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SuperSMOOTH: Leveraging Gate Control Theory in Aesthetic Treatments Using a Novel Er:YAG Laser Modality

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ABSTRACT

SuperSMOOTH™ is a novel Er:YAG laser pulse modality that enables the simultaneous delivery of non-ablative and ablative effects within a single treatment step. Originally developed to optimize multi-step procedures combining Er:YAG and Nd:YAG lasers (such as Fotona4D®), SuperSMOOTH also represents an effective standalone treatment approach for skin rejuvenation.

By combining deep thermal stimulation with controlled superficial ablation, SuperSMOOTH enables efficient tissue remodeling and improves pigmentation and skin texture in a single pass. Additionally, results from the pilot studies presented in this paper indicate that this modality uniquely leverages the gate control theory of pain, resulting in an approximately 30% reduction in perceived pain compared to conventional non-ablative Fotona SMOOTH® Er:YAG laser treatments—exceeding the effect of topical anesthesia under the tested conditions.

These characteristics position SuperSMOOTH not only as an enabling technology within multi-wavelength protocols, such as Fotona4D®, but also as an independent treatment modality capable of delivering fast, effective, and well-tolerated skin rejuvenation treatments. The importance of the reduced pain perception effect as observed in this study is not merely improved comfort, but the ability to use clinically effective treatment parameters without increasing patient discomfort.

Key words: Smooth, SuperSmooth, Er:YAG laser, Fotona4D, gate control theory, skin rejuvenation, pain perception.

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I. INTRODUCTION

Human tissues are complex, multilayered structures that respond differently to laser light depending on wavelength. In the UVB, UVA, and visible ranges, laser energy is predominantly absorbed by melanin, hemoglobin, and keratin [1]. However, at wavelengths above approximately 1,100 nm, water becomes the dominant chromophore. Among the mid-infrared wavelengths absorbed by water, the Er:YAG laser wavelength is particularly prominent, as it corresponds to the peak absorption of water at 2,940 nm [2]. At the other end of the spectrum, the Nd:YAG laser wavelength of 1,064 nm is characterized by deep penetration into human tissue and can interact with multiple chromophores [3].

Laser-based aesthetic treatments often rely on multi-step protocols to target different skin layers and indications. For example, Er:YAG skin rejuvenation treatments commonly involve two sequential steps [4,5]. The first step uses the Fotona SMOOTH® mode [2,4,5], (hereinafter referred to as "SMOOTH" mode), consisting of a 300 ms long sequence of six sub-ablative Er:YAG laser pulses. This step activates cellular signaling pathways and promotes skin regeneration, while simultaneously heating deeper dermal layers to stimulate extracellular matrix production, particularly collagen [4,5]. The second step involves a light peel, i.e., very superficial ablation using short (0.2–0.6 ms) pulses at fluences above the ablation threshold, targeting epidermal pigmentation and dull skin.

Traditionally, these steps are delivered sequentially, requiring the laser device to be reconfigured between steps. As a result, the same skin area must be irradiated twice, increasing treatment time. Furthermore, thermal energy is used inefficiently, as heat generated during the first step dissipates before the second step is applied.

Recent advances in laser pulse engineering have enabled a new approach: integrating multiple tissue effects into a single Er:YAG modality. SuperSMOOTH™ represents such an advancement [6,7]. Enabled by Fotona's ASP (Adaptive Structured Pulse) technology, this modality combines heating with non-ablative SMOOTH mode (for dermal stimulation and collagen remodeling) with superficial ablative pulses (for epidermal renewal and texture improvement) within a single pulse sequence.

While this innovation simplifies and enhances multi-wavelength procedures such as Fotona4D® [8–12], its significance extends beyond this multi-wavelength protocol optimization. SuperSMOOTH introduces a new treatment paradigm in which (i) deep and superficial effects are delivered simultaneously, (ii) treatment time is reduced, and (iii) thermal energy is utilized more efficiently.

Importantly, this modality introduces a novel biological interaction. By combining thermal (painful) and mechanical/acoustic (non-painful) stimuli within the same pulse sequence, SuperSMOOTH leverages the gate control theory of pain [13,14], reducing perceived discomfort and enabling the use of more effective treatment parameters.

In this paper, we report on two pilot studies investigating the gate control effect during simultaneous deep thermal stimulation and superficial ablation using the SuperSMOOTH mode. The hypothesis is that faster-transmitting tactile signals (via large-diameter nerve fibers) inhibit slower nociceptive signals (via small-diameter fibers), resulting in reduced perceived pain.

II. MATERIALS AND METHODS

a) SuperSMOOTH modality

The innovative pulse sequence, referred to as the SuperSMOOTH™ mode (see Fig. 1), consists of a long, non-ablative SMOOTH train of laser pulses, followed by a short superficially ablative MSP – Micro Short Pulse (~175 µs) or SP – Short Pulse (~300 µs)). This novel approach combines a series of sub-ablative pulses designed for controlled bulk skin heating with a terminal ablative pulse targeting only the most superficial tissue layer.

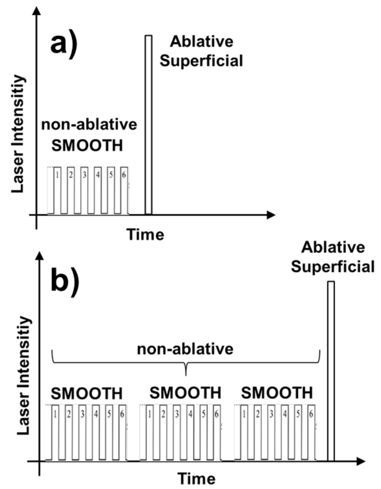

Figure 1: SuperSMOOTH™ pulse sequence architecture. The modality integrates one (a) or multiple (b) non-ablative SMOOTH pulse trains with a single terminal superficially ablative Er:YAG pulse (MSP – Micro Short Pulse (~175 µs) or SP – Short Pulse (~300 µs)). This hybrid pulse structure enables simultaneous delivery of deep thermal stimulation and superficial ablation within a single treatment step.

The SuperSMOOTH sequence integrates both effects, deep non-ablative heating and superficial ablation, into a single treatment step using a unified pulse mode. This not only eliminates the need for mid-treatment adjustments, but also streamlines workflow, enabling faster and more effective procedures.

An example of measured superficial skin temperature evolution during a SuperSMOOTH mode energy delivery is shown in Fig. 2.

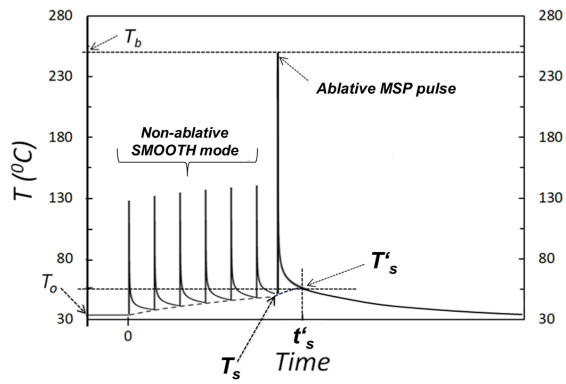

Figure 2: Measured skin surface temperature evolution during SuperSMOOTH energy delivery. The hybrid sequence consists of a non-ablative SMOOTH pulse train followed by a single ablative MSP pulse, with a total duration of approximately 350 ms. The final ablative pulse contributes not only to superficial tissue ablation but also to an additional increase in baseline skin temperature ($\Delta T'_s = T'_s - T_s$), demonstrating a synergistic thermal effect.

For N consecutive Er:YAG laser pulses separated by a pulse interval t_{sep}, the final baseline temperature T_s is defined as the temperature at time $t_s = N \times t_{sep}$, where t_s represents the total effective duration of the pulse sequence duration.

As can be seen from Fig. 2, the final ablative pulse results not only in superficial skin ablation but also contributes to the overall baseline temperature increase in the amount of $\Delta T'_s = T'_s - T_s$. This additional heat deposition represents the synergistic effect of both modalities delivered within the same »hybrid« pulse.

b) Gate control of pain

Moreover, by delivering two distinct laser modalities –the SMOOTH pulse followed almost instantaneously by a cold ablative MSP (Micro Short Pulse) or SP (Short Pulse) – the SuperSMOOTH sequence leverages the gate control theory of pain.

The premise of the gate control theory of pain is that when nerves receive non-painful signals such as vibration or sound, the transmission of pain signals is inhibited (see Fig. 3).

First proposed by Melzack and Wall in 1965, the gate control theory suggests that pain perception is regulated by a "gate control" mechanism in the dorsal horn of the spinal cord. Sensory inputs are transmitted through both large-diameter (Aβ, Aδ) fibers and small-diameter (C) fibers, converging on the substantia gelatinosa (SG), which modulates their transmission to central "T" cells. The relative balance of input from large versus small fibers determines whether the "gate" is open or closed—thus influencing perceived pain [13, 14].

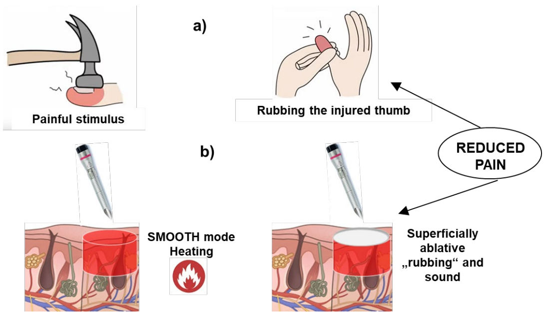

Figure 3: Schematic illustration of the gate control theory of pain applied to laser-tissue interaction. (a) Non-painful stimuli such as mechanical stimulation can reduce pain perception (e.g., rubbing after injury). (b) In the SuperSMOOTH™ sequence, the non-painful mechanical/acoustic stimulus generated by the ablative pulse partially inhibits the thermal pain signal induced by the preceding SMOOTH heating phase.

In this context, the intense heat generated by the SMOOTH mode activates C fibers, initiating nociceptive signaling. The immediate follow-up ablative pulse, although also partially transmitted via C fibers, additionally stimulates Aβ and Aδ fibers. According to the gate control theory, the activation of larger fibers inhibits nociceptive transmission by effectively "closing the gate" to pain signals from C fibers (see Fig. 4). As a result, even though the thermal load of the SuperSMOOTH sequence is higher than that of traditional modes, the overall perceived pain is reduced—enhancing patient comfort and thus enabling higher parameters and better treatment efficacy.

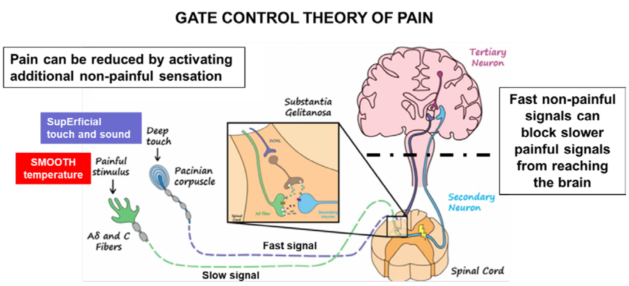

Figure 4: Gate control theory of pain. Pain perception is regulated by a "gate control" mechanism in the dorsal horn of the spinal cord. Painful sensory inputs are transmitted through slower small-diameter (C) fibers, and non-painful signals through faster large-diameter (Aβ, Aδ) fibers, both converging on the spinal cord, which modulates their transmission to the brain's central "T" cells. The relative balance of input from large versus small fibers determines whether the "gate" is open or closed—thus influencing perceived pain.

c) Pain measurement experiment 1

To evaluate gate control-induced pain reduction using the SuperSMOOTH modality, measurements of pain perception were first conducted on the dorsal skin of the hand of 6 volunteers (four male, two female; ages 28-36 years), using different parameters of the SuperSMOOTH pulse. The laser device was a TimeWalker Er:YAG laser (manufactured by Fotona, Slovenia), equipped with the PS03X handpiece (spot diameter d' = 7 mm) (both manufactured by Fotona, Slovenia). Pain perception was assessed using the standard Visual Analogue Scale (VAS) method [17], using a straight line with endpoints labeled "no pain" (marked as distance 0) and "worst imaginable pain" (marked as distance 10). The patient selected a point on the line corresponding to their perceived pain, which was then measured to provide a quantitative score. The standardized VAS method is widely used because it is simple, sensitive, and capable of detecting small changes in pain.

The SuperSMOOTH output consisted of a SMOOTH pulse sequence consisting of N = 6 micro-pulses, separated by t_{ser} = 50 ms, followed by a single ablative MSP pulse (N' = 1) delivered at 50 ms after the last (6th) SMOOTH pulse. This produced a total SuperSMOOTH pulse train duration of t'_s = 350 ms.

We tested various combinations of the SMOOTH mode fluence F_{smooth} and the MSP ablative fluence F_{abl}, resulting in the total SuperSMOOTH fluence $F'_s = F_{smooth} + F_{abl}$. The fluence combinations were chosen such that the final skin temperature increases or ΔT's were approximately the same (See Table 1). This should, in the absence of gate closing, result in approximately the same reported pain, since experiments have shown that the pain perception depends primarily on the final baseline temperature T_s. [9]

The temperature increase, $\Delta T'_s$ was calculated using the experimentally obtained dependence for repetitive Er:YAG laser irradiations with a patterned PS03 handpiece [13]:

$$\Delta T_s = F_S \; x \; A_S \; x \; t_S{}^{K_S} \quad (1)$$

where A_s = 28 and K_s = - 0.43, with the final baseline temperature increase ΔT_s expressed in ^{0}C, the cumulative sequence fluence F_s expressed in J/cm^2, and the effective sequence duration t_S expressed in milliseconds.

In this study [13], it was also found that the pain threshold depends primarily on the baseline temperature increase (ΔTs), rather than on short-duration high-temperature peaks. Furthermore, the pain threshold was not found to depend directly on the number of pulses (N) or the effective pulse duration (ts).

It should be noted that the calculated values were additionally verified by comparing the calculations with the skin temperature measurements as obtained during this study using a thermal camera (ThermaCAM P45, manufactured by FLIR Systems, USA).

Table 1: Combinations of different ratios of SMOOTH to ablative MSP pulse fluences within the SuperSMOOTH pulse mode, as used for pain perception testing. The fluence combinations were chosen to result in approximately the same baseline skin temperature increase.

SMOOTH pulse fluence F_{SMOOTH} (J/cm^2)	Ablative MSP pulse fluence F_{abl} (J/cm^2)	Final baseline temperature $\Delta T'_s$ (^{0}C)
5.5	0	21.7
5.5	0.4	21.6
4.8	1.0	21.5
3.6	2.2	21.7
2.8	3.4	21.4
2.6	4.6	21.6

d) Pain measurement experiment 2

In a second experiment, we conducted a single-blinded study involving 9 participants (five females, four males; ages 35-70 years), in which we compared subjective pain perception between SMOOTH and SuperSMOOTH laser modes, both with and without the use of a topical anesthetic.

Measurements were made using a TimeWalker Er:YAG laser system equipped with a PS03X handpiece (spot diameter d' = 7 mm). The system was configured to deliver a SMOOTH pulse sequence consisting of N = 6 micro-pulses, separated by t_{ser} = 50 ms, followed by a single ablative pulse (N' = 1) delivered at 50 ms after the last (6th) SMOOTH pulse. This produced a total SuperSMOOTH pulse train duration of t'_s = 350 ms.

Patients were irradiated on the backs of both of their forearms, with topical anesthesia (20% benzocaine, 6% lidocaine in 4% tetracaine) applied to the left hand, and placebo (Cicabio regenerative cream, Bioderma) to the right hand. Both hands were covered with a foil for about 20 minutes following the applications, in order to ensure blinded conditions.

Pain was assessed using a visual analogue scale (VAS). The SMOOTH mode fluence was the same in both tests, although the cumulative fluence on the skin was higher with SuperSMOOTH mode, due to the additional ablative MSP pulse at the end (Table 2).

Table 2. Parameters used for SuperSMOOTH and SMOOTH testing during Experiment 2.

		SMOOTH pulse	MSP pulse
SuperSMOOTH	Fluence	6 J/cm^2	3.6 J/cm^2
	Number of stacks	1 stack	/
SMOOTH	Fluence	6 J/cm^2	/
	Number of stacks	1 stack	/

III. RESULTS

a) Experiment 1

Table 3 shows measured average temperature increase and VAS pain score for different SuperSMOOTH™ fluence combinations.

Table 3: Experiment 2 revealed reduced VAS pain scores for higher fluences of the final MSP pulse, in spite of approximately the same measured average temperature increase.

"SMOOTH" pulse fluence F_{smooth} (J/cm^2)	Ablative MSP pulse fluence F_{abl} (J/cm^2)	SuperSMOOTH fluence F's (J/cm^2)	Measured ΔT's (^{0}C)	VAS pain score
5.5	0	5.5	19.6	5.3 ± 0.3
5.5	0.4	5.9	17.9	5.6 ± 0.3
4.8	1	5.8	19.7	5.7 ± 0.3
3.6	2.2	5.8	17.0	4.4 ± 0.3
2.8	3.4	6.2	16.8	3.5 ± 0.3
2.6	4.6	7.2	17.3	3.8 ± 0.3

The dependence of the results on the ablative MSP fluence can be more clearly seen in Fig. 5 below.

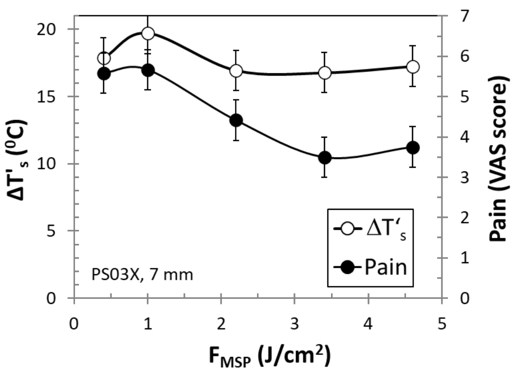

Figure 5: Influence of the fluence (FMSP) of the final ablative MSP pulse on the final skin temperature increase, DT's and perceived pain (i.e., VAS score), following SuperSMOOTH irradiation. While DT's remains approximately constant across tested conditions, increasing the MSP fluence results in a significant reduction in perceived pain.

Note that since Figs 5 and 6 show results for the SuperSMOOTH's 7-pulse sequence (with t_s' = 350 ms), the data for F_{MSP} = 0 J/cm² is not shown, since when F_{MSP} = 0 J/cm², the final, 7th pulse is missing, and the sequence becomes a standard 6-pulse SMOOTH sequence with t_s = 300 ms.

As can be seen from Fig. 5, while the final temperature increase, $\Delta T'_s$ was approximately the same for all tested non-zero fluences of the ablative MSP pulse ($\Delta T'_s = 17.7 \pm 1.1\ ^0C$), the pain score for the same temperature increase was substantially lower when the skin-heating sequence ended with an ablative MSP pulse. This pain reduction effect can be seen also in Fig. 6, which depicts the dependence of the pain ratio r on the fluence of the MSP pulse, representing the ratio of the pain to temperature increase, r = VAS/ $\Delta T'_s$.

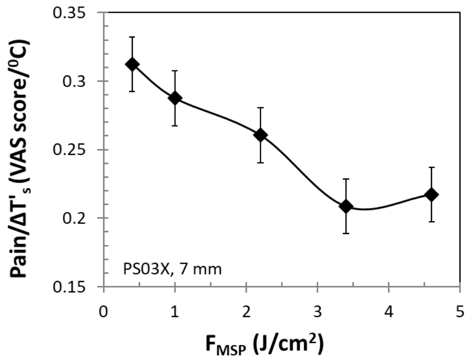

Figure 6: Dependence of the ratio r = VAS/ DT's during SuperSMOOTH treatments, on the fluence of the final ablative MSP pulse. A lower ratio indicates reduced pain perception relative to thermal load. The results demonstrate a substantial decrease in perceived pain when the thermal stimulus is immediately followed by a non-painful ablative stimulus.

As can be concluded from Fig. 6, in comparison to the standard SMOOTH modality, the SuperSMOOTH modality reduces the pain ratio by about 30%.

b) Experiment 2

Average measured temperatures and VAS scores as obtained in Experiment 2 are presented in Table 4.

Table 4. Measured skin temperature and resulting perceived pain (VAS) for SuperSMOOTH and SMOOTH treatments, depending on whether or not a topical anesthesia was applied.

	With anesthesia		Placebo	
	SuperSMOOTH	SMOOTH	SuperSMOOTH	SMOOTH
VAS	5.4±1.0	5.0±1.0	6.3±1.2	6.4±1.2
ΔT (⁰C)	21	14	21	14
VAS /ΔT	0.26±0.05	0.36±0.07	0.30±0.06	0.46±0.09

The difference in the pain ratio r = VAS/ $\Delta T'_s$, between the standard SMOOTH and SuperSMOOTH treatments is presented in Fig. 7 below.

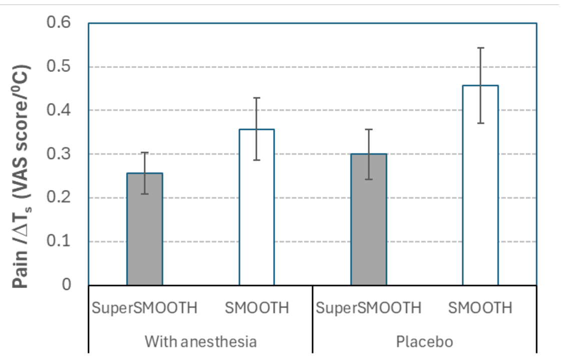

Figure 7: Comparison of the pain ratio (r = VAS / ΔT's) for SMOOTH and SuperSMOOTH treatments, with and without topical anesthesia. SuperSMOOTH demonstrates approximately the same perceived pain compared with SMOOTH alone, despite producing a significantly higher temperature increase. This effect exceeds the effect of topical anesthesia applied to either modality under the tested conditions.

On average, the observed reduction of the pain ratio when comparing a SuperSMOOTH pulse to a SMOOTH pulse (with an equivalent fluence corresponding to the non-ablative portion of the SuperSMOOTH pulse, see Table 2) is approximately 30% (34% without anesthesia; 28% with anesthesia), in agreement with the results obtained in Experiment 1. This effect exceeds the reduction observed with topical anesthesia in this experimental setting, which lowers the pain ratio by only about 28% for SMOOTH and by 15% for SuperSMOOTH modalities. When combined with topical anesthesia, the SuperSMOOTH modality results in an overall reduction in the pain ratio of approximately 44%, compared to the pain ratio experienced with SMOOTH pulse in the absence of anesthesia.

IV. DISCUSSION

The SuperSMOOTH™ modality represents a novel approach to Er:YAG laser treatments by integrating non-ablative and ablative effects within a single pulse sequence. This design enables simultaneous targeting of multiple skin layers, combining deep dermal thermal stimulation with controlled superficial ablation in one treatment step.

From a procedural standpoint, this integration simplifies treatment workflows by eliminating the need for sequential modality switching and repeated irradiation of the same area. As a result, treatment time is reduced and thermal energy is utilized more efficiently, minimizing heat dissipation between steps. In addition, the presence of a visible ablative footprint provides real-time visual feedback to the practitioner, improving control over treatment coverage and handpiece movement—an advantage not available in purely non-ablative modalities.

The results of the present pilot studies indicate that the SuperSMOOTH modality is associated with a consistent reduction in perceived pain compared to conventional SMOOTH treatments. Despite comparable final skin temperature increases, the addition of a terminal ablative pulse led to an approximately 30% reduction in pain perception Importantly, the observed reduction in pain perception was greater than that achieved with topical anesthesia under the tested conditions. This suggests that the SuperSMOOTH modality may allow the use of higher or more clinically effective treatment parameters without increasing patient discomfort. However, given the limited sample size of the present studies, these findings should be interpreted as preliminary until confirmed in larger, controlled clinical trials.

SuperSMOOTH represents a novel aesthetic treatment modality with clinical studies confirming it to be safe and effective, improving multiple skin characteristics. In a prospective, IRB-approved case series conducted by Robert Weiss [15], 27 patients underwent three SuperSMOOTH treatment sessions at one-month intervals using standardized treatment parameters. The procedure duration was relatively short (approximately 7–10 minutes), enabling high patient throughput. Notably, no topical anesthesia was required, thereby simplifying the clinical workflow and reducing the need for consumables. The treatment demonstrated an excellent safety profile, with no reported adverse events. Patients reported visible improvements in skin brightness and overall skin quality. Satisfaction levels were high, with 88% of patients rating their outcomes within the top two categories, and 93% indicating a strong willingness to recommend the treatment.

Similarly, a prospective clinical case series [7] involving participants with mild to moderate signs of aging evaluated the effects of one or two SuperSMOOTH treatment sessions. Aesthetic outcomes were assessed using the Global Aesthetic Improvement Scale (GAIS), along with patient satisfaction and recommendation intent. Improvements were observed across all participants, with the highest mean GAIS scores reported for skin texture, softness, and overall appearance. Nine out of ten participants were satisfied or very satisfied with the results, while one reported a neutral outcome; all participants indicated they would recommend the treatment. No adverse events beyond expected transient erythema and mild peeling were observed. Treatments were well tolerated without the use of anesthesia and were associated with minimal downtime.

These characteristics position SuperSMOOTH as an independent treatment modality capable of delivering fast, effective, and well-tolerated skin rejuvenation treatments, and as well as an enabling technology within multi-wavelength protocols, such as the four-step Fotona4D® procedure [8–12]: (i) an Er:YAG intraoral SmoothLifting step; (ii) a non-ablative Er:YAG SMOOTH step; iii) a Nd:YAG PIANO step; and (iv) an Er:YAG SupERficial step (see Fig. 8). The SuperSMOOTH mode enables two of the Er:YAG steps to be performed simultaneously, making this multi-wavelength treatment shorter and more effective.

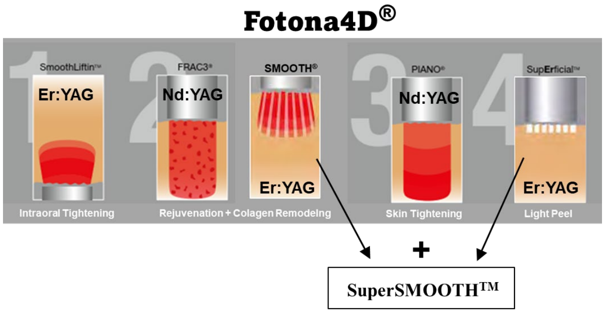

Figure 8: Schematic representation of the Fotona4D® multi-step protocol: (1) Er:YAG intraoral SmoothLifting; (2) non-ablative Er:YAG SMOOTH; (3) Nd:YAG PIANO; and (4) Er:YAG SupERficial. The SuperSMOOTH™ modality enables the combination of two Er:YAG steps into a single treatment pass, improving procedural speed and efficiency. Depending on the clinical indication, step (2) may also include Nd:YAG FRAC3®.

V. CONCLUSIONS

SuperSMOOTH™ represents an important advancement in Er:YAG laser technology by enabling the simultaneous delivery of non-ablative and ablative effects within a single pulse sequence.

While it enhances established multi-step, multi-wavelength treatments such as Fotona4D® by reducing treatment time and improving efficiency, its true clinical value lies in its versatility as a standalone treatment modality.

Key advantages include: i) simultaneous multi-layer tissue targeting; ii) reduced treatment complexity and duration; iii) improved laser energy utilization; iv) visual real-time feedback.

Additionally, the results of the present pilot study indicate that the SuperSMOOTH modality is associated with a consistent reduction in perceived pain compared to conventional purely non-ablative SMOOTH treatments. This effect is consistent with the proposed mechanism based on the gate control theory of pain, whereby the activation of faster-conducting mechanoreceptive nerve fibers modulates and inhibits nociceptive signaling from thermally stimulated tissues.

The usefulness of the reduced pain perception effect as observed in this study is not so much in potentially enabling more comfortable treatments but in enabling the use of clinically effective treatment parameters without increasing the patient's discomfort.

ACKNOWLEDGEMENTS

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