SSP/SWEEPS endodontics with the SkyPulse Er:YAG laser

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Introduction

The goal of endodontic therapy is to eliminate pathogenic substances from the root canal system. However, standard mechanical instrumentation leaves a significant portion of the complex root canal system uninstrumented. Additionally, the mechanical instrumentation itself creates a smear layer and an accumulation of debris that need to be removed as well. For this reason, an irrigation phase of the therapy is required in order to eliminate the potential pathogens, and to remove the debris resulting from the instrumentation phase of the procedure. Different methods and technologies have been introduced with the goal to improve the efficacy of the standard syringe root canal irrigation procedure. One of the most recent techniques involves SSP/SWEEPS® laser-activated irrigation (LAI) using a special type of the Er:YAG (erbium-doped yttrium aluminium garnet) laser with extremely short laser pulses, generating photon-induced photoacoustic streaming of the irrigant throughout the complex three-dimensional root canal system (Fig. 1).

The photon-induced photoacoustic streaming is achieved through the high absorption of the SSP (super-short pulse; 50 µs) Er:YAG laser pulse in the irrigant, which initiates the rapid formation of a vapor bubble at the fibre tip (FT) while it is immersed in the irrigant. Due to the very high absorption coefficient of the Er:YAG laser wavelength (λ = 2,940 nm) in irrigants, all of the laser pulse light is absorbed within the approximately 1 µm-thick fluid layer. Thus, the fluid is locally and instantly heated over the boiling point and a vapor bubble starts to form at the FT's end. After the explosive boiling, the vapor bubble starts to expand. When it reaches its maximum volume, it is nearly empty and it starts to collapse due to the pressure of the surrounding liquid. This phenomenon induces turbulent fluid movement within the whole root canal volume, significantly improving the efficacy of chemomechanical debridement. Additionally, for super-short laser pulses, the effects of thermal diffusion during bubble formation are minimal.

A unique solution for modern endodontics

The ultimate goal of SSP/SWEEPS® is to significantly enhance several irrigation mechanisms: 3D streaming of the irrigant throughout the complex root canal system; increased penetration of the irrigant deeper into the dentinal tubules; removal of debris and the smear layer from the root canal system; more effective chemical activation of NaOCl; direct (non-chemical) removal of biofilm; and direct (non-chemical) disinfection. The clinical efficacy and safety of SSP laser-activated irrigation has been extensively investigated. However, research indicates that further improvements can be achieved by tailoring the Er:YAG laser emission characteristics to the specific requirements of the above irrigation mechanism.

This has led to the development of SSP/SWEEPS® endodontics, where the extremely effective single-pulse SSP irrigation is complemented with an additional, dual-pulse SWEEPS® (shock wave enhanced emission photoacoustic streaming) technique. The SWEEPS® modality is based on the finding that, as opposed to large liquid reservoirs, shock waves, i.e. waves travelling faster than sound, are not observed in spatially confined reservoirs such as root canals. This is because in narrow canals cavitation dynamics are significantly slowed down by the friction on the canal walls and by

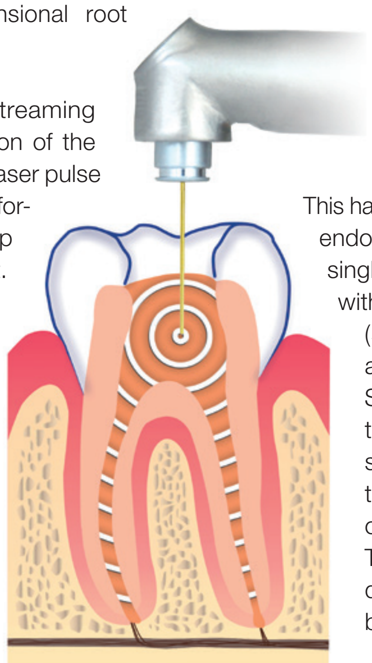

Fig. 1: Laser-activated irrigation technique using SSP/SWEEPS® Er:YAG laser technology and the photon-induced photoacoustic streaming protocol (PIPS). The laser fibre tip is placed in only the coronal portion of the pulpal chamber, and left stationary, allowing the photoacoustic waves to spread into the openings of each canal. This enables a more minimally enlarged canal preparation, and without thermal damage as is seen with techniques requiring placement into the canal system.

the limited space available for the quick displacement of the liquid during the bubble's expansion and contraction. The SWEEPS® modality consists of delivering a subsequent laser pulse into the liquid at an optimal time when the initial bubble is in the final phase of its collapse. The growth of the second bubble exerts pressure on the collapsing initial bubble, accelerating its collapse and the collapse of secondary bubbles, resulting in the emission of primary and also secondary shock waves.

Materials and methods

The Er:YAG laser (λ = 2,940 nm) used in this study was the SkyPulse (Fotona), equipped with the H14 handpiece, optically coupled with interchangeable fibre tips (Fig. 2). The handpiece air/water spray was turned off during all experiments. The following fibre tips were used in the study:

1. Cylindrical flat-ended fibre tips with diameters of 400 µm (Flat Sweeps400) 500 µm (Flat Varian500) and 600 µm (Flat Varian600);*
2. Cylindrical radially-ended (tapered) tips with diameters of 400 µm (Radial Sweeps400) and 600 µm (Radial Sweeps600). Note that the Radial Sweeps600 tip is geometrically equivalent to the standard 600 µm "PIPS" fibre tip.**
3. Conical flat-ended tips with diameters of 400 µm (Conical Sapphire 400) and 600 µm (Conical Sapphire 600).

The SkyPulse laser system was operated in the single-pulse SSP emission mode and in the dual-pulse SWEEPS® emission mode. Since the proper timing of the SWEEPS® pulse pair depends on the cavitation bubble's oscillation time, which depends on the geometry of the access chamber, the SkyPulse's SWEEPS® modality consists of automatic repetitive sweeping of the temporal separation between the SWEEPS® pulse pair back and forth within an optimal range (SWEEPS®) of temporal separations in order to ensure effective irrigation regardless of the tooth type and chamber size preparation. It is the accelerated collapse of the first bubble in the SWEEPS® pulse pair that results in the enhanced shock wave emission and improved irrigation, while the role of the second bubble is mainly to amplify the effect of the first bubble.

Measurement of root canal pressure

Measurements were performed in a simulated tooth model with the entrance diameter of the conically shaped access cavity of 3 mm, submerged 4 mm deep under the water level of a large water-filled reservoir. This provided a stable fluid pressure within the root canal in the absence of LAI, and enabled constant replenishment of irrigant. The laser fibre tip's end was positioned 2.5 mm deep into the access chamber. The average generated pressures (P_{ave}) for different irrigation protocols were calculated based on determining the pressure changes in

Fig. 2

Fig. 2: The SkyPulse Er:YAG laser used in the study is equipped with the two latest laser-activated irrigation modalities: SSP and SWEEPS®, thus enabling a complete SSP/SWEEPS® endodontic treatment.

apical, middle and coronal part of the simulated tooth model. The SkyPulse Er:YAG laser was set to emit radiation in the single pulse SSP emission mode. For comparison, measurements with another Er:YAG laser device, LightWalker (Fotona) were also made under the same conditions and using the same handpiece (H14) and fibre tips. Both lasers were operated with the single-pulse energy of 20 mJ and a repetition rate of 15 Hz.

Measurement of debris removal rate

Cleaning efficacy was measured in a root canal model. The experimental set-up consisted of a transparent root canal model, submerged in a glass container filled with distilled water. The root canal model was filled-up with a suspension paste to simulate debris. A biological calcium hydroxide-based paste was used in the validation phase of the experiment. In the measurement phase, a gel den-

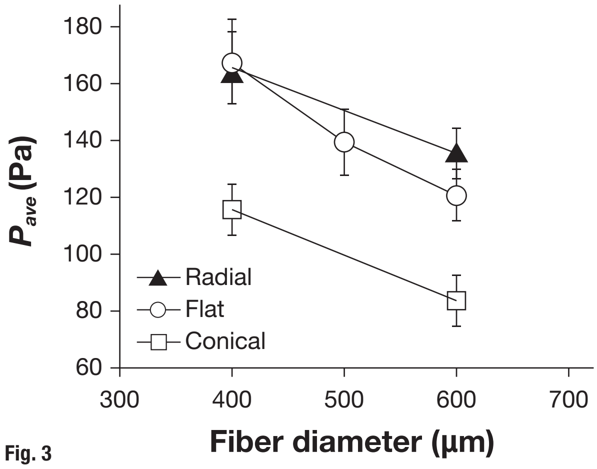

Fig. 3

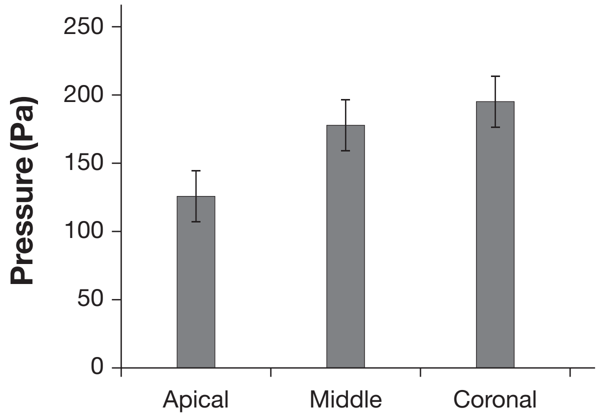

Fig. 4

Fig. 3: Dependence of pressure generation efficacy on fibre tip type and diameter. **Fig. 4:** Measured pressures at different locations within the root canal for different fibre tips. The SSP mode with pulse energy of 20 mJ and pulse repetition of 15 Hz, delivered by a SkyPulse Er:YAG laser device, was used.

tifrice was used, which yielded comparable results to the biological paste but was easier to handle and required less time to empty and refill the root canal model between measurements.

Laser pulses with a single-pulse energy of 20 mJ were delivered through the Flat Sweeps400 fibre tip positioned inside the root canal model. The images of the root canal during LAI were captured by a video camera and analysed using custom-developed software. The cleaning rate was determined from the measured reduction of the height of the simulated debris (paste) within the root canal model, with the irrigation time of 180 s. Shorter irrigation times were used for calculation when the root canal became fully cleaned, i.e. emptied of the paste, already before the expiry of 180 s. Each cleaning rate data point represents an average of at least five repeated irrigations. The cleaning rate measurements were made for the single-pulse SSP emission mode and for the automatically swept SWEEPS® emission mode.

Results

Pressure measurements

Dependence of average pressures P_{ave} (as measured for both LightWalker and SkyPulse laser devices in SSP mode) on fibre tip type (radial, flat or conical) and diameter is shown in Figure 3. Pressure measurement results show that in general the pressure generation efficacy is higher for smaller fibre tip diameters. Detailed pressure distributions within the apical, medial and coronal part of the root canal, as measured with the SkyPulse in SSP mode, are presented in Figure 4. The distribution of irrigant pressures within the root canal as shown in Figure 4 are in agreement with the reported irrigant penetration depths at different root canal areas.

Cleaning rate measurements

The measured debris removal (i.e. cleaning) rates (R_c) for the SkyPulse SSP and SWEEPS® emission modes with single-pulse energy of 20 mJ are shown in Figure 5. The SWEEPS® mode was delivered at repetition rate of 20 Hz while the SSP emission mode was tested in the range of 15–50 Hz, in order to determine whether doubling the single-pulse repetition rate of the SSP mode would yield similar results as the dual-pulse SWEEPS® mode. As can be seen from Figure 5, the debris removal rate of the dual-pulse SWEEPS® mode is significantly higher in comparison to the single-pulse SSP mode, regardless of the SSP mode's repetition rate.

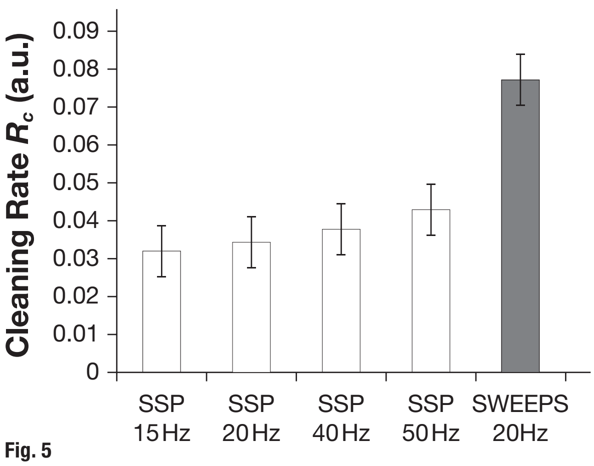

Fig. 5

Fig. 5: Debris removal (cleaning) rates R_c for the SSP and SWEEPS® emission modes with single-pulse energy of 20 mJ. The SWEEPS® mode exhibits a significantly enhanced cleaning rate.

Discussion

The goal of endodontic treatment is to obtain effective cleaning and decontamination of the smear layer, bacteria and their by-products 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. The latest SSP/SWEEPS® technology greatly simplifies root canal therapy while successfully addressing all of the ultimate goals of endodontic irrigation: 3D streaming of the irrigant throughout the complex root canal system, increased penetration of the irrigant deeper into the dentinal tubules, removal of debris and smear layer from the root canal system, more effective chemical activation of NaOCl, direct (non-chemical) removal of biofilm, and direct (non-chemical) disinfection.

3D irrigant streaming

The high absorption of temporally super-short Er:YAG laser light leads to explosive boiling of the irrigant that generates oscillating vapor bubbles causing the mixing of liquid also at distant regions of the complex root canal anatomy. Observations of debris particles show that liquid vorticity effects continue long after the bubble oscillation has ended, significantly contributing to the SSP/SWEEPS® irrigation efficacy (Fig. 6). Using the SSP/SWEEPS® technique, it is now possible to effectively debride and disinfect isthmic, cul-de-sacs, lateral canals, and apical ramifications. SSP irrigation efficacy has been previously studied using a root canal model with a lateral canal (Fig. 7). The fluid motion achieved within the lateral canal during SSP activation was at a speed of 1.5 mm/s, which is sufficient for the irrigation of any lateral canal.

Penetration of irrigants into dentinal tubules

Traditional irrigation during root canal treatment with a syringe and needle is associated with only limited penetration beyond the main canal into dentinal tubules. The limitation is particularly pronounced in the apical area. The SSP/SWEEPS® activation considerably increases the efficacy of the irrigants in the apical area, as demonstrated also by the pressure measurements in this study. The pressure measurements during SSP activation show the pressures in the apical region to be significant, by a factor of only 1.6-times smaller than the pressure in the coronal region (Fig. 4). This is in agreement with a study, which compared different methods of activation of endodontic irrigants including ultrasonic, sonic and SSP, and determined that SSP activation achieved the greatest penetration depths in the middle and apical sections.

Cleaning—removal of debris and smear layer

The present study shows that the latest SWEEPS® modality significantly enhances the debris removal efficacy even in comparison to the SSP irrigation (Fig. 5). As an example, Figure 8 shows the observed difference in the efficacy of debris removal of the SSP and SWEEPS® irrigation.

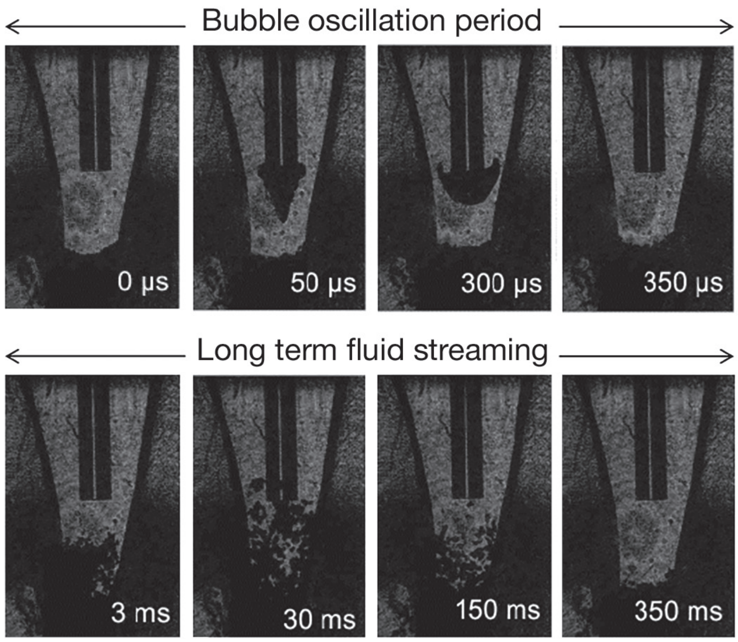

Fig. 6: The series of images shows water vorticity after a SSP laser-induced cavitation bubble using simulated debris particles. Significant water flow can be observed 2 ms after the beginning of the laser pulse, which is long after the collapse of the cavitation bubble (Tosc ≈ 300 μs). The particles settle to the ground in approximately 200 to 300 ms.

Activation, disinfection and biofilm removal

A major mechanism of action of the SSP laser-activated root canal irrigation techniques is believed to be the rapid fluid motion in the canal as a result of expansion and implosion of vapor bubbles, resulting in a more effective delivery of the irrigants throughout the complex root canal system. An additional mechanism which contributes to the efficacy of SSP is the improved removal of the smear layer, microorganisms, and biofilm as a result of the physical action of the turbulent irrigant. In addition, chemical action seems to play a role as well. For example, an increased reaction rate of NaOCl was found to occur upon activation by the pulsed erbium laser. By

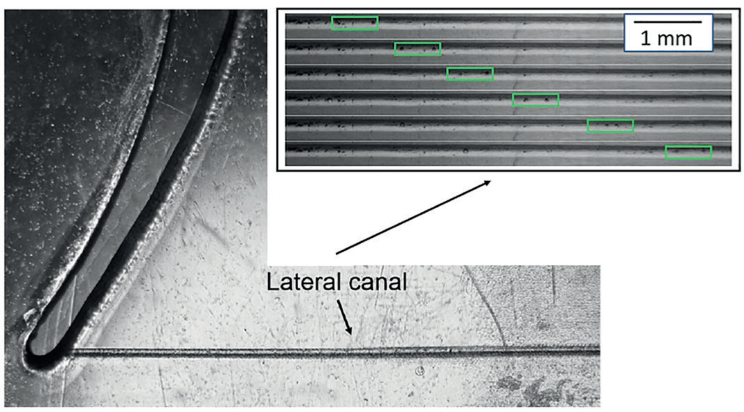

Fig. 7: Root canal model with lateral canal used in the experiment. The lateral canal was ≈ 13.5 mm long and had a diameter of 70–160 μm; observed motion of gas bubbles within the lateral canal during SSP irrigation.

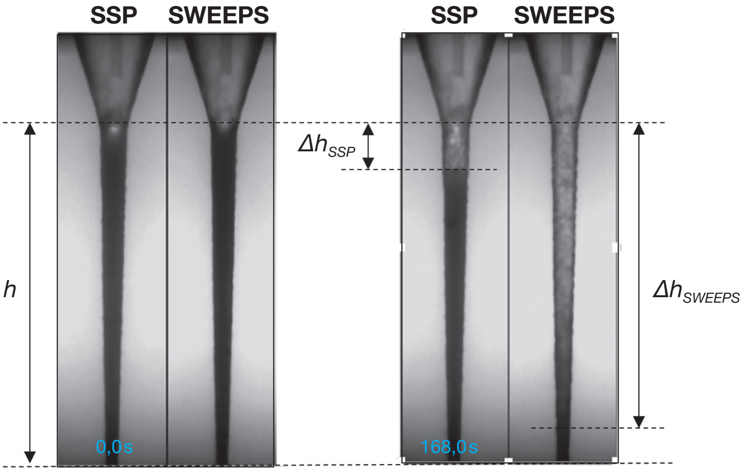

Fig. 7: Images of the filled-up root canal prior to irrigation (left) and images of the partially or fully cleaned root canal following the irrigation sequence (right). An exemplary comparison of the cleaning outcomes following irrigation with SSP and SWEEPS® emission mode is shown.

being able to generate shock waves within narrow root canals, both the physical and chemical actions of SSP can be potentially further enhanced by using the SWEEPS® technique.

Minimal risk of extrusion

It is important to note that the SSP/SWEEPS® irrigation does not result in any increase of apical irrigant extrusion. Recently, a study of the apical irrigant extrusion during SSP and SWEEPS® laser irrigation was carried out, during which irrigation using two standard endodontic irrigation needles (notched open-end and side-vented) was compared with the PIPS and SWEEPS® laser irrigation procedures. In the standard irrigation experiment, the irrigation device was a syringe coupled to either a 30G open-ended or side-vented needle, with flow rates of 1, 2, 5 and 15 mL/min. Both the PIPS and SWEEPS® irrigation procedures resulted in a significantly lower apical extrusion compared to the conventional irrigation with endodontic irrigation needles, in agreement with previous reports.

Optimal fibre tip for SSP/SWEEPS® endodontics

Pressure measurement results (Fig. 3) show that in general the pressure generation efficacy is higher for smaller fibre tip diameters. The highest efficacy was observed for the following cylindrical tips: Radial Sweeps400 and Flat Sweeps400 tips, with no significant difference between the two fibre tip types. For the larger fibre tip diameter of 600 mm, the radially-ended fibre tip was slightly more effective than the flat-ended tip. This is because radially-ended tips generate spherically shaped bubbles where optodynamic energy conversion efficiency is optimal, while flat-ended tips tend to generate more spheroid-shaped bubbles. This difference becomes less pronounced for smaller fibre tip diameters where bubbles become approximately spherical regardless of the fibre tip ending.

The SSP irrigation has been typically performed using the PIPS 600 mm fibre tip, geometrically equivalent to the Radial Sweeps600 tip. However, based on the results of the present study, the narrower Radial Sweeps400 fibre tip is even more effective and therefore appears to be a preferred choice. On the other hand, when fibre tip longevity is of concern, the appropriate choice is the Flat Sweeps400 tip. This tip was found to exhibit the same pressure efficacy as the radially-ended tip (Fig. 3), however, it is more durable, especially when performing SWEEPS® activation where the radial fibre tip's cone can get more readily damaged by the generated shock waves.

Conclusion

Our study indicates that the combined SSP/SWEEPS® technology of the SkyPulse Er:YAG laser system has the potential to greatly simplify root canal therapy while successfully addressing the major goals of endodontic irrigation. The ability of SSP/SWEEPS® to three-dimensionally debride and decontaminate dentinal tubules thus allows the clinician to effectively deliver treatments in less time and with less need to enlarge the canal system, allowing for a more minimally invasive preparation.

* Previous manufacturer's codes for cylindrical 400, 500 and 600 μm fibre tips were Varian400, Varian500 and Varian600, correspondingly.

** Previous manufacturer's codes for tapered cylindrical 400 and 600 μm fibre tips were XPulse400 and XPulse600, correspondingly.

Literature

about the author

Dr Tomaž Ivanušič graduated from the University of Ljubljana's Faculty of Medicine in 2017. Thereafter, he served a one-year internship, where he gained experience in different dental specialties. Primarily focussing on Endodontics, Restorative Dentistry and Laser Dentistry, Dr Ivanušič currently works as a dentist in a private clinic in Slovenia. In addition, he works as researcher, lecturer and trainer, and has been involved in the development of laser systems including the Fotona SkyPulse.

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