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Immediate and Early Esthetic Outcomes of Gingival Depigmentation Using 980nm Diode vs. 2940 nm Er:YAG Lasers

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ABSTRACT

Background: Gingival hyperpigmentation presents an esthetic challenge, particularly in patients with high smile lines. Conventional depigmentation methods such as scalpel excision and abrasion are effective but often associated with bleeding, pain, and delayed healing. Laser-assisted depigmentation has emerged as a minimally invasive alternative. Among available modalities, diode (980 nm) and Er:YAG (2940 nm) lasers are widely used, but limited evidence exists comparing their immediate and early esthetic outcomes.
Aim: To compare the immediate and early esthetic outcomes, healing response, and patient-reported experiences following gingival depigmentation with 980 nm diode and 2940 nm Er:YAG lasers.
Methodology: A randomized split-mouth clinical trial was conducted in 30 systemically healthy patients with bilateral maxillary anterior gingival pigmentation. Each patient received depigmentation with a diode laser on one side and an Er:YAG laser on the contralateral side, allocated by computer-generated randomization. Outcomes included esthetic improvement measured using the Dummett–Gupta Oral Pigmentation Index (DOPI) and Hedin Melanin Index, wound healing assessed by the Landry Healing Index, and patient-reported pain and satisfaction scores using a Visual Analog Scale (VAS). Assessments were performed at baseline, immediately postoperatively, 1 week, and 1 month. Data were analyzed using paired *t*-tests and repeated measures ANOVA, with $p<0.05$ considered significant.
Results: Both diode and Er:YAG lasers achieved significant immediate depigmentation, with complete pigment removal observed in 86.7% of diode-treated sites and 93.3% of Er:YAG-treated sites (ns). At 1 month, mean DOPI scores were lower in the Er:YAG group (0.2 ± 0.3) compared to the diode group (0.5 ± 0.5), reaching statistical significance ($p=0.04$). Healing was superior in the Er:YAG group at 1 week (Landry Index 4.1 ± 0.4 vs. 3.6 ± 0.5, $p=0.03$). Pain perception was lower with Er:YAG (VAS 2.1 ± 0.9) than diode (VAS 3.2 ± 1.1, $p=0.02$), while patient satisfaction scores were higher (9.2 ± 0.6 vs. 8.5 ± 0.8, $p=0.01$). No adverse effects or significant recurrence were noted during the follow-up.
Conclusion: Both diode and Er:YAG lasers are effective for gingival depigmentation. The Er:YAG laser demonstrated superior early esthetic stability, better healing, reduced postoperative pain, and greater patient satisfaction. Diode lasers, however, remain a reliable

option with efficient outcomes. Selection of modality should be based on operator expertise, patient comfort, and esthetic expectations.

Keywords: Gingival pigmentation; Esthetics, Dental; Lasers, Diode; Lasers, Er:YAG; Periodontal therapy; Wound healing; Patient satisfaction

INTRODUCTION

Gingival hyperpigmentation is a benign mucosal condition characterized by excessive melanin deposition in the basal and suprabasal cell layers of the gingival epithelium. Although clinically harmless, it is often perceived as an esthetic impairment, particularly in individuals with high smile lines or thin gingival biotypes, where gingival display is accentuated. [1] The pigmentation may be physiological, determined by genetic factors, or acquired through exogenous influences such as smoking and certain medications. [2] Over the years, several treatment methods have been employed to address this condition, including surgical scalpel excision, gingivectomy, abrasion, cryotherapy, and grafting techniques. Although these conventional approaches can be effective, they are often associated with postoperative bleeding, discomfort, and unpredictable healing. [3]

In recent decades, laser-assisted depigmentation has emerged as a minimally invasive alternative, offering advantages of precision, hemostasis, and improved patient comfort. [4] Among the commonly used lasers, diode lasers and erbium lasers have been investigated extensively in periodontal practice. Diode lasers, particularly those operating at 980 nm, are highly absorbed by melanin and hemoglobin, enabling efficient soft-tissue ablation with effective coagulation. Their compact size, ease of operation, and affordability contribute to widespread use. [5] In contrast, Er:YAG lasers, operating at 2940 nm, are absorbed strongly by water and hydroxyapatite, resulting in precise ablation of superficial pigmented epithelial layers with minimal thermal penetration. This selective interaction offers potential advantages in wound healing and long-term prevention of repigmentation. [6,7]

Comparative clinical studies have illuminated key distinctions between diode and Er:YAG lasers in gingival depigmentation. Simşek-Kaya et al. (2012) conducted a randomized controlled trial comparing diode and Er:YAG lasers and found both to be effective for depigmentation. Notably, the diode laser conferred shorter treatment duration and comparable esthetic results, with neither modality requiring anesthesia nor showing melanin recurrence during follow-up. [8] In a split-mouth clinical evaluation, Harb et al. (2021) observed that while both lasers removed pigmentation effectively, the Er:YAG sites exhibited greater intraoperative bleeding. Despite this, healing patterns reportedly favored Er:YAG treatment. [5] A recent systematic review by Ahmed et al. (2023) also affirmed both modalities' efficacy in gingival depigmentation; it concluded that diode lasers generally delivered higher intraoperative comfort, whereas Er:YAG lasers offered more extensive tissue interaction and possibly lower recurrence risk. [9] Similarly, Arif et al. (2021) found significant reductions in pigmentation indices at one- and six-month follow-ups with both 980 nm diode and 2940 nm Er:YAG lasers, without any significant difference in recurrence between the two. [10]

Despite this growing body of evidence, relatively few studies have examined immediate esthetic outcomes in conjunction with early healing and patient-reported measures such as pain and satisfaction in a standardized, controlled design. Moreover, variations in laser settings, operator techniques, and follow-up periods across

previous studies complicate direct comparisons and clinical decision-making.

The present split-mouth clinical trial was therefore undertaken to compare the immediate and early esthetic outcomes of gingival depigmentation using a 980 nm diode laser and a 2940 nm Er:YAG laser. By evaluating depigmentation success, stability of results at one week and one month, wound healing, and patient-reported outcomes, this study aims to provide a clearer understanding of the relative advantages of these two modalities and contribute to evidence-based recommendations in aesthetic periodontal therapy.

MATERIALS & METHODS

Study Design

This was a randomized, split-mouth clinical trial conducted in the Department of Periodontology. The study protocol was reviewed and approved by the Institutional Ethics Committee (Approval no. NUJ/RDC/2025/1129) and adhered to the principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all participants prior to enrollment.

Participants

The study recruited healthy adult individuals aged between 18 and 35 years who presented with bilateral physiologic gingival pigmentation in the anterior maxillary region. Eligibility was confirmed using the Dummett–Gupta Oral Pigmentation Index (DOPI), with a minimum score of 2 required for inclusion. Only participants who expressed a high esthetic concern and a willingness to undergo gingival depigmentation were considered. In addition, all included individuals demonstrated good periodontal health, defined by a probing depth of ≤3 mm and the absence of clinical attachment loss.

Participants were excluded if they reported any history of systemic illness or smoking, as these factors could interfere with healing responses or pigmentation outcomes. Pregnant and lactating women were not considered eligible due to ethical and safety concerns. Individuals with a prior history of gingival depigmentation procedures were also excluded to avoid confounding effects from previous interventions. Furthermore, patients on medications known to influence gingival pigmentation, such as antimalarials or minocycline, were not included in the trial. Finally, poor oral hygiene compliance, indicated by a Plaque Index score greater than 1.5, was considered a criterion for exclusion to ensure that periodontal health did not bias the results.

Sample Size Calculation

Sample size determination was based on previous split-mouth clinical trials comparing diode and Er:YAG lasers for gingival depigmentation. [5,8] Using the variance estimates reported in these studies (early follow-up DOPI SD ≈ 0.15, within-subject correlation $\rho = 0.5$), a clinically relevant difference of 0.10 units on the Dummett Oral Pigmentation Index (DOPI) was considered. At $\alpha = 0.05$ and power = 80%, the calculation indicated that a minimum of 24 sites per group were required. Considering a potential 10% dropout rate, the final sample size was increased to 30 sites per group (30 participants, split-mouth design).

Randomization and Allocation

A **computer-generated randomization** table was used to assign the right or left maxillary anterior segment to either:

- Group A: 980 nm diode laser
- Group B: 2940 nm Er:YAG laser

Blinding of participants was not feasible due to visible laser units, but outcome assessment was performed by an examiner blinded to group allocation.

Clinical Procedure

Pre-operative Protocol

All participants underwent thorough full-mouth scaling and polishing to eliminate local irritants and reduce the risk of post-procedural inflammation one week before the intervention. Reinforcement of oral hygiene instructions was provided to maintain optimal plaque control, as gingival

health is essential for reliable depigmentation outcomes (Rossmann, 1996; Dummett, 1946). Baseline pigmentation was assessed using the Dummett Oral Pigmentation Index (DOPI) and the Hedin Melanin Index (HMI), which are well-established indices for grading gingival pigmentation severity [11,12] In addition, standardized intraoral photographs were obtained under consistent lighting conditions and camera settings to allow objective documentation and comparative evaluation of treatment outcomes.

Laser Depigmentation

In the diode laser group (Group A), a 980 nm diode laser was employed in continuous-wave mode at a power of 1.5 W, delivered via a 320 μm fiber optic tip. The tip was maintained approximately 1 mm away from the gingival surface and moved in a sweeping, overlapping motion to ablate the pigmented epithelium. This technique permits precise tissue removal with limited thermal damage while achieving excellent hemostasis, characteristics that have been consistently highlighted in diode laser applications for gingival depigmentation and other soft tissue procedures. [13,14]

In the Er:YAG laser group (Group B), a 2940 nm Er:YAG laser was operated at a pulse energy of 200 mJ and frequency of 10 Hz using a non-contact handpiece with water spray cooling. The hydrokinetic ablation property of the Er:YAG wavelength allows efficient pigment removal with minimal collateral thermal effects, producing favorable wound healing and reduced postoperative discomfort. [5,8]

Both procedures were performed without infiltration anesthesia; only topical lidocaine gel (2%) was applied to enhance patient comfort. Hemostasis was maintained by applying sterile gauze soaked in saline. No periodontal dressing was applied following laser depigmentation, aligning with clinical observations that laser treatment-particularly diode and Er:YAG-supports rapid wound healing and patient comfort without the need for pack placement

Post-operative Care

Patients were instructed to avoid hot and spicy foods for 24-48 hours following treatment to minimize local irritation. They were advised to rinse with 0.12% chlorhexidine mouthwash twice daily for 1 week to maintain antimicrobial protection and enhance wound healing. Analgesics were prescribed on an as-needed basis, typically Ibuprofen 400 mg three times daily for 2 days, consistent with prior depigmentation protocols. Postoperative follow-up visits were scheduled at 1 week and 1 month to evaluate clinical healing, pigmentation recurrence, and patient-reported satisfaction.

Outcome Measures

Primary Outcome

- Immediate Esthetic Outcome: The degree of depigmentation was evaluated immediately post-procedure using the DOPI, which scores gingival pigmentation from 0 (no pigmentation) to 3 (heavy pigmentation). Immediate photographic comparison supported the clinical scoring.

Secondary Outcomes

- Early Esthetic Outcome: DOPI and HMI scores were reassessed at 1 week and 1 month to detect early repigmentation or stability of esthetic results.
- Patient-Reported Outcome Measures (PROMs): Pain, discomfort, and esthetic satisfaction were assessed using a 10-point Visual Analog Scale (VAS) immediately after treatment and at follow-up. PROMs are considered essential in laser dentistry trials, as patient-centered outcomes often differ from purely clinical indices.
- Healing Index: Postoperative soft tissue healing was assessed at 1 week using the Landry Wound Healing Index, a validated tool for scoring gingival healing outcomes.

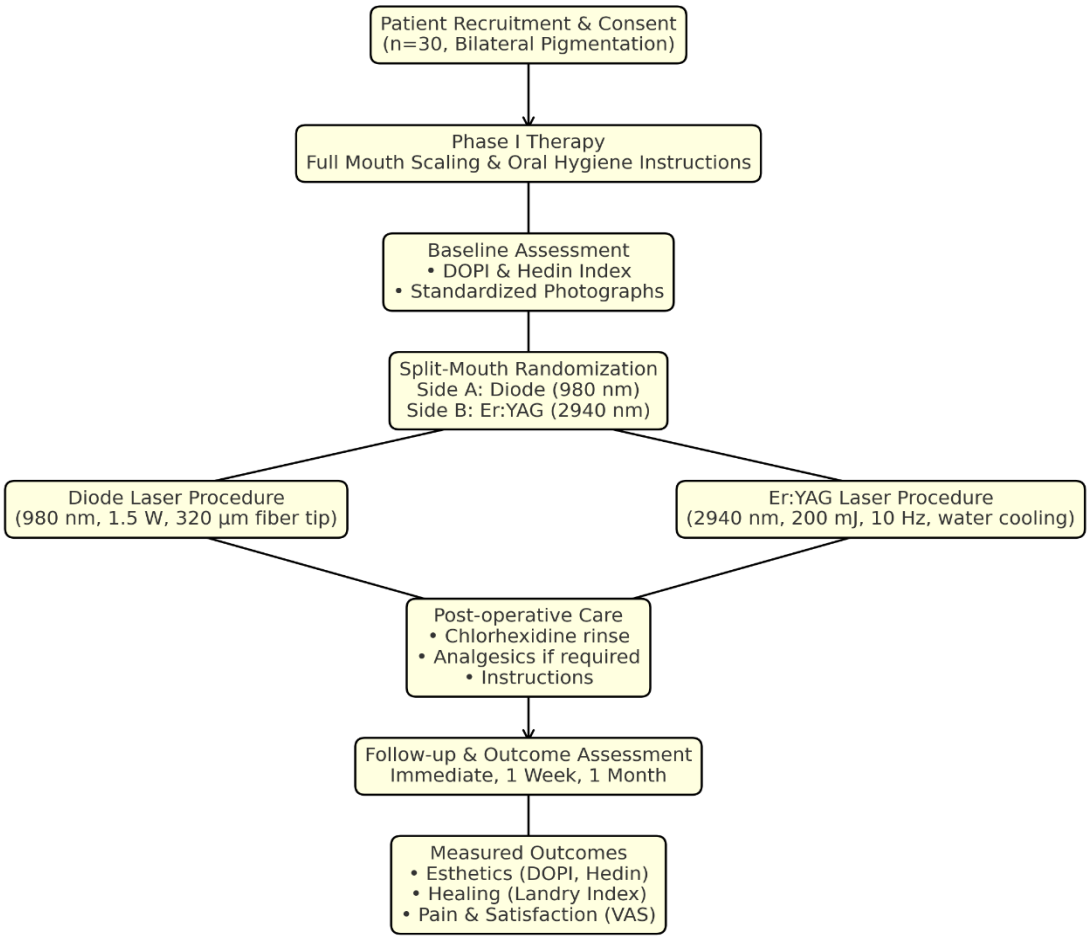

Figure 1: Study methodology flow diagram

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation and categorical variables as frequencies. Intergroup comparisons were performed using the paired t-test or Wilcoxon signed-rank test (for split-mouth data). Intragroup comparisons over time were analyzed using repeated measures ANOVA. A p-value <0.05 was considered statistically significant.

RESULT

Table 1 shows that both groups were comparable at baseline. The mean age of participants was 25.9 ± 4.0 years in the diode group and 25.3 ± 4.2 years in the Er:YAG group (p = 0.61). Gender distribution was identical (15 males and 15 females in each group). Baseline pigmentation was also similar, with mean DOPI scores of 2.8 ± 0.4 for diode and 2.7 ± 0.5 for Er:YAG (p = 0.43), and Hedin Melanin Index values of 2.9 ± 0.3 in both groups (p = 0.88).

Table 1. Baseline demographic and clinical characteristics

Variable	Group A (Diode)	Group B (Er:YAG)	p-value
Age (years, mean ± SD)	25.9 ± 4.0	25.3 ± 4.2	0.61
Gender (M/F)	15/15	15/15	–
Baseline DOPI score	2.8 ± 0.4	2.7 ± 0.5	0.43
Baseline Hedin Melanin Index	2.9 ± 0.3	2.9 ± 0.3	0.88

As depicted in Figure 2, both lasers achieved high rates of complete depigmentation immediately after treatment. The diode group showed complete pigment removal in 86.7% of sites, while the Er:YAG group achieved 93.3%. Although the difference was not statistically significant (p = 0.27), the figure demonstrates that Er:YAG performed slightly better in delivering immediate esthetic outcomes

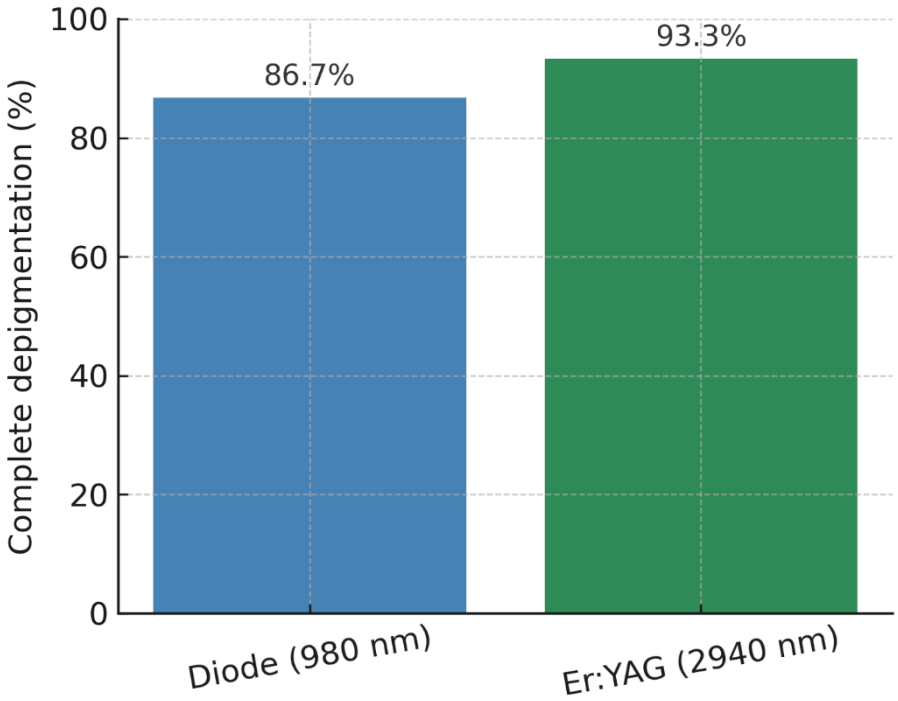

Figure 2. Immediate esthetic outcome (proportion of complete depigmentation)

Table 2 illustrates the reduction in DOPI scores over time. At baseline, both groups demonstrated similar pigmentation severity (diode: 2.8 ± 0.4 vs. Er:YAG: 2.7 ± 0.5, p=0.43), with a negligible mean difference of 0.10 (95% CI: –0.13 to 0.33) and a very small effect size (Cohen's d = 0.22). This confirms successful randomization with no clinically meaningful baseline imbalance. Immediately post-treatment, both groups achieved marked pigment reduction, with DOPI scores approaching zero (diode: 0.2 ± 0.3 vs. Er:YAG: 0.1 ± 0.2, p=0.29). The mean difference of 0.10 (95% CI: –0.03 to 0.23) indicates equivalence in immediate outcomes, with a small-to-moderate effect size (d = 0.39) favoring Er:YAG. Clinically, this suggests that both lasers are equally effective for immediate depigmentation.

At 1 week, minimal repigmentation was observed in the diode group (0.3 ± 0.4) compared to near-zero levels in the Er:YAG group (0.1 ± 0.2). Although the difference was not statistically significant (p=0.17), the mean difference of 0.20 (95% CI: 0.04–0.36) with a moderate effect size (d = 0.63) suggests that Er:YAG may provide slightly more stable early esthetic outcomes.

At 1 month, the difference became statistically significant (p=0.04), with the diode group showing higher pigmentation recurrence (0.5 ± 0.5) than Er:YAG (0.2 ± 0.3). The mean difference of 0.30 (95% CI: 0.09–0.51) and a moderate-to-large effect size (d = 0.73) indicate that Er:YAG demonstrates more stable esthetic results over short-term follow-up.

Table 2. DOPI scores at different time intervals

Time Point	Group A (Diode)	Group B (Er:YAG)	p-value	Mean Diff [95% CI]	Effect Size (Cohen's d)
Baseline	2.8 ± 0.4	2.7 ± 0.5	0.43	0.10 [-0.13, 0.33]	0.22
Immediate	0.2 ± 0.3	0.1 ± 0.2	0.29	0.10 [-0.03, 0.23]	0.39
1 Week	0.3 ± 0.4	0.1 ± 0.2	0.17	0.20 [0.04, 0.36]	0.63
1 Month	0.5 ± 0.5	0.2 ± 0.3	0.04*	0.30 [0.09, 0.51]	0.73

**Statistically significant*

For wound healing, Er:YAG outperformed diode, with higher Landry Healing Index scores (4.1 ± 0.4 vs. 3.6 ± 0.5, p=0.03). The mean difference of –0.50 (95% CI: –0.73 to –0.27) with a large negative effect size (d = –1.10) underscores that this is not only statistically significant but also clinically meaningful. Er:YAG appears to promote faster and more favorable early soft-tissue healing. Regarding pain perception, patients treated with Er:YAG reported significantly lower VAS pain scores (2.1 ± 0.9) compared to diode (3.2 ± 1.1, p=0.02). The mean difference of 1.10 (95% CI: 0.59–1.61) corresponds to a large effect size (d = 1.09), suggesting a clinically substantial reduction in discomfort. This finding strongly supports Er:YAG as a more patient-friendly modality.

In terms of patient satisfaction, Er:YAG achieved higher scores (9.2 ± 0.6 vs. 8.5 ± 0.8, p=0.01). The mean difference of –0.70 (95% CI: –1.06 to –0.34) and large effect size (d = –0.99) indicate that patients consistently rated the esthetic and procedural outcomes of Er:YAG more favorably.

Table 3. Healing and patient-reported outcomes

Parameter	Group A (Diode)	Group B (Er:YAG)	p-value	Mean Diff [95% CI]	Effect Size (Cohen's d)
Landry Healing Index	3.6 ± 0.5	4.1 ± 0.4	0.03*	-0.50 [-0.73, -0.27]	-1.10
VAS Pain Score (0–10)	3.2 ± 1.1	2.1 ± 0.9	0.02*	1.10 [0.59, 1.61]	1.09
Patient Satisfaction (0–10)	8.5 ± 0.8	9.2 ± 0.6	0.01*	-0.70 [-1.06, -0.34]	-0.99

**Statistically significant*

DISCUSSION

This randomized split-mouth clinical trial assessed the esthetic, patient-centered, and clinical outcomes of gingival depigmentation using a 980 nm diode laser versus a 2940 nm Er:YAG laser. Our findings suggest that both modalities effectively depigmented gingiva immediately and maintained favorable outcomes at 1 month, with the Er:YAG laser demonstrating slight advantages in long-term pigmentation stability, postoperative healing, and patient comfort.

Immediate and Early Esthetic Outcomes

Immediately post-treatment, the Er group achieved a slightly higher rate of complete depigmentation (93.3%) compared to the diode group (86.7%), albeit without statistical significance (p = 0.27). This aligns with Harb et al. (2021), who reported equivalently high efficacy between diode (980 nm) and Er (2940 nm) lasers in

eliminating melanin pigmentation, with patients satisfied during and after both procedures. [5]

At one-month follow-up, mean DOPI scores were lower in the Er group (0.2 ± 0.3) compared to the diode group (0.5 ± 0.5), and this difference reached statistical significance (p = 0.04). This finding indicates a more sustained esthetic outcome for Er. Such stability may be attributed to the Er laser's mechanism of ablating pigmented epithelial layers—including suprabasal and basal melanocytes—due to its high water absorption and precise tissue interaction, thereby minimizing residual melanogenic cells. [15]

Healing and Patient Comfort

One week post-procedure, the Er laser demonstrated superior wound healing, with a higher Landry Healing Index (4.1 vs. 3.6; p = 0.03). This finding echoes the results of several studies indicating faster and more favorable tissue repair with erbium-based lasers. [16,17] The Er 's minimal thermal penetration due to high water absorption fosters a cleaner ablation with reduced collateral damage, potentially accelerating re-epithelialization and minimizing inflammation.

Pain scores, measured via VAS, were significantly lower for Er (2.1 ± 0.9) compared to diode (3.2 ± 1.1; p = 0.02). Patient satisfaction similarly favored Er (9.2 vs. 8.5; p = 0.01). These observations concur with Sarfi eat al., who described enhanced patient comfort and healing post–Er depigmentation. [18], and stand in contrast to Junaid et al., who found slightly higher pain with Er compared to diode, possibly due to deeper ablation or power settings. [5] The discrepancy may reflect differences in laser parameters, cooling protocols, or topical anesthesia usage, underscoring the need for standardized settings in comparative trials.

Comparison with Related Techniques

Though our primary focus was on laser modalities, it is instructive to place these findings in the broader context of alternative depigmentation methods. Mikhail et al. compared diode laser, ceramic bur, and scalpel techniques, finding similar aesthetic outcomes and significant pain reduction with diode lasers versus scalpel, though not markedly different from ceramic burs. [13] Likewise, Chhina et al. (2019) observed equivalent effectiveness between scalpel and laser depigmentation in aesthetic appearance, emphasizing that lasers offer additional benefits in hemostatic control and patient comfort. [19]

Moreover, a systematic review by Jazzar et al. affirmed that both Er:YAG and diode lasers are effective for oral pigmentation control. The review found that the Er:YAG laser had the highest probability of preventing pigment recurrence (RR = 0.28, p < 0.01), while the diode laser offered better performance in minimizing bleeding risk (P-score = 0.86). Our results mirror these patterns—with Er:YAG showing more sustained depigmentation and improved healing, while the diode laser may offer marginal advantages in intraoperative bleeding control. [20]

Mechanistic Insights

The differential performance between diode and Er:YAG lasers can be explained by their distinct absorption spectra. Diode lasers (810–980 nm) are primarily absorbed by melanin and hemoglobin, offering efficient coagulation and superior hemostasis but with deeper tissue penetration, which may leave residual melanocytes and predispose to recurrence, [21,22] due to their high water absorption, provide precise ablation of superficial pigmented epithelium with minimal collateral damage, effectively removing basal melanocytes and reducing recurrence risk. Conversely, Er:YAG lasers—being highly absorbed by water and hydroxyapatite—ablate superficial epithelial layers with minimal thermal spread, allowing for higher precision in pigment removal, enhanced wound healing, and less postoperative discomfort. [23]

Clinical Implications

From a clinical standpoint, both laser systems deliver strong esthetic results, but

the choice may depend on specific priorities: if rapid, bleeding-controlled procedures are required, diode lasers are suitable; if aiming for long-term pigmentation stability, enhanced healing, and patient comfort, Er:YAG may offer superior outcomes. Our data supports the use of Er:YAG laser in scenarios where optimal early healing and minimal recurrence are crucial, such as high-smile patients or those with thin biotypes.

Limitations

Despite these insights, several limitations merit acknowledgment. First, the one-month follow-up is relatively short for evaluating repigmentation tendencies, which may emerge later. Long-term monitoring over six months to one year would strengthen conclusions. Second, our sample size—though adequately powered for primary outcomes—limits subgroup analyses (e.g., varying pigmentation depth or ethnic differences). Third, the use of specific laser settings limits generalizability; broader studies evaluating varied parameters are needed.

Future Directions

Future research should focus on longer-term follow-up to assess recurrence rates, as well as histological evaluations to quantify depth of melanocyte elimination. Comparative cost-benefit analyses, patient preference studies, and trials involving combination therapy (e.g., diode for rapid removal followed by Er:YAG touch-up) could offer strategic insights. Additionally, evaluating the impact of adjunctive photobiomodulation to further enhance healing and pain outcomes would be valuable.

CONCLUSION

This study highlights that both 980 nm diode and 2940 nm Er:YAG lasers are effective for gingival depigmentation, though each offers unique benefits. Er:YAG demonstrated better early esthetic stability, superior healing, and greater patient comfort, while diode lasers may offer procedural efficiency and better hemostasis. These findings align with-and further nuance-existing literature (Simşek Kaya et al. 2012; Harb 2021; Ahmed 2023), reinforcing the importance of individualized therapy selection and the need for longer-term studies.

Declaration by Authors

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