Research Article

Assessment of Early Periodontal Tissue Response Following Gingival Depigmentation with 980 nm Diode vs. 2940 nm Er:YAG Lasers

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Abstract

Background: Gingival hyperpigmentation is a common esthetic concern that can adversely affect smile aesthetics and patient confidence. Laser-assisted depigmentation has gained popularity due to improved precision, hemostasis and patient comfort. However, comparative evidence on early periodontal tissue response following different laser wavelengths remains limited. This study was carried out to assess and compare the early periodontal tissue response following gingival depigmentation using a 980 nm diode laser and a 2940 nm Er:YAG laser.

Materials and Methods: A prospective, randomized clinical trial was conducted on 68 patients with physiologic gingival hyperpigmentation. Participants were randomly allocated into two groups: Group A underwent depigmentation using a 980 nm diode laser and Group B using a 2940 nm Er:YAG laser. Early periodontal tissue response was evaluated using a standardized wound healing index at postoperative days 3, 7 and 14. Secondary outcomes included postoperative pain assessed by visual analog scale, gingival inflammation measured using a gingival index, epithelialization status and adverse events. Data were analyzed using appropriate parametric or non-parametric statistical tests such as the independent samples t-test or Mann–Whitney U test for intergroup comparisons. Repeated-measures ANOVA or Friedman test for longitudinal within-group comparisons and chi-square test or Fisher's exact test for categorical variables with significance set at $p < 0.05$.

Results: Both laser modalities achieved effective gingival depigmentation with satisfactory healing. The Er:YAG laser group demonstrated significantly better early wound healing scores at postoperative Day 3 and Day 7 ($p < 0.001$ for both), along with lower postoperative pain scores (Day 1 and Day 3, $p < 0.001$) and reduced gingival inflammation (Day 3, $p < 0.001$; Day 7, $p = 0.01$) compared to the diode laser group. By Day 14, healing outcomes were comparable between the two groups ($p > 0.05$).

Conclusion: Both the 980 nm diode laser and the 2940 nm Er:YAG laser are effective for gingival depigmentation. The Er:YAG laser provides superior early periodontal tissue response, whereas the diode laser remains a reliable and cost-effective alternative. Laser selection should be individualized based on clinical priorities and patient needs.

Keywords: Gingival Depigmentation; Diode Laser; Er:YAG Laser; Periodontal Wound Healing; Esthetic Dentistry

Introduction

Gingival pigmentation is a common esthetic concern characterized by brown to black discoloration of the gingiva, primarily resulting from excessive melanin deposition by melanocytes in the basal and suprabasal epithelial layers [1]. Although

physiologic pigmentation is benign and asymptomatic, increasing esthetic awareness and patient demand particularly in individuals with a high smile line—have led to a growing interest in gingival depigmentation procedures [2,3]. Melanin pigmentation is influenced by genetic factors, ethnicity, smoking habits, systemic conditions and hormonal variations, making its prevalence particularly high in darker-skinned populations [4,5].

Conventional techniques for gingival depigmentation include scalpel surgery, electrosurgery, cryosurgery and chemical cauterization. While these methods can be effective, they are often associated with drawbacks such as intraoperative bleeding, postoperative pain, delayed healing, scarring and recurrence of pigmentation [6–8]. These limitations have accelerated the adoption of laser-assisted depigmentation, which offers improved hemostasis, reduced surgical trauma, enhanced patient comfort and better postoperative healing outcomes [9,10].

Among the various laser systems used in periodontal therapy, diode lasers and erbium lasers have gained particular prominence due to their favorable interaction with oral soft tissues. The 980 nm diode laser is a semiconductor laser with high affinity for pigmented tissues such as melanin and hemoglobin, making it especially suitable for gingival depigmentation procedures [11]. Its advantages include effective coagulation, reduced bleeding and ease of use; however, deeper thermal penetration may increase the risk of collateral tissue damage and delayed epithelial healing if not properly controlled [12].

In contrast, the 2940 nm erbium:yttrium–aluminum–garnet (Er:YAG) laser exhibits strong absorption in water and hydroxyapatite, resulting in precise ablation with minimal thermal diffusion to adjacent tissues [13]. This characteristic enables superficial tissue removal while preserving underlying connective tissue integrity, potentially promoting faster wound healing and reduced inflammatory response [14]. Consequently, Er:YAG lasers have been advocated for minimally invasive periodontal soft-tissue procedures with favorable biological outcomes [15].

Despite the widespread clinical use of both diode and Er:YAG lasers for gingival depigmentation, the existing literature predominantly focuses on esthetic outcomes, patient satisfaction and recurrence rates, with limited emphasis on early periodontal tissue response following laser intervention. Early healing events—such as gingival inflammation, bleeding tendency, epithelial regeneration and patient-reported discomfort—are critical determinants of procedural success and long-term periodontal health, yet remain insufficiently compared between different laser wavelengths [9,10].

Therefore, the present study aims to assess and compare the early periodontal tissue response following gingival depigmentation using a 980 nm diode laser and a 2940 nm Er:YAG laser. By evaluating clinical parameters during the initial healing phase, this study seeks to provide evidence-based guidance for selecting the most biologically favorable laser modality for gingival depigmentation procedures.

Methodology

Study Design and Setting
This prospective, parallel-arm, randomized controlled clinical trial was designed to compare early periodontal tissue response following gingival depigmentation performed using a 980 nm diode laser and a 2940 nm Er:YAG laser. The study was conducted in the Department of Periodontology. The study protocol conformed to the principles of the Declaration of Helsinki and received approval from the Institutional Ethics Committee. All participants provided written informed consent prior to enrolment.

Study Population
Patients seeking esthetic correction for physiologic gingival hyperpigmentation were screened from the outpatient clinic. Eligible participants were adults with clinically evident melanin pigmentation involving the anterior gingiva and a periodontally healthy status Individuals with systemic conditions known to affect wound healing, current or recent tobacco use, pregnancy or lactation, drug-induced gingival alterations, mucosal pathology in the operative field, previous depigmentation procedures in the same area or poor plaque control were excluded from the study [10,11,13,15]. .

Sample Size Calculation
The sample size was calculated to detect a clinically meaningful difference in early periodontal healing outcomes between the two laser modalities. The calculation was based on comparison of two independent groups with a two-sided alpha level of 0.05

and a statistical power of 80%. A moderate standardized effect size (Cohen's d = 0.50) was assumed. This assumption is supported by prior laser-assisted periodontal soft-tissue studies, where moderate effect sizes have been reported for early healing indices and inflammatory parameters following laser interventions and is consistent with methodological recommendations for clinically relevant soft-tissue outcome assessment in periodontal research [16]. Using the formula for comparison of two means:

$$n = \frac{2(Z_{\alpha/2} + Z_{\beta})^2}{d^2}$$

with $Z\alpha/2$ = 1.96, $Z\beta$ = 0.84 and d = 0.50, the calculated minimum sample size was 63 participants. To compensate for potential attrition and non-compliance, the final sample size was rounded up to 68 participants, with 34 subjects allocated to each group.

Recruitment, Randomization and Allocation Concealment
Eligible participants were recruited consecutively until the required sample size was achieved. Randomization was performed in a 1:1 ratio using a computer-generated random sequence prepared by an independent investigator not involved in clinical procedures or outcome assessment. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes that were opened only at the time of intervention.

Blinding
Due to the inherent differences in laser devices and operative techniques, operator blinding was not feasible. However, outcome assessment was performed by a blinded examiner who was unaware of group allocation. Data analysis was carried out on coded datasets to minimize assessor and analytical bias.

Pre-operative Standardization
All participants underwent professional oral prophylaxis one week prior to the depigmentation procedure to eliminate plaque-induced gingival inflammation. Standardized oral hygiene instructions were reinforced and baseline clinical parameters were recorded only after confirmation of gingival health. Pre-operative intraoral photographs were obtained using standardized camera settings, angulation and lighting conditions.

Laser Depigmentation Procedures
Group A: 980 nm Diode Laser
Gingival depigmentation was performed using a 980 nm diode laser delivered through a fiber- optic tip according to the manufacturer's recommendations. After administration of local anesthesia, the initiated fiber tip was applied in a controlled brushing motion over the pigmented gingival epithelium. Tissue ablation was performed in a layer-by-layer manner with intermittent saline-moistened gauze wiping to prevent excessive thermal accumulation and to assess the ablation endpoint. The procedure was continued until complete removal of visible pigmentation was achieved, indicated by a uniform pale pink appearance of the gingival surface with adequate hemostasis [3,10,11,13].

Group B: 2940 nm Er:YAG Laser
In the Er:YAG group, depigmentation was carried out using a 2940 nm Er:YAG laser operating in a short-pulse mode with water spray. Following local anesthesia, superficial scanning strokes were used to ablate the pigmented epithelium. Continuous movement of the handpiece and water irrigation ensured precise tissue removal with minimal thermal diffusion. Ablated tissue was periodically removed using saline-soaked gauze and the procedure was terminated upon complete elimination of pigmentation with preservation of the underlying connective tissue [10,11,13].

Post-operative Care
All participants received standardized post-operative instructions. Analgesics were prescribed on an as-needed basis and chlorhexidine mouth rinse was advised twice daily for one week. Patients were instructed to avoid mechanical trauma, hot or spicy foods and brushing over the surgical site for the first 24 hours, after which gentle oral hygiene was resumed. No periodontal dressing was placed unless clinically indicated [10,11,13].

Outcome Measures Primary Outcome
Early periodontal tissue response was evaluated using a standardized wound healing index assessing parameters such as epithelialization, gingival color, edema, bleeding and patient discomfort at predefined follow-up intervals. These parameters

were assessed according to established periodontal clinical healing evaluation approaches described in laser periodontal therapy studies [10,13,15].

Secondary Outcomes

Secondary outcomes included postoperative pain assessed using a visual analog scale, gingival inflammation assessed using a gingival index, bleeding tendency evaluated through bleeding on probing, clinical epithelialization status and documentation of adverse events such as ulceration, infection, delayed healing or gingival recession. These clinical parameters represent routinely standardized periodontal outcome measures in laser-assisted periodontal and soft-tissue surgical studies [10,11,13].

Follow-up and Documentation

Clinical evaluations were performed at baseline and during early follow-up visits at Day 1, Day 3, Day 7 and Day 14 post-operatively, consistent with established periodontal laser wound-healing assessment protocols described in previous studies [10,13,15]. Standardized intraoral photographs were recorded at each visit to support clinical assessments and documentation.

Statistical Analysis

Data were analyzed using SPSS version 26 (IBM Corp., USA). Normality of data distribution was assessed using the Shapiro–Wilk test prior to analysis. Continuous variables were compared between the two groups using the independent samples t-test when data were normally distributed and the Mann–Whitney U test when normality assumptions were not met. For longitudinal comparisons across follow-up time points, repeated-measures ANOVA was applied for normally distributed data, while the Friedman test was used for non-parametric repeated measurements. Categorical variables were analyzed using the chi-square test or Fisher's exact test as appropriate. Given the randomized study design and the objective of direct comparison between two independent groups, these tests were considered suitable for categorical outcome analysis and regression modeling was not required. A two-sided p-value <0.05 was considered statistically significant.

Results

As shown in Table 1, the baseline demographic and clinical characteristics of participants were comparable between the two groups, indicating effective randomization. The mean age of participants in the diode laser group was 28.6 ± 6.1 years, while that of the Er:YAG laser group was 29.2 ± 5.8 years, with no statistically significant difference (p = 0.68). Gender distribution was also similar between groups (p = 0.80). Baseline gingival health, assessed using the Gingival Index, showed low scores in both groups (0.42 ± 0.18 for diode and 0.45 ± 0.20 for Er:YAG; p = 0.54), confirming the absence of pre-existing inflammation prior to intervention. Baseline pigmentation scores were comparable (2.9 ± 0.3 vs 2.8 ± 0.4; p = 0.36), ensuring uniformity of pigmentation severity across study arms.

Parameter	Diode Laser (N=34)	Er:YAG Laser (N=34)	P-Value
Age (years), mean ± SD	28.6 ± 6.1	29.2 ± 5.8	0.68
Gender (M/F)	14/20	13/21	0.80
Baseline Gingival Index [10,13,15]	0.42 ± 0.18	0.45 ± 0.20	0.54
Baseline Pigmentation score [3,4]	2.9 ± 0.3	2.8 ± 0.4	0.36

Table 1: Baseline demographic and clinical characteristics.

Early periodontal tissue response, assessed using the wound healing index, demonstrated a clear difference between the two laser modalities during the initial postoperative period. As detailed in Table 2 and illustrated in Fig. 1, the Er:YAG laser group exhibited significantly higher healing scores at both Day 3 and Day 7. At Day 3, mean healing scores were 3.2 ± 0.4 in the Er:YAG group compared to 2.6 ± 0.5 in the diode laser group (p < 0.001). This trend persisted at Day 7, with scores of 4.1 ± 0.5 for Er:YAG and 3.5 ± 0.6 for diode laser (p < 0.001), indicating faster epithelialization and reduced inflammatory response in the Er:YAG group.

By Day 14, healing scores improved substantially in both groups, reaching 4.3 ± 0.4 in the diode laser group and 4.4 ± 0.3 in the Er:YAG group, with no statistically significant difference (p = 0.28).
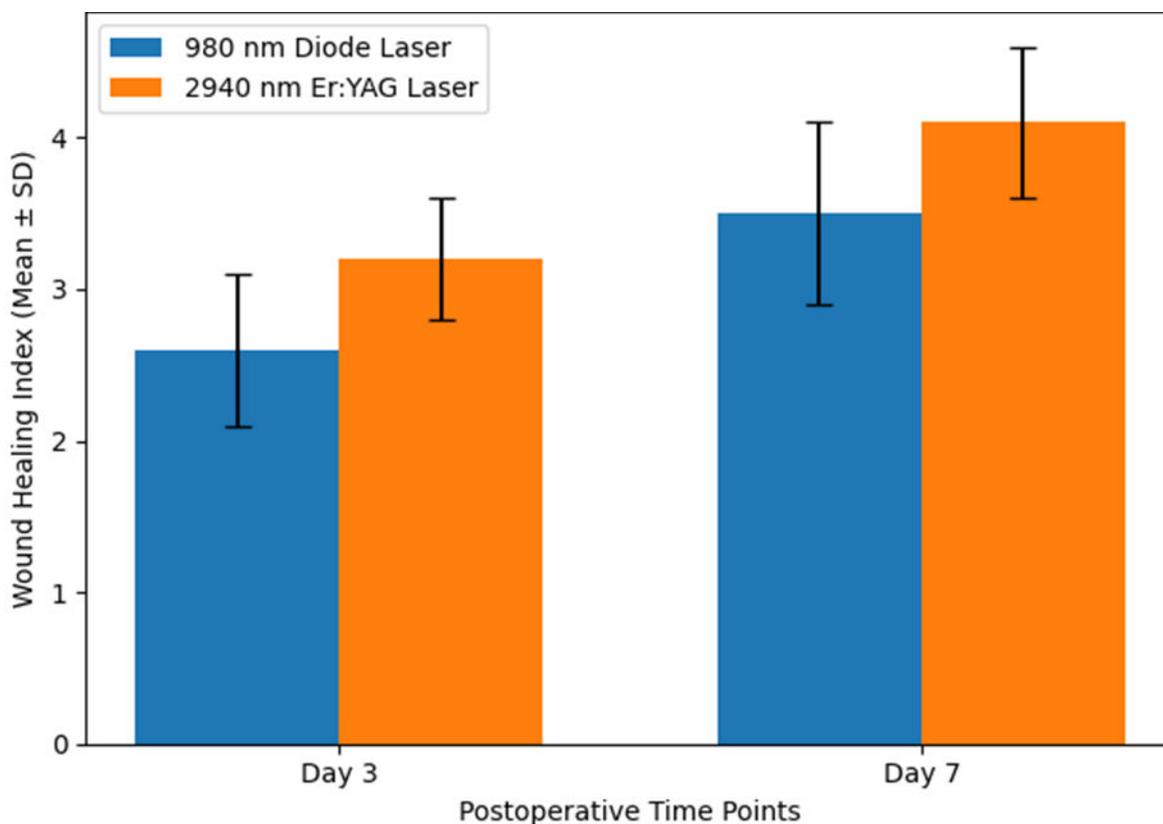
Figure 1: Comparison of early wound healing index scores between 980 nm diode laser and 2940 nm Er:YAG laser groups at Day 3 and Day 7 postoperatively. The Er:YAG group demonstrated significantly higher healing scores at both time points (p < 0.001). Error bars represent standard deviation.

Time Point	Diode Laser (Mean ± SD)	Er:YAG Laser (Mean ± SD)	P-Value†
Day 3	2.6 ± 0.5	3.2 ± 0.4	<0.001*
Day 7	3.5 ± 0.6	4.1 ± 0.5	<0.001*
Day 14	4.3 ± 0.4	4.4 ± 0.3	0.28
* Statistically significant; †Independent samples t-test (Mann–Whitney U test used if normality was violated)			

Table 2: Comparison of wound healing index scores between groups.

Post-operative pain trends, assessed using the Visual Analog Scale, are presented in Table 3 and graphically depicted in Fig. 2. On the first postoperative day, patients treated with the diode laser reported significantly higher pain scores (4.8 ± 1.1) compared to those treated with the Er:YAG laser (3.2 ± 0.9; p < 0.001). A similar pattern was observed on Day 3, with pain scores of 2.9 ± 0.8 in the diode group and 1.8 ± 0.6 in the Er:YAG group (p < 0.001). By Day 7, pain levels had markedly decreased in both groups, with mean VAS scores of 0.8 ±0.4 in the diode group and 0.6 ± 0.3 in the Er:YAG group. The difference at this time point was not statistically significant (p = 0.09), indicating resolution of postoperative discomfort.

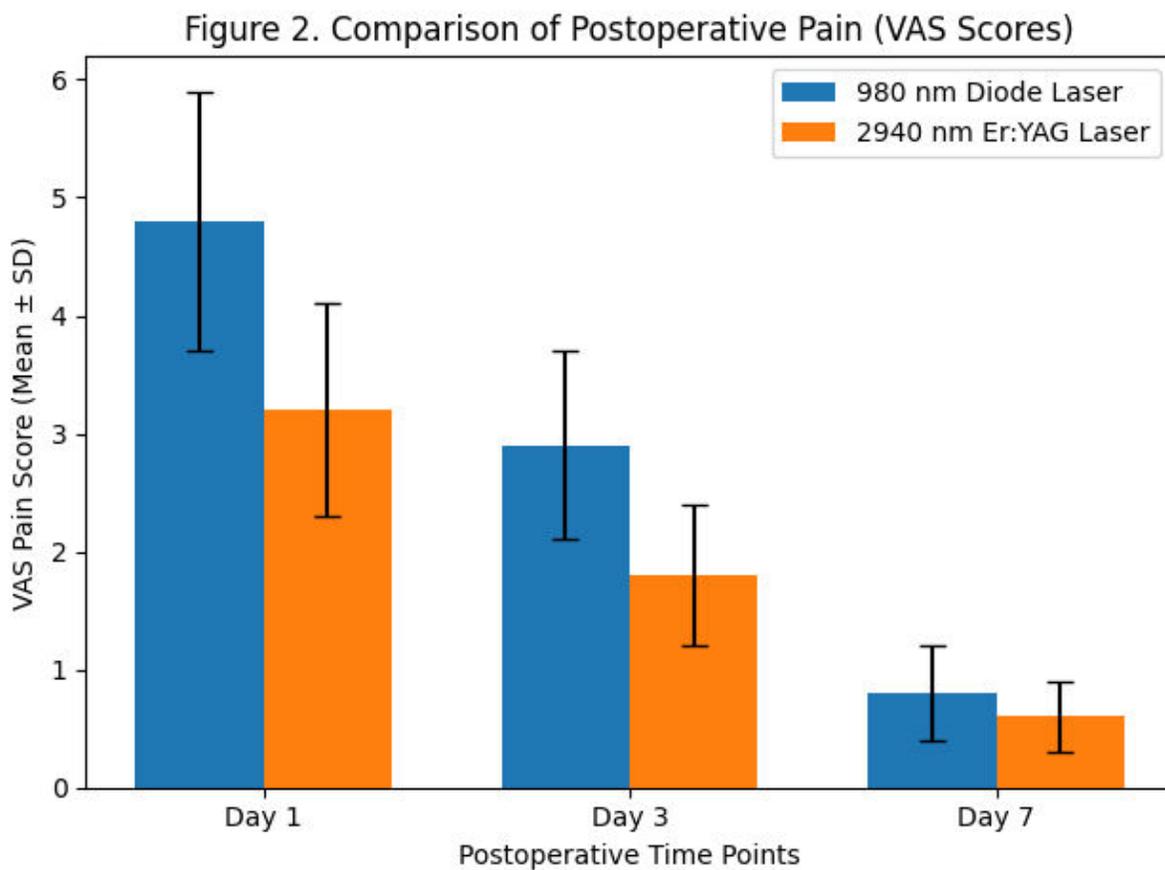| Time Point	Diode Laser (Mean ± SD)	Er:YAG Laser (Mean ± SD)	P-Value†
Day 1	4.8 ± 1.1	3.2 ± 0.9	<0.001*
Day 3	2.9 ± 0.8	1.8 ± 0.6	<0.001*
Day 7	0.8 ± 0.4	0.6 ± 0.3	0.09
* Statistically significant; †Intergroup comparisons were performed using the independent samples t-test (or Mann–Whitney U test when normality assumptions were not met).			

Table 3: Comparison of VAS pain scores.

Figure 2: Comparison of postoperative pain (Visual Analog Scale scores) between 980 nm diode laser and 2940 nm Er:YAG laser groups at Days 1, 3, and 7. Significantly lower pain scores were observed in the Er:YAG group at Days 1 and 3 (p < 0.001), while no significant difference was noted at Day 7 (p = 0.09). Error bars represent standard deviation.

Changes in gingival inflammation over time are summarized in Table 4. Both groups showed a transient increase in Gingival Index scores at Day 3 following the procedure. However, the increase was significantly lower in the Er:YAG group (0.82 ± 0.26) compared to the diode laser group (1.12 ± 0.30; p < 0.001). At Day 7, gingival inflammation continued to decrease in both groups, with scores of 0.68 ± 0.24 in the diode group and 0.52 ± 0.20 in the Er:YAG group (p= 0.01). By Day 14, Gingival Index scores approached baseline values in both groups (0.46 ± 0.19 for diode and 0.43 ± 0.17 for Er:YAG; p = 0.60), indicating resolution of inflammation.

Time Point	Diode Laser (Mean ± SD)	Er:YAG Laser (Mean ± SD)	P-Value†
Baseline	0.42 ± 0.18	0.45 ± 0.20	0.54
Day 3	1.12 ± 0.30	0.82 ± 0.26	<0.001*
Day 7	0.68 ± 0.24	0.52 ± 0.20	0.01*
Day 14	0.46 ± 0.19	0.43 ± 0.17	0.60
* Statistically significant; †Intergroup comparisons at each time point were performed using the independent samples t-test (or Mann–Whitney U test when normality assumptions were not met).			

Table 4: Gingival Index scores at follow-up.

Clinical epithelialization outcomes are presented in Table 5. At Day 7, complete epithelialization was observed in 85.3% of sites treated with the Er:YAG laser, compared to 61.8% of sites treated with the diode laser, a difference that was statistically significant (p = 0.03). This finding corroborates the superior early healing observed in the Er:YAG group. By Day 14, nearly complete epithelialization was noted in both groups, with 97.1% of diode laser sites and 100% of Er:YAG laser sites showing complete epithelial coverage (p = 0.31).

Time Point	Diode Laser N (%)	Er:YAG Laser N (%)	P-Value†
Day 7	21 (61.8%)	29 (85.3%)	0.03*
Day 14	33 (97.1%)	34 (100%)	0.31
Statistically significant; †Proportions were compared using Fisher's exact test.			

Table 5: Proportion of sites with complete epithelialization.

Adverse events were minimal and self-limiting in both groups, as summarized in Table 6. Transient erythema was more frequently observed in the diode laser group (26.5%) compared to the Er:YAG group (8.8%). Similarly, reports of transient burning sensation were higher in the diode group (20.6%) than in the Er:YAG group (5.9%). Delayed healing was observed in 5.9% of diode laser cases, whereas no such events were recorded in the Er:YAG group. Importantly, no cases of infection, scarring or gingival recession were observed in either group during the follow-up period, confirming the overall safety of both laser modalities.

Adverse Event	Diode Laser N (%)	Er:YAG Laser N (%)
Transient erythema	9 (26.5%)	3 (8.8%)
Burning sensation	7 (20.6%)	2 (5.9%)
Delayed healing	2 (5.9%)	0
Infection/scarring	0	0

Table 6: Adverse events.

Discussion

The present randomized clinical trial evaluated and compared the early periodontal tissue response following gingival depigmentation using a 980 nm diode laser and a 2940 nm Er:YAG laser. The findings demonstrate that while both laser systems were effective in achieving satisfactory depigmentation and eventual tissue healing, the Er:YAG laser exhibited superior early healing characteristics, particularly during the first postoperative week. The significantly higher wound healing index scores observed in the Er:YAG laser group at Day 3 and Day 7 indicate faster epithelial regeneration and reduced inflammatory response when compared to the diode laser group. This finding can be attributed to the distinct tissue– laser interaction mechanisms of the two wavelengths. The Er:YAG laser (2940 nm) is highly absorbed by water, resulting in precise superficial ablation with minimal thermal penetration into adjacent tissues [13,16]. This photothermal behavior limits collateral damage to the underlying connective tissue, thereby preserving the biological environment required for rapid epithelial migration and wound maturation.

In contrast, diode lasers operate primarily through photothermal coagulation, with deeper penetration into pigmented tissues such as melanin and hemoglobin [17]. Although this property is advantageous for hemostasis and pigment removal, it may lead to greater thermal diffusion, which can transiently delay epithelialization and intensify early inflammatory response, as reflected by lower healing scores in the diode group during early follow-up [18]. The convergence of healing scores between groups by Day 14 suggests that both laser modalities ultimately support complete periodontal healing, consistent with previous reports that laser-assisted depigmentation procedures achieve favorable long-term tissue outcomes regardless of wavelength [19,20].

Postoperative pain scores were significantly lower in the Er:YAG group during the immediate postoperative period. This observation aligns with earlier studies demonstrating reduced nociceptive stimulation following Er:YAG laser surgery due to minimal heat generation and limited nerve irritation [6,10]. The water-mediated ablation mechanism of the Er:YAG laser reduces protein denaturation and thermal necrosis, which are key contributors to postoperative discomfort. Conversely, higher early pain scores in the diode laser group may be explained by deeper thermal penetration and localized tissue coagulation, which can stimulate inflammatory mediators and nociceptors in the immediate postoperative phase [21,22]. Importantly, pain levels in both groups decreased substantially by Day 7, reinforcing that laser depigmentation is generally well tolerated and associated with minimal prolonged discomfort, as reported in previous clinical studies [23]. The gingival index scores demonstrated a transient postoperative inflammatory response in both groups, with significantly lower scores in the Er:YAG group at Day 3 and Day 7. This finding underscores the biological advantage of minimal thermal insult associated with Er:YAG laser use. Reduced inflammation and bleeding tendency have been consistently reported with erbium lasers in periodontal soft-tissue procedures, owing to their selective interaction with water-rich tissues and reduced lateral heat spread [23,24].

The diode laser group exhibited higher early gingival inflammation, which is consistent with reports describing short-term inflammatory changes following diode laser surgery due to thermal effects on surrounding tissues [9]. However, resolution of inflammation by Day 14 in both groups indicates that these effects are temporary and self-limiting, provided appropriate laser parameters and postoperative care are maintained. The significantly higher proportion of complete epithelialization observed in the Er:YAG group at Day 7 further supports its role in promoting rapid soft-tissue healing. Faster epithelial coverage has been previously associated with Er:YAG laser procedures and is believed to result from preservation of the basal lamina and minimal disruption of fibroblast activity [18]. Early epithelialization is clinically important, as it reduces the risk of secondary infection, patient discomfort and postoperative complications.

By Day 14, epithelialization was nearly complete in both groups, indicating that diode laser depigmentation, despite slower early healing, does not compromise final tissue integrity. Similar observations have been reported in comparative laser studies evaluating soft-tissue healing endpoints [25]. Both laser systems demonstrated a favorable safety profile, with no serious adverse events recorded. The higher incidence of transient erythema and burning sensation in the diode laser group is consistent with earlier studies describing mild thermal reactions following diode laser use [17]. The absence of infection, scarring or gingival recession in either group confirms that laser-assisted depigmentation is a safe and predictable procedure when performed using standardized protocols.

Clinical Implications

The present study demonstrated that both the 980 nm diode laser and the 2940 nm Er:YAG laser were effective for gingival depigmentation and resulted in satisfactory periodontal healing outcomes. The Er:YAG laser showed significantly better early postoperative wound-healing scores, lower pain levels and reduced gingival inflammation during the first postoperative week. However, by Day 14, healing outcomes were comparable between the two groups, indicating that both laser modalities ultimately support successful periodontal tissue recovery. These findings suggest that while Er:YAG laser therapy may provide advantages in the early healing phase, both laser systems remain clinically viable options for gingival depigmentation.

Limitations and Future Directions

This study has certain limitations. First, the follow-up period was limited to the early postoperative phase and longer-term outcomes such as repigmentation rates and stability of esthetic results were not evaluated. Second, although strict eligibility criteria, preoperative prophylaxis and standardized postoperative instructions were implemented to minimize potential confounding factors, residual individual variations in tissue healing response cannot be completely excluded. Third, the assessment of healing was based on clinical indices rather than histological evaluation, which may limit detailed biological interpretation of tissue response. Future studies with extended follow-up durations, larger sample sizes and incorporation of objective biological or histological markers may provide a more comprehensive understanding of laser-assisted gingival depigmentation outcomes.

Conclusion

Both the 980 nm diode laser and the 2940 nm Er:YAG laser are effective modalities for gingival depigmentation with favorable clinical outcomes. The Er:YAG laser offers superior early healing, reduced postoperative discomfort and lower inflammatory response, while the diode laser remains a practical and cost-effective alternative with satisfactory final healing. Overall, laser selection should be individualized based on clinical objectives, patient comfort and available resources to achieve optimal esthetic and periodontal outcomes.

Data Availability Statement

Not applicable.

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore, was exempt.

Informed Consent Statement

Informed consent was taken for this study.

Authors' Contributions

All authors contributed equally to this paper.

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