming units (CFU) per apex.[4] For persistent infections, 5.4×10^4 CFU per apex were determined.[5] Bacteria may enter very deeply into the dentinal tubules and ramifications of the root canal system.[6] Colonies of *E. faecalis*, for example, can be found up to 500 µm away from the main canal (Fig. 1).[7] The bacteria within the infected canal system appear either in plankton form, i.e. swimming in tissue fluid[8], or relatively "organised" in the so-called "biofilm". This is a conglomerate of various bacterial species, which organise themselves in an extra-polysaccharide matrix that adheres tightly to the canal walls and the dentinal tubules (Fig. 2).[9] The almost symbiotic interrelations among the bacteria within the biofilm results in a much higher resistance of the individual bacterial species against antimicrobial agents.[10] In advanced stages of apical periodontitis, you can therefore always refer to an infectious disease triggered by biofilm.[11] With regard to the preferably complete removal of bacteria from the canal system and the dentinal tubules, the increased resistance of the bacteria embedded in biofilm, together with the extremely strong adhesion due to the extra-polysaccharide matrix, is one of the essential problems in endodontic treatment. In summary, bacteria are the main cause of apical periodontitis.[12] The purpose of any endodontic therapy must therefore be the extensive eradication of microorganisms, infected tissue residues, and infected dental hard tissue from the canal system and dentinal tubules.[13]

Antimicrobial treatment concept

To meet this requirement as best as possible, it is necessary to comply with a strict antimicrobial treatment concept. This includes the imperative application of a dental dam, the removal of potentially infected dental restorations and scrupulously exact caries excavation as well as the preparation of a dentin-adhesive tight pre-endodontic buildup. The preparation of the correct access cavity facilitates all



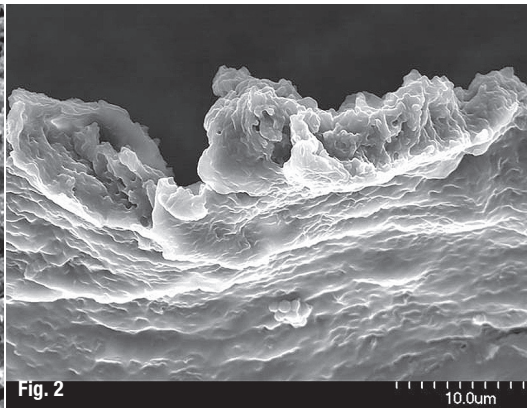
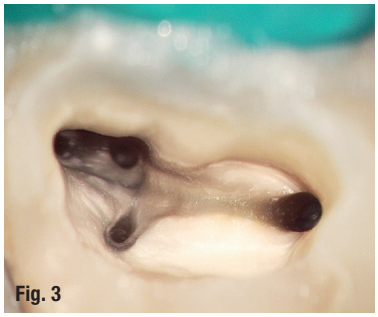
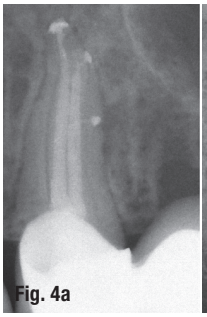
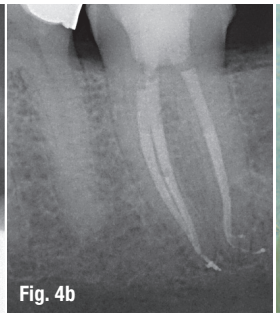


Fig. 1: Bacterial infection of dentinal tubules. Source: Prof. V. Kaitsas.
Fig. 2: Biofilm. Source: Prof. V. Kaitsas.


Fig. 3


Fig. 4a


Fig. 4b

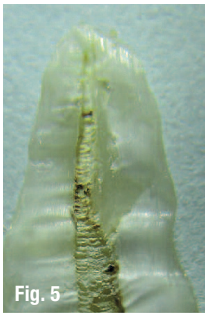

Fig. 5

Fig. 3: Correctly prepared access cavity of the upper molar.
Figs. 4a & b: Upper molars after reciprocal preparation, irrigation with 5 % NaClO and 17 % EDTA, PUI and thermoplastic obturation.
Fig. 5: Surface after laser treatment in dry canal with end firing tip; Er:YAG laser at 75 mJ, 15 Hz, 1.1 W, and 300 micron.[57]

work steps following the pre-endodontic build-up. The direct correlation between the correctly prepared endodontic access cavity and the success of endodontic therapy has been verified (Fig. 3).[14] After having applied the access cavity and prepared the coronal root canals, we measure the length of the root canal and determine the working length. Given the development of electrometric measurement systems in the past years, electrometric length determination is the measure of choice for this purpose.[15]

Chemomechanical preparation

As already mentioned above, bacterial infections of the root canal system are the main cause of apical periodontitis.[16] Solely preparing the root canals mechanically does not lead to sufficient reduction of microbial contamination. It was shown that major parts of the canal were not even attended to mechanically by means of mechanical preparation using rotating instruments.[17] The combination of mechanical preparation, activated irrigation by means of antimicrobial and tissue-resolving agents as well as the application of antimicrobial medication between the treatment sessions may reduce bacterial contamination of the canal system considerably.[18]

Mechanical preparation

Mechanical root canal preparation, depending on the available anatomy of the canal, may be performed with either manual instruments or rotating nickel-titanium instruments. Compared to manual instruments, the use of rotating instruments leads to considerably improved results with regard to the preparation geometry and the preservation of the original topography of the canal.[19] The introduction of a novel preparation pattern, i.e. reciprocal preparation movements, facilitates an even better mechanical preparation. Besides the reduced risk of fracture[20], better alignment of the files in the canal system and the resulting predictable and repeatable preparation seems to be one of the main advantages of reciprocal movements. Another advantage over fully rotating systems is the effective and thus more rapid canal preparation.[21] Because of the improved mechanical properties of reciprocal file systems, the preparation can be limited to a few file sizes, depending on the available canal anatomy. This makes handling easier for the attending doctor and his/her team.

Chemical preparation— irrigation solutions

The irrigation solutions applied to reduce bacterial contamination must fulfill various tasks in the root canal system:[22]

1. Antibacterial effectiveness against a broad microbial spectrum
2. Destruction of biofilm
3. Dissolution of potentially infected tissue
4. Removal of the smear layer

The smear layer is debris generated by the mechanical preparation, consisting of die dentin chips, bacteria, infected tissue, organic particles etc.[23] Especially with the rotating or reciprocal preparation, this debris is positively pressed into the dentinal tubules and compacted by the rotational movement. The smear layer thus prevents intra-canal antimicrobial agents and drugs from entering into the dentinal tubules and sub-canals.[24] The combination of sodium hypochlorite (NaClO) and ethylene diamine tetraacetate (EDTA) is the gold standard for the chemical reduction of intra-canal microorganisms to this day and has been proven in many research studies. The combination of both solutions and the mechanical preparation makes it possible to reduce contamination of root canals by the factor of 100 to 1,000.[25] NaClO has an excellent antimicrobial effect against most of the microorganisms that are significant in endodontics.[26] With regard to the tissue-resolving effect, NaClO is clearly superior to all other known irrigation solutions.[27] This tissue-lytic, effect combined with the excellent antimicrobial effectiveness, are key factors to accomplish comprehensive bacterial reduction in the root canal system. Concentrations between 1 per cent and 5.25 per cent are discussed. The higher the concentration, the quicker the lysis of the tissue.[28] Because of the rapid inactivation of NaClO when it contacts organic tissue, a large quantity of irrigation fluid of at least 10 ml per canal is required.[29] Heating the NaClO increases the effectiveness of the irrigation solution in the canal sys-

Fig. 6: PIPS® tip.


Fig. 6

tem.[30] Furthermore, you can improve the effectiveness by a longer reaction time.[31]

Ethylene diamine tetra-acetate (EDTA) serves to remove the smear layer mentioned above. Irrigation with approx. 5 ml of EDTA in a concentration of 17 per cent leads to the complete removal of the smear layer within one minute.[32] The reason why this effect is so important is that antimicrobial agents like e.g. NaClO can react deeply in the dentinal tubules only after the smear layer was removed. We should also mention that the effectiveness of EDTA against fungi like e.g. *Candida albicans* has been proven (Fig. 4).[33] The antimicrobial effect of EDTA is of rather minor importance.[34] The combination of the two described irrigation solutions is still the gold standard. Please refer to the related technical literature for more detailed information.

Laser in endodontics

In the past decades, lasers were established in endodontics.[35] Laser is the abbreviation of light amplification by stimulated emission of radiation. They are electromagnetic waves with a high-energy density. In endodontics, lasers of different wavelengths are used. By photothermal and partly photomechanical effects, laser radiation can unfold its bactericidal effect, depending on the wavelength and the associated absorption in the irradiated tissue. Mostly because of heating and the subsequent change of the osmotic gradient within the bacterial cell wall, the cell dies.[36] Lasers used in endodontics so far differ in their wavelengths, which again have critical influence on the interaction with the irradiated tissue.[37] Nd:YAG lasers function at a wavelength of 1,064 nm, diode lasers within a range between 810 nm and 980 nm, and erbium lasers at 2,780 nm (Er,Cr:YSGG) and 2,940 nm (Er:YAG).

First reports on the application of Nd:YAG lasers in the root canal were published in 1984 already.[38] In this procedure, special endodontic optical fibers were used which could emit the laser light only linearly. For this reason, the optical fiber had to be moved in spirals in the canal to reach as many canal sections as possible. At 15 Hz and 100 mJ, the antibacterial effect may then reach up to 1,000 µm[39] and enter deeply into the dentinal tubules.

Compared to that, the reduction of bacteria using NaClO was proven to a depth of only 100 µm.[40] However, the linear emission and the high energy density in connection with the work in the dry canal had detrimental effects. The antibacterial effect is lower in curved canals because of the linear emission of laser radiation.[41] In addition, heat of up to 38°C developed in the canal, which may cause the dental hard tissue to burn (Fig. 5).[42]

Matusomo et al. explain that, due to the linear emission of the laser beam, on the one hand consistent wall contact was impossible and on the other hand, because of the heat formation, emission over the apex had to be avoided, making the work in the apical third considerably harder.[43] When comparing the disinfecting effect of Nd:YAG lasers with "traditional" disinfection using NaClO and ultrasound, DeMoore et al. arrived at the conclusion that the Nd:YAG laser has no advantage in this respect.[44] The effects described for the Nd:YAG laser apply to the diode laser as well.

Two different wavelengths are differentiated for erbium lasers: 2,780 nm for Er,Cr:YSGG and 2,940 nm for Er:YAG lasers. These wavelengths have their maximum absorption in water and hydroxyapatite.[45] When erbium laser radiation hits the dental hard tissue directly, the water contained in the tissue evaporates immediately and dental hard tissue is ablated "gently" with only minimal thermal effects.[46] With regard to endodontics, experimental studies with erbium lasers proved the removal of the smear layer to be more effective than by other types of lasers and endodontic irrigation solutions.[47] Furthermore, the canal walls were free from debris and smear layer and had mostly open dentinal tubules.[48] Because of the linear emission of the laser beam by the optical fiber and due to the cumbersome handling, the canal walls were cleaned imperfectly.[49]

To resolve these limitations, special endodontic so-called "side-firing" tips were developed, which are intended to emit irradiation laterally and apically sealed:[50] Unfortunately, a construction-related re-

quirement for the application was the minimum preparation size of ISO 60, which resulted in the unnecessary sacrifice of dental hard tissue. Because of the apical sealing, the apical cleaning effect was only low.

Laser Activated Irrigation (LAI)—a revolution

How can the major advantages of erbium laser radiation be maintained without having to accept the application-related drawbacks? In 2007, Blanken et al. described for the first time the intra-canal application of a pulsed erbium laser in the canal lumen filled with NaClO.[51] They observed a few interesting effects: Each laser pulse caused great acceleration of the fluid in the root canal. At the same time, they proved a strong cavitation effect in the root canal.[52] Both effects combined resulted *in vitro* in a cleaning effect, which is superior to the passive ultrasonic irrigation (PUI), the previous gold standard of cleaning.[53] LAI in root canals, however, had some disadvantages too.

Irrespective of the laser tip design, sometimes a lot of irrigation fluid was extruded through the apical constriction. This extrusion was significantly higher than in conventional irrigation systems.[54] Additionally, the formation of gas bubbles because of the laser pulse may cause the irrigation fluid to vanish from the respective canal section completely, which again may cause thermal damage of dental hard tissue.[55]

PIPS®—the evolution of revolution

In 2010, DeVito presented a novel tip design for the first time, combining all advantages of erbium laser radiation, Laser Activated Irrigation (LAI) and the minimisation of the risk of irrigation fluid being extruded (Fig. 6).[56]

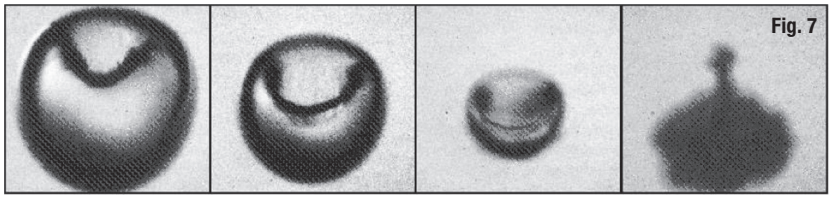


Fig. 7: Cavitation. Luther et al. 2001.

PIPS® is the abbreviation of Photon Initiated Photoacoustic Streaming. In this procedure, the PIPS® tip is inserted only into the pulp cavity filled with irrigation fluid. The pulsed laser beam generates shockwaves in the irrigation fluid and cavitation effects in the whole root canal system, intended to create a cleaning effect in the entire canal system, including isthmuses, lateral canals and deep down into the dentinal tubules, which is superior to any of the previous techniques. The almost complete elimination of bacteria, smear layer, and biofilm was proven in the *in vitro* experiment for NaClO and for EDTA.[57] No indication of irrigation fluid being extruded was noticed.[58]

What does the mechanism leading to this superior cleaning effect look like? When the laser pulse starts, the rapid heating of the irrigation fluid causes an expanding vapor bubble to form. The more the vapor bubble expands, the more it cools down, leading finally to its implosion.

This affects the root canal in the following ways:

1. The volume changes of the vapor bubble lead to heavy movement of the fluid in the root canal.[59]
2. The implosion of the bubble is a high-energy process. Shockwaves with large amplitudes and "micro-jets" develop. Shear stress builds up near surfaces (primary cavitation).[60]

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3. In addition to the primary cavitation, secondary cavitation processes are caused by the formation of subsequent, smaller bubbles (Fig. 7).[61]

These laser-induced effects depend on the absorption spectrum of the endodontic irrigation medium. That means: The better a certain medium absorbs the laser radiation, the better is the primary and the secondary cavitation effect. NaClO 5.3 %, EDTA 17 % and water have almost the same absorption spectrum.[62]

Wavelengths that are badly absorbed by the irrigation fluid may cause damage to the root canal walls, dentinal tubules, or even the periodontal ligament. This is one of the key differences between the two erbium wavelengths. The absorption coefficient of Er:YAG at 2,940 nm is almost twice as high as that of Er,Cr:YSGG. The PIPS® system operates exclusively at the wavelength of Er:YAG of 2,940 nm.

The PIPS® tip design is also a key influence on the effectiveness of cleaning: It is a 9 mm long tip with a diameter of 600 µm, the apical 3 mm of which are not sheathed with polyamide and have a tapered end (Fig. 6). The lacking sheath of the apical 3 mm results in better lateral emission. The tip is connected to the laser source (LightWalker®, Fotona, Slovenia) via a special endodontic handpiece. The free axial flexibility facilitates the application even in difficult anatomic situations (Fig. 8).

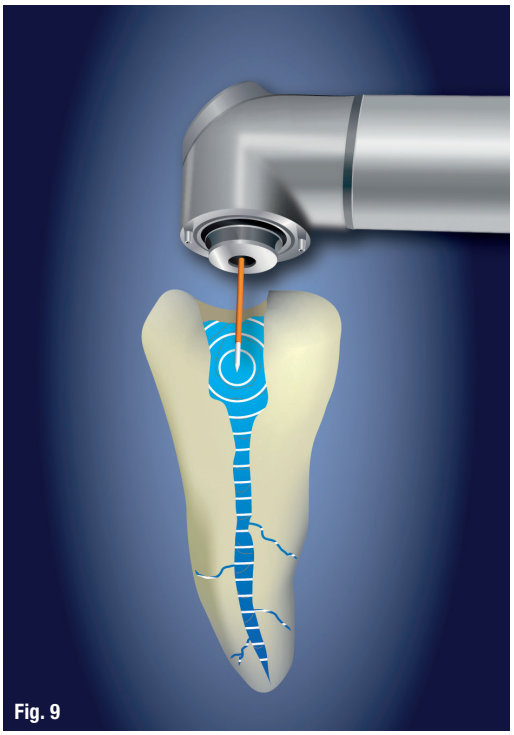


Fig. 8

The manufacturer recommends the following settings for PIPS®: 50 µS pulse length, 10 to 20 Hz and 0.15 to 0.5 W, i.e. peak powers of 400 W up to 1,000 W are achieved with each pulse due to the interaction with irrigation fluid. Air/water spray is not required. These settings triggered the shockwaves and the strong current of irrigation fluid as described above.[63] The temperature of the root surface increased by only 1.5 °C with the PIPS® activated for 20 to 40 s.[64] Clinical application should follow the manufacturer's instructions.

At the end of the preparation, irrigation with 17 % EDTA is performed to remove the smear layer. The pulp cavity should be flooded with EDTA. Then the PIPS® tip is inserted into the orifice and activated for 30 seconds (Fig. 9). After rinsing intermediately with saline solution, rinsing with NaClO is performed. This is followed by activating the NaClO twice for 30 seconds respectively with a break of 30 seconds between the intervals. A sufficient quantity of fluid in the orifice is important in this procedure. If necessary, the assistant needs to add irrigation fluid continuously.

Fig. 8: Fotona LightWalker® and PIPS® handpiece.
Fig. 9: PIPS® tip in orifice.


Fig. 9

The research results regarding PIPS® so far have been promising. One study compared the bacterial reduction as well as the biofilm removal between PUI and PIPS® *in vitro*. The application of PIPS® resulted in the reduction of bacterial contamination by 99.5 %, the significantly better reduction of biofilm, and the significantly greater number of samples that are free from bacteria.[65] In another study, Jaramillo et al. compared the removability of biofilm applying various techniques to activate the irrigation. Besides PIPS® (LightWalker®, Fotona, Slovenia), these were the passive ultrasonic irrigation (PUI) and sonic activation (EndoActivator). The laser-induced irrigation with PIPS® was significantly superior to all other techniques as regards removing the biofilm (Fig. 10).[66] Another study deals with the removability of calcium hydroxide from root canals. The authors compared as well PIPS®, PUI, and sonic activation of irrigation fluids. After the laser-activated irrigation with PIPS®, all the samples were free from calcium hydroxide, 24 per cent still showed residues in case of PUI.[67] The removal of *E. faecalis* from artificially infected root canals using PIPS® and the sole irrigation with saline solution without activation was the subject matter of another study. The remarkable result of this study was the complete removal of *E. faecalis* from all canals in the PIPS® group, in which the preparation was effected only to the Pro Taper® F1 file.[68] This study may be an in-

dicator that minimally invasive canal preparation might be possible because of the good cleaning effect of PIPS®, certainly always depending on the anatomic situation.

PIPS®—the force awakens

The eradication of microorganisms and tissue from the root canal system must be the goal of every endodontic therapy. Complete removal of bacterial contamination was achieved only rarely so far due to complex anatomic canal structures and technology-related limitations. The development of PIPS® to reduce bacteria by laser-induced activation of irrigation fluid could have the crucial advantage over all currently known therapeutic procedures. The research results have been promising so far, but further studies should and will be conducted, in particular *in vivo* studies, to consolidate the positive trend. All endodontic treatment steps must be implemented in the therapy using PIPS®. However, the superior cleaning effect of PIPS® seems to realise two key advantages for dentists specialising in endodontics:

1. Improved cleaning effect of the canal systems, which will result in an improved success rate of endodontic therapies.
2. More substance-friendly preparation because of the better cleaning effect. This preserves the dental material, which again influences the fracture behavior of endodontically treated teeth directly.

The integration of PIPS® into a strictly antibacterial endodontic treatment concept might improve the therapeutic success of endodontic therapies again considerably. PIPS® will be in any case a clear evolution in endodontic treatment. Only the future can show whether the introduction of PIPS® will revolutionise endodontology in a similar way as the introduction of NiTi files. However, the force of laser-induced irrigation has awakened._

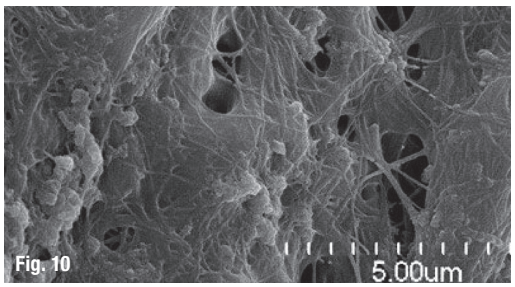


Fig. 10: Dentinal tubules after PIPS® application. Jaramillo et al. 2010.

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Kurz & bündig

Bei PIPS® (Photon Induced Photoacoustic Streaming) handelt es sich um eine photoakustische Spülmethode. Durch die Energie eines Er:YAG-Lasers werden nichtthermische photoakustische Schockwellen erzeugt, mit denen die Reinigungs- und Säuberungslösungen in den Kanal eingeführt werden. Nach dieser Behandlung sind die Kanäle und Seitenkanäle gereinigt und die Dentinkanälchen von der Schmierschicht befreit. Zu Beginn des Laserimpulses kommt es durch die rapide Erhitzung der Spülflüssigkeit zur Entstehung einer sich ausdehnenden Dampfblase. Je weiter sich diese Dampfblase ausdehnt, desto mehr kühlt sie sich ab, was letztlich zu ihrer Implosion führt. Dies führt zu folgenden Effekten im Wurzelkanal: Die Volumenänderungen der Dampfblase führen zu einer starken Flüssigkeitsbewegung im Wurzelkanal.[60] Die Implosion der „Bubble“ ist ein sehr energiereicher Prozess. Es kommt zur Ausbildung von Schockwellen mit großer Amplitude und zur Ausbildung von „micro-jets“. Nahe von Oberflächen kommt es zum Aufbau von Scherspannungen (primäre Kavitation).[61] Neben der primären Kavitation kommt es durch Ausbildung nachfolgender, kleinerer „Bubbles“ zu sekundären Kavitationsprozessen (Bild 7).[62] Diese durch Laser induzierten Effekte sind vom Absorptionsspektrum des endodontischen Spülmediums abhängig, das bedeutet, je besser die Absorption der Laserstrahlung durch ein bestimmtes Medium, desto höher der primäre und sekundäre Kavitationseffekt. NaClO 5,3 %, EDTA 17 % und Wasser haben annähernd dasselbe Absorptionsspektrum.

PIPS® ist ebenso wirksam als abschließende Spülung im Vorfeld der Obturation. Zur Anwendung von PIPS® in Ihrer Praxis benötigen Sie einen Fotona Er:YAG-Laser.