ISSN 1855-9913

Er:YAG Laser Photoacoustic Irrigation in Periodontal and Implant Therapy

Saša Terlep[1], Špela Levičnik-Höfferle[1]
[1]Fotona d.o.o., Stegne 7, Ljubljana, Slovenia

ABSTRACT

Er:YAG laser photoacoustic irrigation offers a non-invasive and effective solution for removing biofilms in periodontal and implant therapy. By generating shock waves through laser-activated fluid cavitation, this method enables access to areas previously inaccessible to traditional tools. Advanced pulse modes like USP and AutoSWEEPS enhance cleaning efficiency, even in complex and hard-to-reach areas. Studies have shown rapid and significant reduction of biofilm, and clinical results confirm improved healing and resolution of pockets. This technique presents a promising alternative to conventional debridement, with benefits for both patients and clinicians.

Key words: Er:YAG, photoacoustic irrigation, SWEEPS, USP, periodontitis, peri-implantitis, biofilm

Article: J. LA&HA, Vol. 2026, No.1; onlineFirst.
Received: Jul 17, 2025; Accepted: March 4, 2026

I. INTRODUCTION

Biofilm-related infections remain one of the most persistent challenges in modern periodontology and implantology. Bacterial biofilms form on the surfaces of tooth roots and implants. These biofilms are not only resistant to conventional antimicrobial agents but are also mechanically difficult to remove, especially from deep periodontal pockets and rough implant surfaces. Their presence triggers inflammatory responses in soft tissues, leading to conditions such as gingivitis, peri-implant mucositis, and more advanced diseases like periodontitis and peri-implantitis. If not addressed effectively, these conditions can lead to irreversible bone loss, pocket formation, tooth loss or implant failure [1-4]. Conventional debridement techniques, including mechanical scaling with hand instruments, ultrasonic scalers, and air-polishing, are widely used but often insufficient for complete biofilm eradication, particularly in deep and anatomically complex areas. Numerous studies and clinical trials have shown that even after thorough scaling and root planing, residual biofilm and bacterial activity can persist, especially in sites with limited access [4,5]. This has driven the need for enhanced treatment modalities that can reach beyond the limitations of conventional tools.

II. ER:YAG PHOTOACOUSTIC IRRIGATION: MECHANISM AND ADVANCEMENTS

One of the most promising advancements in this field is the use of Er:YAG laser technology for photoacoustic irrigation. Unlike traditional near-contact laser debridement, photoacoustic irrigation works in a non-contact mode by activating a liquid medium inside the periodontal or peri-implant pocket. When the Er:YAG laser is fired into the irrigant—typically saline, chlorhexidine, or hydrogen peroxide—the laser energy is rapidly absorbed by water molecules. This results in rapid thermal expansion and the formation of vapor bubbles known as cavitation bubbles. These bubbles expand and collapse rapidly, producing strong acoustic or shock waves that propagate through the fluid [6]. The energy of these shock waves physically disrupts and detaches the biofilm from the root or implant surface [7-9]. This phenomenon allows the laser to clean even the most inaccessible areas of the pocket without direct contact or mechanical scraping. Photoacoustic treatment has effectively addressed the challenges of biofilm removal in endodontics, where the complex root canal anatomy presents significant obstacles [7].

The technology has been refined through the development of different laser pulse modes. The SSP (Super Short Pulse) mode delivers single short pulses optimized for gentle cavitation in general cleaning applications. The USP (Ultra Short Pulse) mode produces more intense cavitation, additionally improving the effectiveness of cleaning. The SWEEPS (Shock Wave Enhanced Emission Photoacoustic Streaming) modality represents a dual-pulse enhancement, in which a second laser pulse is delivered at a precisely timed interval after the first pulse. This second pulse boosts the collapse of the initial cavitation bubble, amplifying the generated shock wave and increasing cleaning power even further. AutoSWEEPS automatically adjusts the time between pulses to match the anatomy and fluid dynamics of the treatment area, ensuring consistent cleaning performance across a variety of pocket depths and geometries [10,12].

III. LATEST RESEARCH IN PERIODONTOLOGY AND IMPLANTOLOGY

Extensive in-vitro research has demonstrated the effectiveness of Er:YAG laser photoacoustic irrigation in simulated periodontal and peri-implant environments.

In a study by Terlep et al. (2022), Enterococcus faecalis biofilms grown on titanium discs were treated with saline, 0.2% chlorhexidine, or 3% hydrogen peroxide, both alone and in combination with SSP-mode Er:YAG laser irrigation. As seen in Figure 1, up to 92% of the biofilm could be removed within just 10 seconds of laser treatment, far outperforming chemical irrigation alone. Furthermore, the study showed that adding chemical agents did not significantly enhance the effect of the laser, indicating that the mechanical impact of the cavitation itself was the primary mechanism of cleaning [8]. In another investigation, Terlep et al. (2023) compared the Er:YAG-SSP and Er:YAG-AutoSWEEPS modalities for cleaning narrow geometries simulating peri-implant pockets. Both methods showed significant reductions in biofilm mass and viable bacteria, but the dual-pulse AutoSWEEPS modality was particularly effective as it removed up to 98.5% of biofilm in only 10 seconds [12], as depicted in Figure 2.

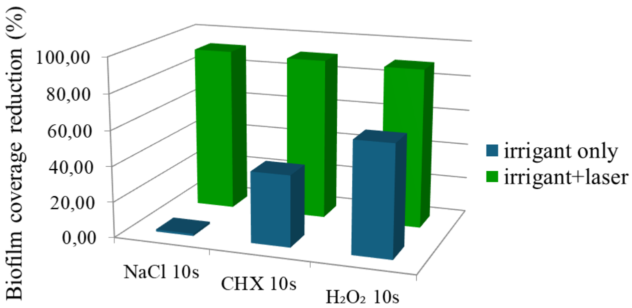

Figure 1: Biofilm surface coverage reduction after treatment with saline solution, chemical, or photoacoustic treatment for 10 s [8].

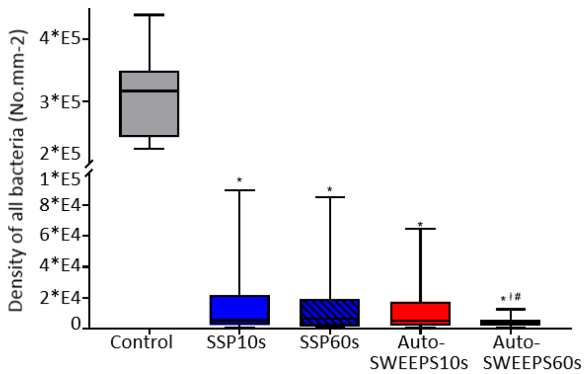

Figure 2: The effectiveness of Er:YAG-SSP and Er:YAG-AutoSWEEPS modalities for biofilm removal (narrow square gap model). The surface density of all bacteria (live + dead) on titanium discs before treatment (control) and after Er:YAG-SSP (blue) or Er:YAG-AutoSWEEPS (red) irrigation of saline solution for 10 and 60 s. [12].

Jezeršek and colleagues (2023) further designed a wedge-shaped model mimicking a periodontal pocket using glass surfaces and a soft polydimethylsiloxane (PDMS) material to simulate inflamed gingival tissue. Their study showed that softer, more elastic boundary conditions (as in inflamed tissues) reduced cavitation efficiency due to energy absorption by the surrounding medium. However, even under these conditions, dual-pulse AutoSWEEPS was able to generate secondary cavitation and maintain a high level of cleaning efficacy (Figure 3). The research highlighted that effective cavitation, especially secondary cavitation, occurred in the tip of the wedge, an area unreachable by mechanical tools, demonstrating the key advantage of this approach in managing inflamed periodontal conditions [13].

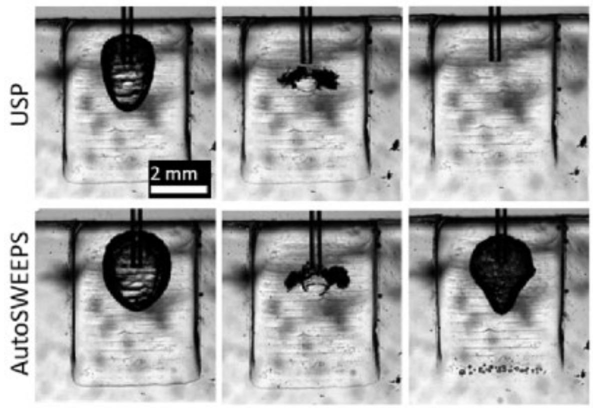

Figure 3: Cavitation dynamics in the narrow-wedge geometry for the dual-pulse AutoSWEEPS modality. Comparison of images of bubble formation for the single-pulse USP (top images) and AutoSWEEPS (bottom images) modalities. First column: primary cavitation developed after triggering the laser. Middle column: collapse of the primary bubbles. Third column: generation of secondary bubbles for the AutoSWEEPS modality [13].

Volk et al. (2025) extended this research by constructing an experimental zero-gap model using titanium surfaces and PDMS layers that mimicked the tight pocket space between the soft tissue wall and the implant surface. Using the Er:YAG-USP laser modality, they demonstrated cleaning effectiveness even in narrow, high-resistance spaces. In the wedge region of the model, over 95% of biofilm was removed. In the zero-gap area, more than 85% of biofilm was eliminated near the fiber tip, and even at 5.5 mm away from the tip, over 60% biofilm reduction was achieved. This indicates that the shock waves can propagate efficiently through confined fluid pathways, cleaning well beyond the laser's direct reach [14].

Another notable finding was that inflamed soft tissues (modeled by softer PDMS) absorbed more cavitation energy, making cleaning more difficult. Nonetheless, laser treatment with USP and

AutoSWEEPS modes still achieved high levels of decontamination in these settings. This is clinically relevant because many chronic periodontitis and peri-implantitis cases involve inflamed, swollen, and soft tissues. The ability of laser-induced photoacoustic cavitation to overcome these obstacles suggests that it may provide better outcomes than conventional debridement, particularly when surgical access is not feasible [13, 14].

In a clinical case described by Ivanusic (2025), the left side of the maxilla was treated using a modified TwinLight® protocol that incorporated AutoSWEEPS photoacoustic irrigation instead of conventional Er:YAG ablation (Figure 4). Treatment began with supragingival debridement, followed by Nd:YAG laser application. AutoSWEEPS was then used for subgingival cleaning, and final decontamination was performed with Nd:YAG laser. When comparing both sides, greater clinical improvement was observed on the left side treated with AutoSWEEPS. All probing sites ≥ 4 mm were eliminated (21 to 0), whereas one residual site remained on the right side treated with TwinLight (18 to 1). Similarly, bleeding on probing was reduced more markedly on the left side (73.6% to 5.6%) compared with the right side (71.2% to 16.7%). [15].

a)

b)

Figure 4: Clinical situation before (a) and after (b) periodontal treatment with a modified TwinLight® protocol that incorporated Er:YAG-AutoSWEEPS photoacoustic irrigation on the left side of the mouth.

IV. CONCLUSION

Er:YAG laser photoacoustic irrigation may offer a non-invasive, efficient, and safe method for deep biofilm removal in periodontal and peri-implant therapy. It reduces the need for surgical access, preserves healthy tissue, and eliminates the risk of damaging root or implant surfaces with metal instruments [15]. In addition, the method avoids cytotoxic irrigants, relying instead on physical forces generated by laser-induced fluid dynamics. For patients, this may result in less discomfort, reduced healing time, and lower risk of recurrence. For clinicians, it provides a high-precision, reproducible solution for managing challenging cases of periodontitis and peri-implantitis.

The use of Er:YAG laser with photoacoustic irrigation, especially using advanced pulse modalities like USP and AutoSWEEPS, represents a powerful evolution in biofilm management. With consistent in-vitro evidence showing high levels of biofilm removal across multiple geometries and tissue conditions, this technology offers great potential for integration into everyday periodontal and implant practice. As further clinical trials confirm its safety and effectiveness, it may become a standard tool in the arsenal of non-surgical periodontal therapy, adjunctive implant maintenance, and surgical decontamination procedures.

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