Lasers in Dental Science
https://doi.org/10.1007/s41547-017-0019-7

ORIGINAL ARTICLE

Minimally invasive erbium flap (MINIE^{TM} flap)—a retrospective surgical treatment for chronic periodontitis

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Received: 6 April 2017 / Accepted: 21 December 2017

Abstract

This clinical retrospective split-mouth study was designed to evaluate the efficacy of two (FDA approved) erbium laser wavelengths in a minimally invasive flapped approach for the treatment of generalized chronic periodontitis. Twenty-eight (28) patients diagnosed with generalized chronic periodontitis with pocket depths ranging from 4 to 9 mm had 551 posterior teeth surgically treated in a minimally invasive manner and were followed over 6 months. Minimally invasive erbium (MINIE) flaps were performed in all four posterior sextants (distal of cuspid to distal of second molar) in a traditional split-mouth design. Mean baseline probings were 5.4 mm. Patients were randomly assigned to Laser 1 (Er:YAG, Erbium doped yttrium, aluminium, garnet, 2940 nm or Laser 2 (Er, Cr:YSGG, Erbium, chromium doped yttrium, scandium, gallium, garnet, 2780 nm) in the first appointment. The alternate laser wavelength was used in the second appointment. Pre-surgical examination for pocket depth (PD), recession (RC), and clinical attachment levels (CAL) was performed and then repeated 6 months post-surgery. Patients with history of traditional flap surgery (> 5 years ago) completed a visual acuity test (VAT) describing their surgical experience compared to the conventional approach. The results showed statistically significant improvements in PD (1.43 mm) and reduction in CAL (1.41 mm), whereas the change in RC (0.01 mm) was not statistically significant. Clinical improvements of PD and CAL in this study are consistent with the range reported in previous landmark papers implementing a modified Widman flap (MWF) or osseous surgery (OS). The difference compared to traditional procedures was that there was no statistically significant change in RC over 6 months. The patients' experience was much improved compared to traditional flap surgery [1, 2].

Keywords Periodontal flap surgery · Periodontal disease · Chronic periodontitis

Introduction

Periodontal disease is a biofilm-initiated inflammatory disease that is easily diagnosed and treated, and yet, its incidence is not decreasing. Disease prevalence increases with age, showing a peak incidence at 38 years of age [3]. The host's inflammatory response to biofilm is responsible for the pathogenesis of periodontal disease culminating in hard and soft tissue resorption, gingival recession, root exposure, dentinal sensitivity, dark triangles, and eventual tooth loss [4].

Periodontal flap therapy has proven to be successful in the short (< 6 months), intermediate (2–4 years) [2], and long terms (5+ years), but leaves the patient with undesirable side effects of gingival recession, root sensitivity, open embrasures, and poor aesthetics. The average tooth loss per year with surgical intervention is reported to be 0.05 teeth/year [1], in comparison to 0.6 teeth/year in untreated patients [5]. These statistics clearly demonstrate the benefit of surgical treatment over no treatment in keeping one's teeth.

A closed, flapless approach to instrumentation has variable and inconsistent success in removing local noxious factors and is never completely able to remove factors subgingivally beyond 4 mm [6]. These inefficiencies are exaggerated in multi-rooted teeth with furcations compared to single-rooted teeth [7–9]. The verification of complete calculus removal can only be accomplished by direct visualization, which is inadequate with a closed flapless approach [10].

Periodontal pathogens are able to infiltrate the inner sulcular tissues from the local accretions on the adjacent root surfaces [11]. Surgical curettage studies designed to eliminate

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Published online: 29 January 2018

the inner granulomatous tissues, much like the Modified Widman Flap (MWF's) initial incision, have been undertaken in the past to treat the inner lining [12]. With over 1000 identified microbes in the oral cavity including bacteria, viruses, fungi, and parasites, a mechanical incision with a blade would be, at best, an imprecise method of inner lining removal. A narrow spectrum of antibiotics would also not be a feasible option to effectively deal with this sulcular microbial infiltration, especially with the widespread resistance to antibiotics looming.

Finally, the problem of dimensional limitations of surgical equipment used today still remains (i.e., dental drills, blades, mechanical instruments). Traditional osseous surgery involving one isolated interproximal periodontal pocket necessitates the need to elevate the whole sextant. This allows for safe and efficacious curettage, root instrumentation, and osseous adjustment. Cortellini [13] and Cristiano and Wikesjo [14] have shown that a minimally invasive surgical treatment (MIST) and modified-MIST (M-MIST) surgeries improve clot stability resulting in an expedited repopulation of fibroblasts, leading to regeneration of connective tissue which is the precursor to osseous regeneration.

Numerous studies have postulated alternatives to traditional surgical therapy, for a more patient-friendly resolution of chronic periodontal disease. One of the earliest wavelengths, CO2 laser (10,600 nm), adapted from medicine as an adjunct to flap therapy, was shown to have improved long-term stability of CAL, pocket depth (PD), and lack of progression of recession (RC) from baseline, compared to classically implemented treatments of osseous surgery (OS), MWF, and flap curettage [15].

The most promising laser wavelengths on the market for the complicated hard and soft tissue periodontal pocket environment are the erbium family [16, 17]. The absorption spectrum of erbium lasers in water is superior to any other lasers' wavelength. Their capability to effectively ablate both soft and hard tissues without scatter and transmission into deeper layers is their true advantage [18]. Recent comparative studies implementing both the Er:YAG and Er,Cr:YSGG lasers have shown inconclusive and varied results [19]. Consequently, there are no standardized or consistent treatments supported by the scientific literature. This paper aims to describe a new surgical approach to address all previous success-limiting factors. A new minimally invasive erbium (MINIE^{TM}) laser flap procedure will be discussed, which is based on the gold standard of osseous flap surgery, while maintaining a minimally invasive approach, implementing two FDA-approved erbium laser wavelengths.

Methodology

All patients were referred to the same periodontics facility, for the treatment of the generalized chronic periodontal disease. The sample data was collected from January to November 2015; a periodontal exam including PD, RC, and CAL measurements was completed by a single periodontist. Patients who suffered from diabetes, other health issues, and smokers were NOT excluded. No patients had been treated with antibiotics or anti-inflammatories dating back 12 months prior to surgery. All patients underwent full-mouth debridement with local anesthetic (initial therapy) in two sessions of 60 min, with a hygienist. Four weeks after the initial therapy, the subjects were re-evaluated by the same periodontist. If the patient was a candidate for full-mouth periodontal treatment with surgical pocket elimination (i.e., > 30% pockets of 5+ mm in posterior sites and within the range of 5–12 mm PD), they were then scheduled for two surgical appointments set 1–2 months apart. A total of 28 patients (12 male and 16 female) qualified for posterior sextants' flap therapy, with an average age of 55.6 years (women 55.7 and men 55.4 years). All were compliant with surgical appointments within the allotted 1–2 months and the 6-month post-surgical re-evaluation. Out of the 28 patients, 10 were past smokers, 4 presently smoked, 4 had medical history significant for hypertension, one had a cancer history, and one suffered with controlled type II diabetes. The only exclusion criterion was patients who had received antibiotics and anti-inflammatory medications. From these 28 patients, a total of 551 posterior teeth, with PDs ranging from 4 to 10 mm, were sequentially treated with identical protocols using Laser 1 (Er:YAG, 2940 nm, Fotona Lightwalker, *Ljubljana, Slovenia*) alternating with the Laser 2 (Er,Cr:YSGG, 2780 nm, Waterlase iPlus, *Biolase, Irvine, California*) on the contralateral side, respectively, for the treatment of generalized chronic periodontal disease (American Academy of Periodontology classification).

Patients were treated in a split-mouth fashion: the right posterior sextants (03 and 08 together) on day 1 and the left posterior sextants (05 and 06 together) on day 2, or visa versa. Patients were scheduled for the first surgery with either Laser 1 or Laser 2. Upon booking the second surgery, the alternate wavelength was used to complete treatment on the remainder of the mouth. The procedures were completed within the scheduled time of 2.5 hrs for two sextants (actual treatment time 60 min/sextant). If any clinical mobility was detected, extra-coronal buccal splinting with composite resin was performed on the day of surgery. Following each surgery, a 1-week and 3-week post-operative follow-up appointments were scheduled. The final evaluation was done by the same periodontist at 6 months post-operatively. After 6 months, the patient was returned to a hygiene schedule alternating with the referring dental office and the periodontal office.

The surgical procedure is detailed as follows:

a) Step 1: outer flap gingivoplasty and de-epithelialization, using chiseled sapphire tip (Figs. 1a and 2a)

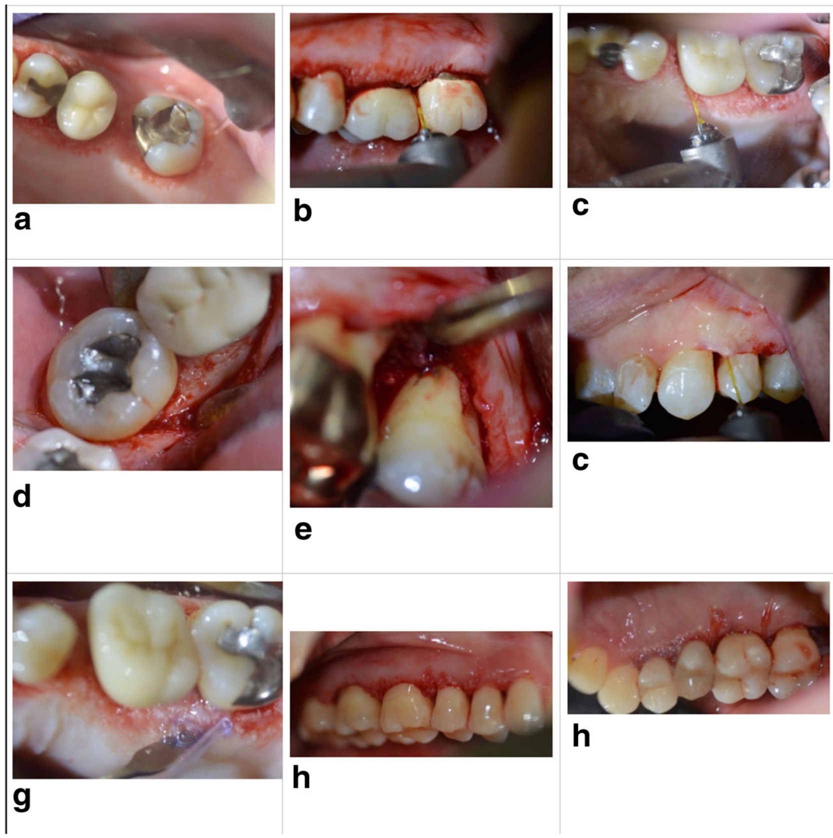

Fig. 1 Surgical procedure

b) Step 2: inner flap degranulation and de-epithelialization, using gradual circumferential troughing action starting from the occlusal aspect, ablating the inner flap's epithelial layers until touching coronal aspects of the alveolar bone, at which point a slight pull back action along dentinal surface using conical sapphire tip or quartz tip.

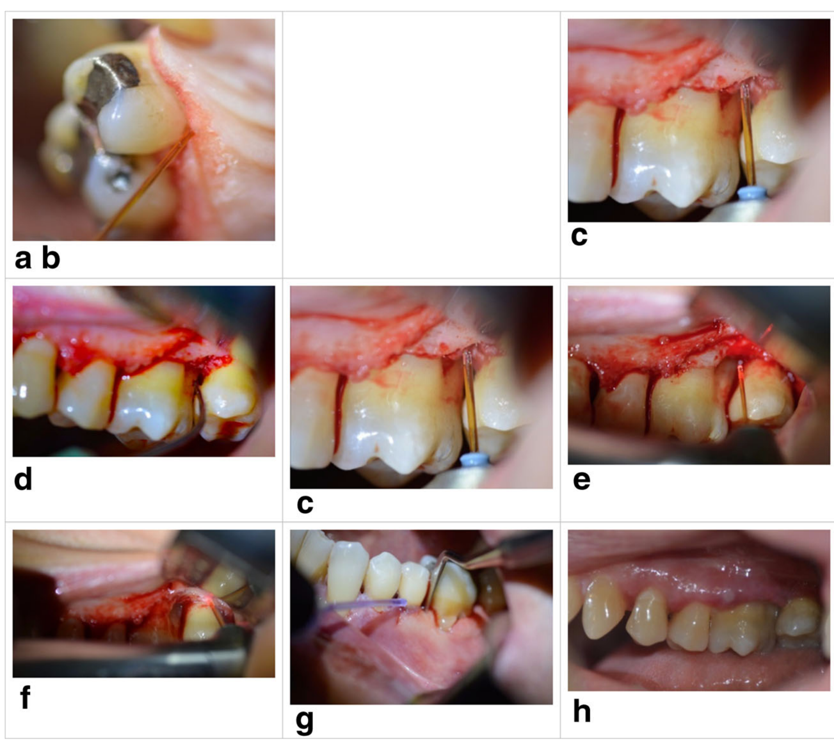

Fig. 2 Surgical procedure

The interproximal papillae were scalloped inferiorly of all granulation tissue and shaped to a "V" shape (Figs. 1b, c, and 2b)

c) Step 3: MINIE flap elevation by reaching apically beyond the alveolar margins on facial and palatal, as needed, to visualize interproximal craters and osseous architecture through 5.5-6× magnification loupes (Univet, Italy). The osseous re-contouring was done with the same settings as above, while visualizing the whole root surface up to the alveolar margins; sharp craters of the alveolar margins not conducive to the flap's passive repositioning were plastied and eliminated (Figs. 1d, e, and 2c)
d) Step 4: ultrasonic and hand instrumentation removing hard calcified deposits visible to the eye (Figs. 1e and 2d)
e) Step 5: smear layer removal, by visualization, is possible by access to the furcations, grooves, concavities, and CEJ margins of the remaining calculus. The lasers' air/water spray enables better visualization than the ultrasonics, as well as easier access to the areas where rigid mechanical instrumentation does not reach. The newly cleaned dentinal root surfaces are concurrently finely etched (Figs. 1f and 2e).
f) Step 6: once the granulation tissue is removed, overt oozing stops and only minor bleeding is present. Following flap repositioning and external pressure, a natural clot forms. One minute later, cyanoacrylate (Figs. 1g and 2f) is flowed to approximate tissue surfaces against the tooth. The interproximal clot prevents apical flow of cyanoacrylate in between the flap, and the tissue glue sets via exothermic reaction and moisture. Only in one case, 4–0 gut sutures needed to be placed for proper flap adaptation, due to the extensiveness of flap elevation for access (Figs. 1h and 2h).
g) Step 7: post-operative instructions included no brushing or flossing for 1 week in surgical sites, chlorhexidine rinse for maintenance of plaque levels, 1st week postop, cyanoacrylate removal, and maturation of clot visualized. Tooth brushing with proxi-brush interproximally accessing from the palatal or lingual aspects to massage and mold the soft tissue architecture interproximally was demonstrated. At 4 weeks, flossing was resumed, reiteration of oral hygiene at 6 weeks. At 6 months, final reprobing was done.

	Laser 1 (ER:YAG 2940 nm)	Laser 2 (Er,Cr:YSGG 2780 nm)
Step 1	Chiseled sapphire tip 12/1.5–.5 mm 72561, MSP (100 μs pulse duration), 2.25 W, 15 Hz, 150 mJ, 3A/3 W (fluence of 76 J/cm^2)	Sapphire chisel MC3 tip, 2.25 W, 50 Hz, 60%A/65%W, 60 μs pulse duration (fluence 12.5 J/cm^2)
Step 2	Conical sapphire tip 12/1.3–.6 mm 72857 tip MSP, 1.85 W, 15 Hz, 160 mJ, 4°/4 W (fluence 43 J/cm^2)	MZ6 tip 9 mm 1.75 W, 40 Hz, 60%A 65%W, 60 μs pulse duration (fluence 15 J/cm^2)
Step 3	Quartz X-pulse cylindrical conical 600/14 90334 1.50 W, 15 Hz, 100 mJ, 4A/4 W (fluence 35 J/cm$^{2)}$	MZ6 tip 9 mm 1.75 W, 40 Hz, 60%A 65%W, 60 μs pulse duration (fluence 15 J/cm^2)
Step 5	Quartz X-pulse cylindrical conical 600/14 90334 1.50 W, 15 Hz, 100 mJ, 4A/4 W (fluence 35 J/cm$^{2)}$	Quartz RFPT5 1.5 W, 50 Hz, 60%A 65%W, 60 μs pulse duration (fluence 15 J/cm^2)

Statistical analysis

For the purpose of our analysis, the clinical changes in the variables (probing depth PD, gingival recession RC, and clinical attachment levels CAL) were measured 6 months after surgical therapy.

Results

The clinical parameters measured were the changes in PD, RC, and CAL from post-initial therapy to the 6-month examination. Twenty-eight patients completed the 6-month follow-up and were included in the analysis. Six PD measurements per tooth were averaged to one data point, as were the RC and CAL readings. The PD improvement of each tooth was the "change" calculated by taking the average of the difference between post-surgery and post-initial therapy measurements for each of PD, RC, and CAL (Table 1). The data is presented as a mean +/− standard deviation (SD). Within-group comparisons were determined using the Wilcoxon and Mann-Whitney *U* tests.

Table 1 summarizes average change in PD, CAL, RC +/− SD.

Table 2 shows *p* values and confidence intervals (CI) for true means where PD and CAL show statistical significance ($p < 2.2e\text{-}16$), while recession RC shows no statistical difference from before and after surgery, irrelevant of laser used ($p = 0.053$).

Table 1 Average changes (mm) in PD, RC, and CAL after 6 months, compared to post-initial therapy, stratified by side and Laser

		Total	Laser 1	Laser 2
PD	Right	− 1.39 +/− 1.1	− 1.55 +/− 1.17	− 1.40 +/− 1.04
	Left	− 1.47 +/− 1.1	− 1.4 +/− 1.02	− 1.37 +/− 1.19
RC	Right	0.01 +/− 0.28	0.08 +/− 0.24	− 0.05 +/− 0.31
	Left	0.02 +/− 0.25	− 0.02 +/− 0.30	0.06 +/− 0.17
CAL	Right	− 1.45 +/− 1.09	− 1.46 +/− 1.17	− 1.45 +/− 1.01
	Left	− 1.37 +/− 1.08	− 1.42 +/− 1.03	− 1.3 +/− 1.14

The null hypothesis of the study is that there is no difference in surgical treatment of right vs. left sides. At baseline (post-initial therapy), there were no statistically significant differences between the two treatment groups (Laser 1 and Laser 2) in any of the recorded parameters (PD, RC, CAL). Table 1 shows the average change in millimeters in PD, RC, and CAL. Table 2 summarizes significant differences in PD and CAL by showing *p*-values < 0.05 at 95% CI (confidence intervals). RC shows no statistical difference (*p* value > 0.05) from before and after surgery irrespective of laser used. Table 3 shows no significant differences attributable to either erbium laser wavelength is used, or which side of the mouth is treated. There is significant improvement in PDs and CAL, while RC is, in essence, unchanged from pre-surgical levels. This correlates to the visual acuity test (VAT) survey from the patient's perspective that bleeding and post-operative pain are minimal; root sensitivity and food impaction are also minimal compared to traditional flap surgery which 9/28 patients had experienced in the past. Surgical healing was uneventful in all cases.

To account for the non-normality of the overall data, a Mann-Whitney *U* test was used to test whether there was a significant overall difference between Δ Laser 1 vs. Δ Laser 2. The 95% confidence interval for Δ′ refers to the estimated median. A *p* value ≥ 0.05 indicates no significant difference.

VAT survey results

Of the patients who had previous traditional pocket surgery (total 9):

6 (67%) experienced less pain than traditional flap surgery

6 (67%) experienced less root sensitivity than traditional flap surgery

6 (67%) had less food impaction than traditional flap surgery

8 (89%) had less post-surgical bleeding vs. traditional flap surgery

Our study clearly indicates that regardless of laser wavelength used, both erbium lasers have shown a statistically significant reduction in PD and CAL gain, with no effect on RC. There was also no statistically significant difference between the Er:YAG and the Er,Cr:YSGG wavelength with respect to PD and CAL gain or RC change, nor was the right vs. left-sided treatment statistically different.

Table 2 Average change in PD, RC, and CAL over 6 months

	Total change (mm)	*p* value	95% CI
PD	− 1.43 +/− 1.1	*p* < 2.2e-16	(− 1.49, − 1.33)
RC	0.01 +/− 0.27	0.053	(0, 0.16)
CAL	− 1.41 +/− 1.09	*p* < 2.2e-16	(− 1.49, − 1.32)

Table 3 Summary of the three parameters measured at different significance levels for the right vs. left sides, for Laser1/Laser2

	Laser	Side	*p* value	95% CI for change
PD	*p* = 0.19	*p* = 0.07	0.56	(− 0.17, 0.17)
RC	*p* = 0.26	*p* = 0.81	0.44	(− 00002, 0.00006)
CAL	*p* = 0.35	*p* = 0.07	0.68	(− 0.17, 0.17)

Discussion

Minimally invasive surgical techniques have recently surfaced as a novel approach to reducing surgical trauma and post-operative discomfort, yet allowing surgical access to furcations, infrabony defects, and developmental grooves. These techniques show a clear clinical advantage with improved PD and CAL gains, while providing ample access to the surgical sites [20–22]. We know that alveolar bone, once exposed to the dental drill, will continue to remodel, further undermining the newly created "positive architecture." Alveolar resorption will occur at different rates within the same mouth, and a relationship exists between resorption rate and initial bone density prior to tooth extraction [23]. Furthermore, the atrophy-related remodeling process commences earlier and progresses further in molar sites, compared to anterior teeth [24]. Even after remodeling, trabecular organization is more haphazard in the posterior maxilla, compared to other sites [25]. Our goal of creating a positive architecture necessitates access to the alveolar margin for plasty. This has stimulated a search for a more minimally invasive alternative to the full thickness flap [26–28]. Eriksson et al. demonstrated that a dental drill at 400,000 rpm can kill osteoblasts at 47'C and at 56'C denatures alveolar proteins [29].

A recent flapless approach to periodontal treatment with the Er:YAG laser [30] showed a statistically significant improvement in periodontal probing and CAL compared to the ultrasonic scaler at 2-year follow-up, especially in moderate and deep pockets. These results appear to be superior to those of the traditional flap therapies previously proposed [31]. Similarly, Gaspric et al. showed the same improvement over 5 years with single-rooted teeth in PD reduction and CAL gains with an Er:YAG laser using similar parameters to our study, compared to MWF [32]. Similarly, Sanchez [33] found that Er:YAG at 1.6 W was beneficial for moderate chronic periodontitis over 5 years vs. traditional non-surgical treatment.

Access to the deepest pockets in multi-rooted teeth is challenging even in the most experienced hands, whether flapless surgery is implemented or not. Full thickness flaps allow better visual access to posterior teeth. The Gaspric [32] and Ting [34] studies showed benefit at 1.0–1.5 W, in vitro on flatter roots of anterior teeth. Clinically and practically, periodontal pocketing studies must address the posterior teeth in view of their complicated root anatomy because our mechanical instruments will not fit every nuance of the molar anatomy successfully. The advantage of the flexible quartz tips, which both lasers implement, is their extensive reach and access capability. Rigid burrs, ultrasonics, piezoelectrics, and curettes cannot provide similar access, even after full-thickness flap visual access. Regeneration of periodontal tissues without bone grafting materials or growth factors was demonstrated following erbium laser flap surgery in dogs [35]. In micro computerized tomography scans, there was evidence of new bone and connective tissue (CT), cementum and periodontal ligament (PDL) attachment at the 12-week period post-surgery, compared to only scaling and root planing in furcation sites. Miller's prognostic indicators need to be readdressed in light of the results of these recent erbium laser studies. He stated that "any molar with a residual PD < 5 mm had a higher probability of being retained for at least 15 years" [36].

The removal of inner epithelial lining in the second step of MINIE flap therapy enables the removal of all the pro-inflammatory cells and the microbial load locally. The whole pocket is decontaminated, whether it is *P gingivalis (Pg)* or Aggregatibacter actinomycetemcomitans *(Aa).* At a minimal setting of 0.3 J/cm^2 and higher [37], the granulation tissue is, furthermore, eliminated. The advantage here is that the erbium wavelengths are not selective in ablation of particular chromophores (melanin and hemoglobin) of microbes, as are the diodes, CO2 or Nd:YAG lasers. Due to its preferential selection of the water chromophore, it provides photoablation to all water-containing organic tissues, often contaminated with Aa, which is known to be found in plaques around the heart [38]. Lipopolysaccarides (LPS) on the cell surface of gram negative bacteria have been acknowledged to play a role in host macrophage activation and toxic effects on the local host's sulcular environment. The Er:YAG wavelength at 300 mJ/cm^2 energy output (100 mJ, 15 Hz) was found to remove 83.1% of LPS after its application to root surfaces [39]. In fact, Ishikawa suggested the possibility of granulation tissue removal by the Er:YAG laser during periodontal flap surgery, thereby removing a large variety of gram negative anaerobic bacteria [40]. Kreisler demonstrated the high bactericidal potential, in vitro, of Er:YAG laser on titanium implants with different surface characteristics [41]. Lopes et al. proved that there was a definitive reduction in the key periodontopathic bacteria counts in the soft tissue lining of the pocket with laser application. He also proved that bacterial toxins on the root's cementum are removed, leaving no smear layer at only 1.0 W of power output (12.9 J/cm^2) [42]. In the era of pandemic antibiotic resistance, this is very helpful from a clinical standpoint, as the erbium wavelengths provide us with superior localized antimicrobial potential without the usage of antibiotics [43].

Calculus removal

Traditional root instrumentation leaves soft tissue remnants and biofilm, while there is accumulating evidence that the erbium laser wavelengths do not. The erbium laser's output energy can be precisely controlled on the machine to target the water-containing tissues and chromophores. This output energy is not only carried in the water spray but also, coincidentally, provides target tissue cooling. Unlike diodes, Nd:YAG or CO2 lasers, the organic materials of the target hard and soft tissues are safely protected from thermal side effects [44].

When studying different parameters and settings, Igarashi found that output energy had a much stronger effect on the depth and volume of ablation, when compared to the repetition rate [45]. He found that 120 mJ energy exclusively removed the demineralized tissue providing a more flattened surface, when compared to the higher energy outputs. This was also confirmed by Hakki [46], who showed that long pulses resulted in rougher dentinal surfaces vs. short pulses. These energy levels and pulse intervals were all implemented in our study's design and parameters.

Folwaczny studied differing angles of laser tip applications [47]. He implemented a laser tip angle at 20–30′ to the root surface in non-contact mode for 40–60 s per root and measured root roughness with various laser parameters, compared to the controls. He found no significant difference between the mean roughness values of the root surfaces (0.52–0.81 μm) utilizing laser irradiation, compared to untreated control samples (0.53 μm), which were instrumented with curettes. In another paper, Keller [48] showed the Er:YAG dentinal roughness was on average 20–25 μm, which is the average tip width of a hand instrument. In fact, it was shown that Er:YAG laser increases the fibroblastic diffusion process onto the dentinal root surfaces without any thermal damage, while Nd:YAG laser alters the dentin's chemical structure [49]. Cortellini's M-MIST surgical technique also promotes the formation of a fibrin clot onto the root surface if chemotaxis is aided by a biofilm-free dentinal root surface. Ting confirmed that an output power of 1.0–2.0 W with 600-μm fiber tip diameter is optimal for calculus removal with respect to the morphologic changes, without producing visible morphologic alterations on the root surface [34]. Our results also confirmed that in many cases treated, after instrumentation and ultrasonics, remnants of subgingival calculus could still be visually observed after step 3 of MINIE flap therapy. Only after the fourth step of MINIE flap therapy, all calcified deposits were finally removed using these parameters.

Hakki [46] showed that fibroblasts on the roots exposed to Er,Cr:YSGG short pulses were well aligned and healthy. He demonstrated that once this happens, fibroblasts can differentiate into osteoblasts and cementoblasts, compared to the hand instrumentation alone or even with long pulsing. After the seventh day, he showed that root samples where scaler alone or long laser pulses were used, looked histologically similar to each other, and both were completely different from short laser pulses. Schwarz even concluded that the Er:YAG laser "seems to be the alternative instrument for effective calculus removal and creation of a biocompatible surface for new cell or tissue or reattachment" [50].

Er:YAG laser scaling has been suggested as an alternative to conventional scaling, and has been reported to exhibit "high bactericidal properties" [40]. Sasaki showed that the unique water ablative and cooling capability of the erbium wavelengths resulted in the pocket being free of toxic byproducts, such as cyanate (NCO-) and cyanamide (NCN-2) [51]. He also showed that the CO2 laser produced extremely high temperatures due to the lack of cooling to the dentinal root surfaces and could potentially inhibit reattachment and migration of fibroblasts and inhibit the removal of gram negative anaerobic bacteria. This is not the case with the erbium lasers due to the water spray. In fact, Theodoro [44] showed that the Er:YAG laser with water spray decreased the temperature of the root surface by 2.2 °C ± 1.5 °C. This heat diffusion effect depended on the thickness of cementum, the dentinal tubules, the opening diameters of the tubules, calcifications located on the root, as well as the patient's age. In the same study, SEM's showed no residual calculus and absence of smear layer with the Er:YAG laser. Crespi showed in two studies that the Er:YAG laser removed calculus effectively with minimal cementum damage and a significantly higher fibroblastic cell attachment density vs. ultrasonically treated root surfaces [52, 53]. Additionally, de Oliveira showed an equivalent residual root roughness compared to traditional mechanical instrumentation when using Er,Cr:YSGG laser with higher output power and lower Hz without adequate water/air parameters with a 400-μm fiber tip at 45 and 60 degree angles [54]. Thus, even with inappropriate clinical parameters, safety of the erbium laser is no worse than the harm caused by mechanical instrumentation or a dental drill.

Biofilm and smear layer removal

Biofilm is a complicated ecosystem matrix of organic matter with interconnected attachment factors, consisting of bacteria, viruses, fungi, and host factors. This symbiotic complex becomes more resistant to removal, higher temperatures, and acidic pH. The inability to remove biofilm leaves an inadequate dentinal surface onto which local host's fibrin clot cannot attach and mature for regeneration [55].

Smear layer has been reported to be detrimental to periodontal tissue healing by potentially inhibiting or slowing reattachment of cells to the root surface and affecting chemotaxis of regenerative cells [56, 57]. In vitro and in vivo papers have mixed results on the efficacy of smear layer removal, to enhance connective tissue attachments, with EDTA, HTCL, and citric acid application to the root surfaces [58]. In fact, Er:YAG laser and EDTA treated roots show similar micromorphology to each other [59, 60]. Feist et al. analyzed the biocompatibility of root surfaces treated by Er:YAG laser, comparing the adhesion and growth of cultured human gingival fibroblasts on root surfaces treated by Er:YAG laser or curette [61]. The surfaces treated with 60 mJ/pulse of Er:YAG irradiation promoted faster adhesion and growth, compared to surfaces treated with either root planing or a higher energy output of 100 mJ/pulse. Although mechanical debridement removes local factors, the undisturbed biofilm, presence of smear layer, microbial toxins, contaminated cementum, and cellular macerations are still present on the root surface. This must contribute to the lack of stability of strong connective tissue attachment in key periodontal studies in the past.

Decortication

Osteoblasts are derived from the periosteum, endosteum, and undifferentiated pluripotential mesenchymal cells in the bone marrow and are responsible for new bone formation [62]. The benefits of decortication are increased bleeding, access for progenitor cells and blood vessels, interlocking of bone, and spatial relationships of decortications in traditional OS. Prior to lasers, decortication could have only been done mechanically by scalers or dental drills only [63].

Nelson reported that the Er:YAG laser ablated bone effectively with minimal thermal damage to the adjacent tissues. The ability to remove bone incrementally with minimal chemical and morphological changes to the irradiated and surrounding surfaces was demonstrated. A typical irregular pattern, which consisted of biological apatites surrounded by organic matrix, was observed in the irradiated bone and this laser system has been demonstrated to be useful for bone ablation and osseous re-contouring during periodontal surgery. There is also a possibility that the bone is biostimulated after Er:YAG laser irradiation, but further experiments have to be carried out to elucidate the exact mechanism of Er:YAG biostimulation in alveolar bone tissue [64]. Kimura et al. also demonstrated that the Er,Cr:YSGG could cut bone efficiently without damage, thermal overheating, or altering the Ca:P ratio of the remaining bone. Due to its unique emission qualities of the absorption in the hydroxyl group (OH^-) chromophore, and not just the water chromophore alone [65, 66], this remains a benefit in any OS.

Various erbium laser parameters have been studied since the 1990's to elucidate a safe range of operator parameters and settings for clinical benefit and efficacy. What differentiates the erbium lasers from other laser wavelengths is the spray of water creating photo-ablative and photo-acoustic effect which, simultaneously, has been proven to keep the tissues cooled to within 2–3 °C of baseline [67–69]. At 2 W, a temperature increase of only 0.05–2.59 °C in the dental root canals was seen. At 5 W (far above that which is required in any periodontal clinical indication), the temperature increase was only 10 °C, much lower than any dental drill [29].

Conclusions

Within the limitations of this study, the MINIE flap procedure shows stable 6-month results of PD, RC, and CAL for the treatment of generalized chronic periodontitis. This study has great practical and clinical applicability, as patients were not excluded for smoking, diabetes, or other health issues, and all 551 teeth were posterior teeth. Both erbium laser wavelengths 2780 and 2940 nm show improved clinical results and have equivalency at 6 months to traditional periodontal flap surgery in pocket reduction and better attachment gain. Insignificant recession is evident from MINIE flaps compared to traditional periodontal flap surgery. There is less post-operative root sensitivity, compared to traditional periodontal surgery, from the patient perspective. The patient acceptance to the treatment of generalized chronic periodontitis is improved, compared to traditional OS. The erbium family has been FDA approved since 1993 for hard and soft tissue applications in dentistry.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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