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AutoSWEEPS Modality of SkyPulse Endo Er:YAG Laser

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SUMMARY

a) Introduction

Root canal preparation consists of mechanical instrumentation followed by chemical irrigation. Because of the highly complex anatomy of root canal systems, the standard method of hand syringe irrigation has been found unsatisfactory for cleaning and disinfecting the root canal wall from debris and bacteria. For this reason, laser-activated irrigation (LAI) has been introduced to enhance the irrigation action [1–8].

During LAI, Er:YAG laser pulses are delivered through a fiber tip (FT) into the irrigant-filled coronal access cavity. Due to the strong absorption of the Erbium wavelength (λ = 2.94 μm) in the irrigant, a vapor bubble is generated at the end of the submerged fiber tip [9]. The rapid expansion and collapse of the bubble (See Fig. 1) results in secondary cavitation and fluid motion along the entire root canal system [10 - 11], leading to enhanced chemo-mechanical irrigation [4, 12] when EDTA and NaOCl solution are used as irrigants. This long-distance action of LAI represents an important advantage in comparison to other irrigation techniques that require a different tip/needle to be inserted up to the apical area [13 -15].

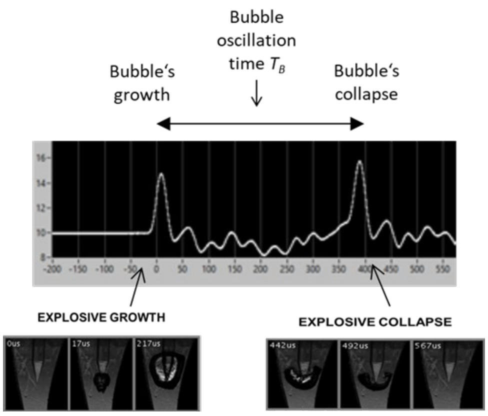

Fig 1: The acoustic signal following the emission of a single Er:YAG laser pulse. The initial rapid growth and final explosive collapse of the laser-generated bubble (below) during the bubble's oscillation time (T_B) result in two acoustic signal peaks (above).

However, due to friction on the cavity walls the bubble oscillation is significantly slowed down, reducing the intensity of the bubble collapse within the root canal. Therefore, the shock waves that are usually emitted in an unconstrained environment following a bubble's collapse are diminished or not present at all [16, 17].

b) Dual-pulse SWEEPS mode

To intensify the bubble collapse within the root canal, a special dual-pulse Shock Wave Enhanced Emission Photo-dynamic Streaming (SWEEPS) modality has been introduced, where the second laser pulse is applied just before the collapse of the first laser pulse's bubble [16 -18].

Figures 2-4 show the dual-pulse emission of the SWEEPS modality as measured for the latest generation SkyPulse Endo Er:YAG laser systems (manufactured by Fotona, Slovenia). It is to be noted that SWEEPS pulses are designed to start with sharp initial intensity peaks that additionally enhance the dynamics of photo-acoustic irrigant streaming.

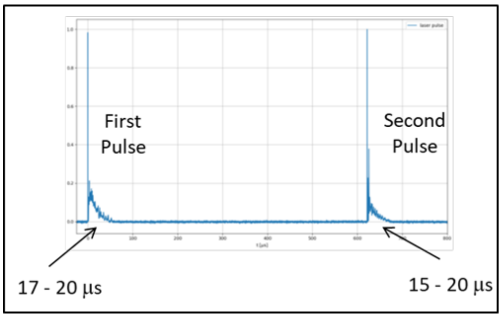

Fig. 2: Temporal shape of the latest generation SkyPulse Endo's dual-pulse SWEEPS mode with nominal single-pulse durations of 25 μs. Measurement was made for E_{SWEEPS} = 2 x E_L = 2 x 20 mJ at the SWEEPS mode repetition rate of 15 Hz.

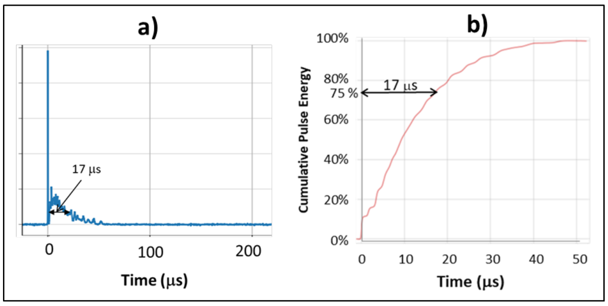

Fig 3: a) Temporal shape of the first pulse of the SWEEPS pulse pair shown in Fig. 2. b) Temporal delivery of the cumulative laser energy during the pulse. The pulse duration of 17 μs represents the time when 75% of the total laser pulse energy of E_L = 20 mJ has been delivered.

The sudden expansion of the second bubble generated by the second laser pulse exerts additional pressure on the initial bubble, leading to its accelerated collapse, during which shock waves are emitted. Furthermore, shock waves are also emitted from the collapsing secondary cavitation bubbles that are formed throughout the entire length of the canal during laser-induced irrigation [17].

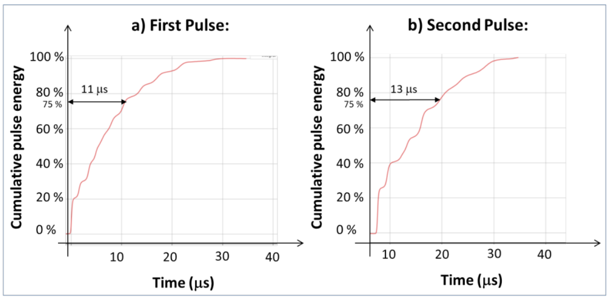

Fig 4: Temporal shape of the first pulse (a) and of the second pulse (b) of the latest generation SkyPulse SWEEPS mode as measured for E_{SWEEPS} = 2 x E_L = 2 x 10 mJ at the SWEEPS mode repetition rate of 15 Hz.

The largest enhancement of shock waves and internal irrigant pressures occurs when the temporal separation (T_{SWEEPS}) between the two SWEEPS laser pulses does not deviate substantially from the optimal separation time, i.e., the resonant time (T_{res}), corresponding to the time when the second laser pulse of the SWEEPS pulse pair is delivered near the end of the collapse phase of the primary bubble generated by the first laser pulse ($T_{res} \approx 0.9$ x T_B) [17, 22] (see Fig. 5).

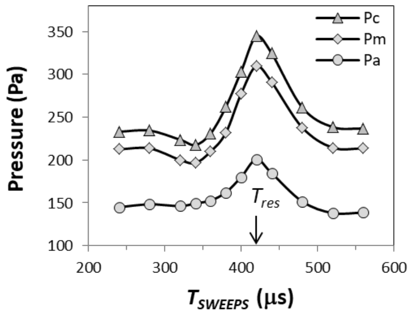

Fig 5: Dependence of the measured pressures in the coronal (P_c), medial (P_m) and apical (P_a) areas of the root canal, as a function of the temporal separation (T_{SWEEPS}) of the SWEEPS dual pulses. The largest pressure increase occurs when the start of the rapid growth of the second bubble at $t \approx T_{res}$ coincides with the collapse of the first bubble towards the end of its oscillation period T_B [22].

c) ¸AutoSWEEPS mode

A challenge involved in using SWEEPS in dental practice is posed by the fact that the bubble oscillation time T_B critically varies depending not only on laser parameters that can be controlled such as laser pulse energy (E_L), but also on the endodontic access cavity dimensions that vary depending on the treated tooth, with T_B being longer for smaller cavity dimensions [17, 22] (see Fig. 6).

As an improved solution, a special AutoSWEEPS laser modality was developed [16, 19, 21], in which the temporal separation between the pair of laser pulses is continuously swept back and forth between T_{SWEEPS} = 200 µs and T_{SWEEPS} = 650 µs. This ensures that during each sweeping cycle there is always at least a 50 µs wide temporal separation range when the pulses are separated by $T_{SWEEPS} \approx T_{res}$, as required for optimal enhancement. The sweeping modality also ensures that the optimal conditions are approximately reached along the depth of the access cavity by matching the changing diameter conditions during the AutoSWEEPS cycle.

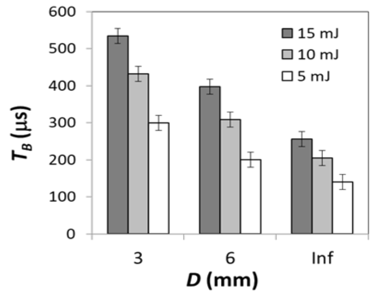

Fig 6: An example of the dependence of the cavitation bubble oscillation period (T_B) on the diameter D (3 mm, 6 mm and "Infinite") of an irrigant-filled cavity [22].

Under comparable conditions the AutoSWEEPS modality has been reported to be about 50% more effective than the standard single-pulse SSP (Super Short Pulse, 50 µs nominal pulse duration, also known as PIPS) modality in generating pressures within the root canal, resulting also in significantly better penetration of irrigants into the dentinal tubules [20]. Also, as measured in laboratory conditions, the simulated debris removal rate of the AutoSWEEPS modality has been shown to be almost three times higher compared to that of the SSP modality [19] (See Fig. 7).

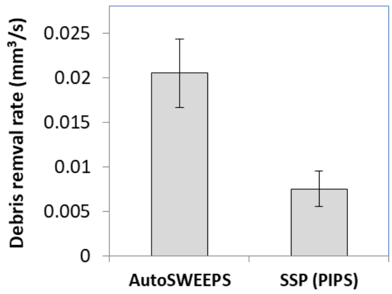

Fig 7: Comparison of debris removal rate of AutoSWEEPS and SSP (PIPS) Er:YAG laser modalities [19].

Similarly, in a recent study, the efficacy of the removal of accumulated hard-tissue debris from the root canal system for AutoSWEEPS irrigation was compared with the SSP laser-assisted irrigation as well as with ultra-sonically activated irrigation (UAI) using microcomputed tomography [23]. The AutoSWEEPS modality resulted in significantly improved debris removal in each portion of the root canals compared with SSP and UAI.

Additionally, studies in artificial models with apical constrictions of ISO40 [21] and ISO45 [20] and a lateral canal opening of ISO35 [20] indicate that the new SWEEPS method does not increase the risk of apical extrusion as compared with single-pulse LAI or standard syringe irrigation (see Fig. 8).

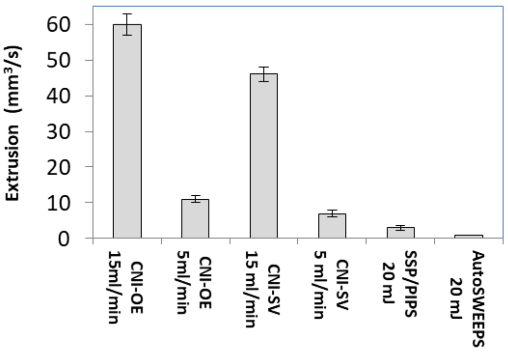

Fig 8: Mean values of irrigant extrusion in groups using i) conventional needle irrigation with open-ended needle (CNI-OE) or ii) side-vented needle (CNI-SV), using flow rates of 5 or 15 mL/min, and using LAI with iii) SSP (PIPS) LAI (20 mJ), and iv) AutoSWEEPS LAI (2x 10 mJ) [21].

d) Conclusions

In conclusion, the AutoSWEEPS modality as is available in the latest generation SkyPulse Endo Er:YAG laser systems has been shown to result in shock-wave generation and significantly enhanced flushing action [19], and due to increased pressure generation along the depth of the root canal, enhanced penetration of irrigants into dentinal tubules is also achieved [20] without increasing the risk of apical extrusion [21].

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