

Efficacy of Cryosurgery and Diode Laser on Clinical Outcomes of Gingival Repigmentation — A Systematic Review and Meta-Analysis

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ABSTRACT

Gingival hyperpigmentation is a common aesthetic concern, particularly among individuals with a high smile line. Cryosurgery and diode laser therapy are widely used minimally invasive approaches for gingival depigmentation; however, their comparative clinical effectiveness remains uncertain. This systematic review and meta-analysis aimed to compare cryosurgery and diode laser therapy in the management of gingival hyperpigmentation with respect to depigmentation, postoperative pain, healing, and recurrence. The review was conducted according to PRISMA 2020 guidelines and registered in PROSPERO (CRD42024618472). MEDLINE/PubMed, Web of Science, Scopus, Embase, and Google Scholar were searched up to December 2024. Four split-mouth randomized controlled trials involving 75 participants were included. Outcomes were assessed using the Dummett Oral Pigmentation Index, Visual Analogue Scale for pain, and healing indices. Both techniques demonstrated effective gingival depigmentation. Diode laser generally showed lower postoperative pain and favorable clinical outcomes, although differences were not consistently statistically significant. Meta-analysis of pain scores showed a nonsignificant trend favoring diode laser (SMD -0.59; 95% CI -1.59 to 0.41; P = 0.25), with substantial heterogeneity ($I^2 = 85\%$). Overall, both techniques appear effective, while current evidence is insufficient to establish clear superiority of either modality.

Keywords: Gingival hyperpigmentation; Gingival depigmentation; Cryosurgery; Diode laser; Gingival repigmentation; Postoperative pain; Wound healing; Meta-analysis.

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INTRODUCTION

Gingival hyperpigmentation constitute an integral component of smile esthetics, and the color, contour of the gingiva are considered as significant as tooth shape, alignment, and shade in the overall assessment of smile harmony.¹ Common esthetic concerns associated with the gingiva include recession, irregular gingival contour, overgrowth, delayed eruption, and pigmentation.² Gingival pigmentation is a deviation from the normal colour of the gingiva and oral mucosa. Although it is not a pathological condition, but can be viewed as an aesthetic problem, particularly in those who have a high smile line.^{3,4}

Pigmentation is classified as physiological, attributed to racial and genetic predisposition or pathological resulting from exogenous factors (e.g., smoking, medications) or

endogenous conditions (e.g., systemic disease, genetic disorders)^{5,6}.

Melanin pigmentation occurs across all racial groups, due to genetically determined melanocytic hyperactivity, persons with darker skin phenotypes produce more melanin. In India, complexion and correspondingly pigmentation tends to increase from north to south. Among individuals of African descent, oral pigmentation is most common in the gingiva (60%), hard palate (61%), buccal mucosa (22%), and tongue (15%).^{7,8}

Treatment modalities for gingival pigmentation include chemical techniques utilizing phenol, alcohol, or ascorbic acid, as well as surgical depigmentation procedures such as gingival abrasion, split-thickness epithelial excision, and combination approaches. Additional therapeutic

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modalities include free gingival grafting, laser therapy, cryosurgery, and radiosurgery.^{9,10}

The present review focuses on the comparative efficacy between cryosurgery and diode laser as existing literature has demonstrated significant improvements in the treatment of gingival hyperpigmentation with both treatment modalities. Cryosurgery involves tissue destruction through the application of extremely low temperatures using agents such as liquid nitrogen, liquid nitrous oxide, or solidified carbon dioxide. This process induces freezing of the cellular cytoplasm, resulting in vascular injury and subsequent cell death. Cryosurgery is characterized as a simple, effective, and minimally painful procedure associated with high patient acceptance and favorable clinical outcomes.^{11,12,13} Previous literature reported no statistically significant recurrence of gingival repigmentation after cryosurgery during 18 months follow-up, which suggests that the depigmentation result is stable in the long term.¹⁴

Advances in laser dentistry have established it as one of the most effective techniques for gingival depigmentation, offering enhanced precision and reduced postoperative discomfort.¹⁵ Various laser, employed for selective photothermolysis of pigmented lesions, have demonstrated efficacy, patient comfort, and reliability, with minimal postoperative discomfort and accelerated wound healing.¹⁶ Diode lasers selectively ablate melanin-containing cells through energy absorption by melanin, effectively eliminating pigmented tissue. This solid-state semiconductor device converts electrical energy into light energy via gallium arsenide, combined with elements such as aluminum and indium.¹⁷ The principal advantages of laser-based systems are high precision and the absence of ionizing radiation.¹⁸ Existing literature reported effective reduction of gingival pigmentation with favorable healing and sustained depigmentation during the 12-month follow-up period.¹⁹

Both cryosurgery and diode laser therapy carry advantages and disadvantages. In addition to the complications that are already known, including postoperative pain, bleeding, discomfort, technical difficulty and delayed healing. The results of studies comparing the efficacy of cryosurgery with diode laser are inconsistent, with some studies favoring cryosurgery, some favoring diode laser. The results of comparative studies have been inconsistent when it comes to the use of diode laser versus cryosurgery for gingival repigmentation. Jokar et al. reported that healing and depigmentation were faster with the diode laser than with cryosurgery.¹⁹ Esfandiary et al. reported that there was no significant difference or recurrence with either technique.²⁰

Therefore, this systematic review and meta-analysis aimed to evaluate the efficacy of cryosurgery and diode laser

therapy on the clinical outcomes of Gingival Repigmentation.

The objectives of this systematic review were to compare the efficacy between cryosurgery and diode laser therapy for the management of gingival hyperpigmentation across four key clinical parameters: the amount of depigmentation achieved, assessed using the Dummett Oral Pigmentation Index (DOPI); postoperative pain and discomfort, evaluated using the Visual Analogue Scale (VAS), healing outcomes (Healing index) and the rate of recurrence (repigmentation) on follow-up. A systematic synthesis of existing evidence is to critically evaluate and compare the clinical outcomes of both techniques and to provide evidence-based recommendations for optimizing esthetic outcomes and patient satisfaction in the management of gingival repigmentation.

2. MATERIALS AND METHODS

Review Question and Protocol

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines and was prospectively registered in the PROSPERO database (Registration ID: CRD42024618472). The review question was: “Is there a difference in gingival repigmentation when using cryosurgery versus diode laser in patients with gingival hyperpigmentation?”

PICO criteria

The following is a review question created using the PICO framework: Population (P): Patients with gingival hyperpigmentation; Intervention (I): diode laser; Comparator (C): cryosurgery; Outcomes (O): Gingival Repigmentation, pain and discomfort, healing.

Eligibility criteria

Studies involving patients with gingival hyperpigmentation, in which diode laser was used as an intervention and cryosurgery as the comparator were included. Studies that compared diode laser with cryosurgery were included if they included patients with gingival hyperpigmentation. Studies using other conditions (e.g., gingival inflammation), other laser types or other comparators (e.g., scalpel surgery, abrasion, electrosurgery) were not included. The non-randomized and other study designs were excluded with the exception of randomized controlled trials (RCTs) that included a split-mouth design using diode laser versus cryosurgery for the treatment of gingival hyperpigmentation.

Search Strategy

Two independent researchers searched four databases MEDLINE (via PubMed), Web of Science, Scopus, and Embase up to December 2024, supplemented by Google Scholar. Only articles published in English were included. The database-specific search strings are reported below.

Table 1 - Search strategy of databases

Database	Search Strategy
PubMed	((("cryosurgery"[MeSH Terms] OR "cryosurgery"[All Fields] OR "cryosurgeries"[All Fields]) AND ("lasers, semiconductor"[MeSH Terms] OR ("lasers"[All Fields] AND "semiconductor"[All Fields]) OR "semiconductor lasers"[All Fields] OR ("diode"[All Fields] AND "laser"[All Fields]) OR "diode laser"[All Fields]) AND ("depigmentations"[All Fields] OR "hypopigmentation"[MeSH Terms] OR "hypopigmentation"[All Fields] OR "depigmentation"[All Fields])) OR (("gingiva"[MeSH Terms] OR "gingiva"[All Fields] OR "gingival"[All Fields] OR "gingivally"[All Fields] OR "gingivals"[All Fields] OR "gingivitis"[MeSH Terms] OR "gingivitis"[All Fields] OR "gingivitis"[All Fields]) AND ("pigment"[All Fields] OR "pigmental"[All Fields] OR "pigmentation"[MeSH Terms] OR "pigmentation"[All Fields] OR "pigmentations"[All Fields] OR "pigmented"[All Fields] OR "pigmenting"[All Fields] OR "pigmentous"[All Fields] OR "pigments"[All Fields])) AND ("pain"[MeSH Terms] OR "pain"[All Fields]) AND ("wound healing"[MeSH Terms] OR "wound healing"[All Fields] AND "healing"[All Fields]) OR "wound healing"[All Fields])
Embase	('diode laser'/exp OR 'diode laser' OR 'laser, diode' OR 'laser, semiconductor' OR 'lasers, semiconductor' OR 'semiconductor laser' OR 'semiconductor lasers') AND ('cryosurgery'/exp OR 'cryo-surgery' OR 'cryogenic surgery' OR 'cryosurgery' OR 'surgery, cryogenic') AND ('depigmentation'/exp OR 'hypopigmentation'/exp OR 'hypomelanosis' OR 'gingival depigmentation')
Scopus	TITLE-ABS-KEY("diode laser" OR "DIOMED 630" OR mediostar OR "laser diode" OR "diode laser system" OR "diode laser systems" OR "diode lasers") AND TITLE-ABS-KEY(cryosurgery OR "cryosurgical ablation" OR "cryosurgery methods" OR "cryosurgery devices") AND TITLE-ABS-KEY(hypopigmentation OR "gingival hypopigmentation" OR "gingival hypomelanosis" OR "gingival depigmentation" OR depigmentation)
Web of Science	TS=("diode laser" OR "DIOMED 630" OR mediostar OR "laser diode" OR "diode laser system" OR "diode laser systems" OR "diode lasers") AND TS=(cryosurgery OR "cryosurgical ablation" OR "cryosurgery methods" OR "cryosurgery devices") AND TS=(hypopigmentation OR "gingival hypopigmentation" OR "gingival hypomelanosis" OR "gingival depigmentation" OR depigmentation)
Google Scholar	Gingival depigmentation AND cryosurgery AND diode laser AND hyperpigmentation AND pain AND bleeding AND healing AND split mouth design.

Study Selection

After uploading of the retrieved references in RIS format, the duplicate records were identified and eliminated by the CADIMA software. The remaining records were

subsequently independently screened, using the inclusion and exclusion criteria, by two reviewers. Any disagreements between the reviewers were resolved through discussion and consultation with a third reviewer.

Screening

The study selection was done in two stages: screening for title and abstract followed by full-text screening after duplicate removal. Studies that failed to meet the pre-defined PICO criteria were excluded based on an agreement between the reviewers. The full text of the remaining potentially eligible studies was then included in the present review.

Data Extraction

All studies that fulfilled the inclusion criteria were systematically extracted to enable a uniform and comparable overview of the included literature. For all articles meeting the inclusion criteria, data extraction was performed. The data extracted involved the following variables: (a) Author and year of publication, (b) Type of study, (c) Location of study, (d) Source of data, (e) Characteristics of the study population, (f) Characteristics of the control population, (g) Variables of assessment, (h) Duration of assessment, (i) Findings in the test population, (j) Findings in the control population, (k) Statistical significance between populations, and (l) overall inference.

Risk-of-Bias Assessment

The methodological quality of the included RCTs was independently evaluated by two investigators using the JBI critical appraisal tool for randomized controlled trials; disagreements were resolved by consultation with a third investigator. Studies were rated as having a high, low, or unclear risk of bias across five domains comprising 13 questions, with responses recorded as “yes,” “no,” “unclear,” or “not applicable.” Domain 1 (selection and allocation, 3 items) addressed randomization, allocation concealment, and baseline comparability. Domain 2 (administration of intervention/exposure, 3 items) addressed blinding of participants and treatment providers, and identical treatment of groups other than the intervention of interest. Domain 3 (assessment, detection and measurement of outcome, 3 items) addressed blinding of outcome assessors and reliability/consistency of outcome measurement. Domain 4 (participant retention, 1

item) addressed completeness of follow-up. Domain 5 (statistical conclusion validity, 3 items) addressed intention-to-treat analysis, appropriateness of statistical methods, and trial design.

Statistical Analysis

Data from studies meeting the eligibility criteria were synthesized using both qualitative and quantitative approaches. Quantitative synthesis was undertaken when sufficient and clinically comparable data were available. Meta-analysis was performed in Review Manager (RevMan, version 5.3.5). For continuous outcomes, treatment effects were summarized as standardized mean differences (SMDs) with 95% confidence intervals (CIs) to accommodate variation in outcome measurement scales across studies. Because of anticipated clinical and methodological heterogeneity among the included studies — including differences in study design, participant characteristics, interventions, and outcome-assessment methods — a random-effects model was used to estimate pooled effect sizes. Statistical heterogeneity was evaluated using the I^2 statistic, with values greater than 50% considered indicative of substantial heterogeneity; where substantial heterogeneity was observed, results were interpreted cautiously. Statistical significance was set at $P \leq 0.05$. Individual-study and pooled estimates were displayed as forest plots. Meta-analysis was performed specifically for outcomes comparing the two intervention groups where data allowed pooling.

RESULTS

Included Studies

A total of 62 studies were found from detailed literature search. 2 studies were eliminated due to duplication and 60 studies were screened. These studies were assessed by their title, abstract and eligibility criteria. These studies were reviewed based on their titles, abstracts, and eligibility criteria. Out of these, 13 studies were selected for further review, but 9 were excluded due to duplication or not meeting the outcome criteria. Finally, 4 studies were included for data extraction.^{19,21-23} The PRISMA flowchart illustrates this process.(Fig 1)

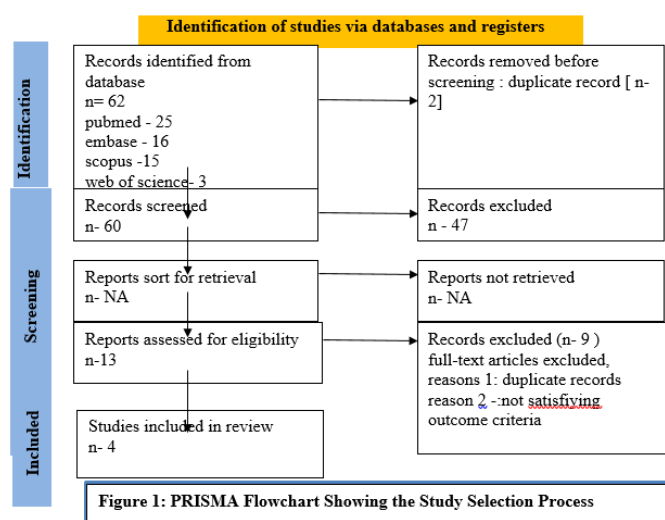


Table 2. General characteristics of included studies

Author & Year	Country	Study Design	Study Population	Sample Size	Age Group (yrs)	Study Duration	Variables Measured
Ponagnati Venkata et al. ²¹	India	Split-mouth randomized controlled trial	Gingival hyperpigmentation patients	20	18–30	9 months	Plaque index, gingival index, gingival bleeding index, oral pigmentation index, pain
Leila Jokaret al. ¹⁹	Iran	Split-mouth randomized study	Gingival hyperpigmentation patients	15	17–35	1 year	Pain, gingival healing, gingival pigmentation index
Disha Gupta et al. ²²	India	Split-mouth randomized study	Gingival hyperpigmentation patients	25	18–35	1 year	Pain, melanin oral pigmentation index, healing index
Aritra Mandal et al. ²³	India	Split-mouth randomized study	Gingival hyperpigmentation patients	15	18–40	6 months	Pain, oral pigmentation index

The total of four studies included were split-mouth RCTs with a total of 75 subjects.^{21,19,22,23} Diode laser was compared with cryosurgery in each study for the treatment of gingival hyperpigmentation. The studies have been carried out in India and Iran, and evaluated for 6 months to 1 year.(Table 2)

Table 3. Gingival repigmentation characteristics of included studies

Author & Year	Technique Used	Scale Used	Score at 6 Months	Inference
Ponagnati Venkata et al. ²¹	Cryosurgery	DOPI	1.8 ± 0.6	Statistically significant
	Diode laser		0.7 ± 0.7	
Disha Gupta et al. ²²	Cryosurgery	DOPI	0.0 ± 0.41	Not statistically significant
	Diode laser		0.04 ± 0.62	
Aritra Mandal et al. ²³	Cryosurgery	DOPI	0.21 ± 0.52	Not statistically significant
	Diode laser		0.13 ± 0.35	

Table 3 compares cryosurgery and diode laser for gingival repigmentation across the three studies reporting this outcome (Ponagnati Venkata et al., 2014; Disha Gupta et al., 2023; Aritra Mandal et al., 2024).^{21,22,23} Ponagnati Venkata et al. (2014) found cryosurgery associated with a significantly higher (worse) DOPI score than diode laser (1.8 ± 0.6 vs 0.7 ± 0.7), indicating greater repigmentation with cryosurgery in that trial. In the other two studies, both techniques showed very low pigmentation scores at 6 months with no significant between-group difference, indicating comparable performance.(Table 3)

Table 4. Pain (VAS) outcomes of included studies

Author & Year	Time Point	Scale	Cryosurgery	Diode Laser	Inference
Ponagnati Venkata et al. ²¹	During procedure	VAS	1.8 ± 1.7	1.3 ± 2.0	Not statistically significant
	After 24 h	VAS	0.5 ± 0.7	0.0 ± 0.0	Statistically significant
	After 7 days	VAS	0.0 ± 0.0	0.0 ± 0.0	Not statistically

Author & Year	Time Point	Scale	Cryosurgery	Diode Laser	Inference
					significant
Leila Jokar et al. ¹⁹	After 24 h	VAS	1.60 ± 1.68	2.36 ± 1.83	Not statistically significant
Disha Gupta et al. ²²	After 24 h	VAS	4.28 ± 1.98	3.36 ± 1.67	Statistically significant
Aritra Mandal et al. ²³	During procedure	VAS	4.97 ± 1.01	3.09 ± 0.57	Statistically significant
	After 7 days	VAS	0.47 ± 0.51	0.07 ± 0.25	Statistically significant

Table 4 shows that pain varied between cryosurgery and diode laser depending on the time of assessment. During the procedure, Ponagnati Venkata et al. (2014) reported slightly higher with cryosurgery (1.8 ± 1.7) than diode laser (1.3 ± 2.0), but not statistically significant (Ponagnati Venkata et al., 2014).²¹ Similarly, the pain associated with the cryosurgery (4.97 ± 1.01) was significantly higher than diode laser (3.09 ± 0.57) ($p < 0.05$) as reported by Aritra Mandal et al. (2024).²³ This means that in the studies reporting this result, diode laser was correlated with less immediate procedural pain.

At 24 hours, Ponagnati Venkata et al. (2014) reported significantly lower pain with diode laser (0.0 ± 0.0) compared with cryosurgery (0.5 ± 0.7).²¹ Disha Gupta et al. (2023) also reported significantly lower pain with diode laser (3.36 ± 1.67) than cryosurgery (4.28 ± 1.98) ($p <$

0.05).²² Leila Jokar et al. (2019), however, found slightly less pain with cryosurgery (1.60 ± 1.68) than diode laser (2.36 ± 1.83), but the difference was not statistically significant ($p > 0.05$).¹⁹ Therefore, although the results were not uniform in all studies, two of the three studies reporting pain at 24 hours found significantly less pain with diode laser.

Ponagnati Venkata et al. (2014) reported no pain at 7 days in either group (0.0 ± 0.0) and no statistically significant difference.²¹ Aritra Mandal et al. (2024) reported significantly lower pain with diode laser (0.07 ± 0.25) compared with cryosurgery (0.47 ± 0.51) ($p < 0.05$).²³ This means that by 7 days, there was little pain with either technique, and a slight advantage with diode laser in one study. (Table 4)

Table 5. Healing outcomes of included studies

Author & Year	Technique Used	Healing Score at 3 Weeks	Inference
Leila Jokar et al. ¹⁹	Cryosurgery	9.47 ± 4.41	Statistically significant
	Diode laser	5.07 ± 3.13	
Disha Gupta et al. ²²	Cryosurgery	4.72 ± 0.45	Statistically significant
	Diode laser	5.00 ± 0.0	

Table 5 compares healing outcomes at 3 weeks after gingival depigmentation using cryosurgery versus diode laser. In Leila Jokar et al. (2019), the healing score was 9.47 ± 4.41 for cryosurgery and 5.07 ± 3.13 for diode laser, with a statistically significant difference.¹⁹ In Disha Gupta et al. (2023), the healing score was 4.72 ± 0.45 for cryosurgery and 5.00 ± 0.00 for diode laser, which was also statistically significant.²² The results were different between the two studies. One study showed a lower healing score with diode laser, while the other showed a slightly lower score with cryosurgery. (Table 5)

Risk of Bias

The methodological quality of the included RCTs was evaluated using the revised JBI critical appraisal tool, and the scores ranged from 7 to 9 out of 13. In general, the studies met several important methodological standards: they were well randomized, baseline comparability between groups, appropriate statistical analysis, and reliable outcome assessment. Some limitations were reported across the studies, however, with unclear or unreported allocation concealment and no blinding of participants, operators, and outcome assessors. These limitations may have increased the risk of selection, performance, and detection bias and should be considered when interpreting the findings of the review. (Table 6)

Table 6. Risk-of-bias assessment using the JBI critical appraisal tool for randomized controlled trials

Domain / Question	Ponagnati Venkata et al. ²¹	Leila Jokar et al. ¹⁹	Disha Gupta et al. ²²	Aritra Mandal et al. ²³
Selection & allocation: Was	Y	Y	Y	Y

Domain / Question	Ponagnati Venkata et al. ²¹	Leila Jokar et al. ¹⁹	Disha Gupta et al. ²²	Aritra Mandal et al. ²³
true randomization used?				
Was allocation to treatment groups concealed?	U	U	U	N
Were treatment groups similar at baseline?	Y	Y	Y	Y
Intervention: Were participants blind to treatment assignment?	N	U	U	N
Were those delivering treatment blind to treatment assignment?	N	N	N	N
Were treatment groups treated identically other than the intervention of interest?	Y	Y	Y	Y
Outcome: Were outcome assessors blind to treatment assignment?	U	N	U	U
Were outcomes measured in the same way for treatment groups?	Y	Y	Y	Y
Were outcomes measured in a reliable way?	Y	Y	Y	Y
Retention: Was follow-up complete, and if not, were differences adequately described/analyzed?	Y	Y	Y	Y
Statistical validity: Were participants analyzed in the groups to which they were randomized?	Y	Y	Y	Y
Was appropriate statistical analysis used?	Y	Y	Y	Y
Was the trial design appropriate, with deviations accounted for?	Y	Y	Y	Y

Y = Yes; N = No; U = Unclear.

Ponagnati Venkata et al.²¹ scored 9 out of 13, indicating moderate to good methodological quality, with strengths in randomization, baseline similarity, and reliable outcome assessment, though allocation concealment and blinding were unclear.

Leila Jokar et al.¹⁹ scored 7 out of 13, reflecting moderate quality; randomization and outcome assessment were adequate, but the absence of blinding increased the risk of performance and detection bias.

Disha Gupta et al.²² scored 9 out of 13, with good randomization and outcome reporting but unclear allocation concealment and blinding.

Aritra Mandal et al.²³ scored 8 out of 13, with appropriate randomization and follow-up but lack of allocation

concealment and blinding, increasing the risk of selection and performance bias. Overall, unclear or absent allocation concealment and blinding were the most consistent limitations across studies.

Meta-Analysis

Four included randomized controlled trials, three were eligible for meta-analysis comparing diode laser and cryosurgery.²¹⁻²³ Pooled analysis of Visual Analog Scale (VAS) pain scores (3 studies; 60 participants per arm) showed a standardized mean difference (SMD) of -0.59 (95% CI: -1.59 to 0.41), favoring diode laser but this difference was not statistically significant ($Z = 1.16$, $P = 0.25$). Combined results across the pooled studies showed no statistically significant overall difference between diode laser and cryosurgery; only Ponagnati Venkata et al. (2014) individually found diode laser significantly better

than cryosurgery on this outcome. Moderate to substantial heterogeneity was observed among the studies ($I^2 = 85\%$, $P = 0.001$; $\text{Tau}^2 = 0.67$; $\text{Chi}^2 = 13.65$, $\text{df} = 2$), likely reflecting differences in sample sizes, pain-assessment

timing, and baseline patient characteristics. The forest plot (Figure 2) illustrates this variability, with most individual study confidence intervals crossing the line of no effect.

META ANALYSIS

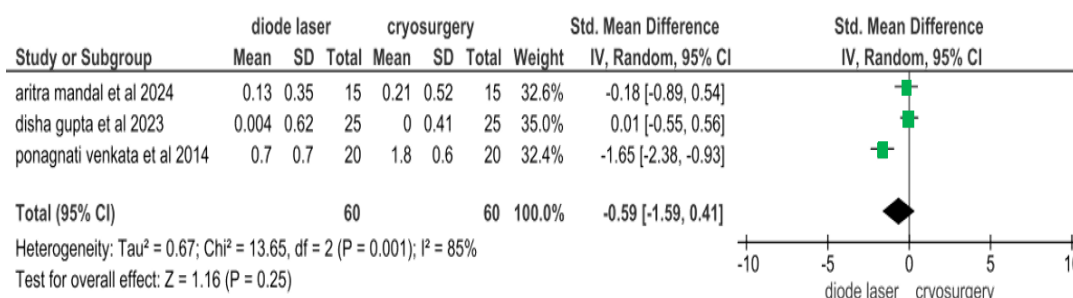


Figure 2. Forest plot of standardized mean difference in VAS pain scores, diode laser vs cryosurgery (random-effects model)

DISCUSSION

This systematic review was designed to compare the relative efficacy of cryosurgery versus diode laser in four clinical parameters: reduction in pigmentation (DOPI), pain level (VAS), wound healing and recurrence on follow-up, including four split-mouth randomized controlled trials (RCTs) with 75 patients. Ponagnati Venkata et al. (2014) demonstrated that diode laser had significantly lower DOPI scores at six months (0.7 ± 0.7) than cryosurgery (1.8 ± 0.6) indicating that diode laser was superior when it comes to reduction of pigmentation in short-term period and Disha Gupta et al. (2023), Aritra Mandal et al. (2024) both found that the pigmentation scores were similarly low. This is similar to Farahmand et al. (2014) who reported to have achieved highly effective depigmentation results with both laser and cryosurgery, with no depigmentation observed at follow-up, with small sample sizes in the included trials, which would not be typical for generalizability of results regarding depigmentation recurrence.^{21,22,23,13} This differs from Kumar et al. (2013), who found that only cryosurgery alone may continue to provide a stable result at two year follow-up.¹² These findings may be attributed to different types of cryogen or different follow-up periods from those included, or to the small number of patients in the trials included, limiting the generalizability of results regarding depigmentation recurrence.

Postoperative pain had a more consistent trend favoring diode laser. Similarly, lower VAS scores were reported during procedure and at 24 hours (Ponagnati Venkata et al. 2014) and intraoperatively as well as postoperatively (Disha Gupta et al., 2023; Aritra Mandal et al., 2024) with diode laser. One study (Leila Jokar et al. 2019) found slightly less (but statistically insignificant) pain 24 hours after the cryosurgery.^{21,22,23,19} A pooled meta-analysis of VAS scores across three studies resulted in a standardized mean difference of -0.59 (95% CI: -1.59 to 0.41) in favor

of diode laser, which was not statistically significant, and exhibited a large amount of heterogeneity ($I^2 = 85\%$). This overall result was consistent with Singh et al. (2012) who concluded that diode laser was better than tetrafluoroethane cryosurgery for both intraoperative and postoperative pain after a 18-month follow-up, and with the overall conclusions of Gul et al.'s, which found association between laser therapy and reduced postoperative discomfort; it was partially discordant with Jokar et al.'s individual result, since the variability of the individual studies prevented a definite conclusion being drawn. For the third finding, wound healing, the results were not as consistent between the two studies that reported on this outcome.^{24,18,19}

In their study, Leila Jokar et al. (2019) has reported a more favorable healing score in diode laser group compared to cryosurgery group at 3 weeks (5.07 ± 3.13 versus 9.47 ± 4.41), but Disha Gupta et al. (2023) indicated a more favorable healing score for cryosurgery group compared to diode laser group at 3 weeks (4.72 ± 0.45 versus 5.00 ± 0.0) and the difference was statistically significant in each study.^{19,22} This splits the evidence: it supports Elavarasu et al. (2015), who said that the diode laser technique resulted in better patient compliance and complete healing within one week, due to its precision, hemostatic effect and tissue-regenerative properties; but it does not support the potential for the same favourable and low-morbidity healing effect that cryosurgery can have versus scalpel technique, as raised by Narayankar et al. (2017) in that context.^{26,10}

Healing results differed between the two studies available, indicating that the healing outcome might be more dependent on the operator's technique, the choice of healing index, and the individual's healing response to the depigmentation modality than on the modality itself.

Overall, both cryosurgery and diode laser appear to be effective and safe for managing gingival hyperpigmentation, each with distinct clinical advantages. Diode laser therapy appears to provide superior intraoperative comfort and favorable early postoperative recovery, whereas cryosurgery may offer more predictable healing in some settings along with cost-effectiveness and reduced technique sensitivity. The variability observed in pigmentation outcomes underscores the importance of individualized treatment planning based on clinical presentation, patient-related factors, and operator expertise.

Strengths and Limitation

The present systematic review extensively searched the major databases (MEDLINE/PubMed, Web of Science, Scopus, and Embase) and Google Scholar, and directly compared the diode laser and cryosurgery methods for gingival repigmentation. Direct within participant comparisons were made in four split-mouth randomized controlled trials. The JBI critical appraisal tool was used to evaluate the methodological quality. The VAS was used to assess pain outcomes, enabling quantitative comparisons, and three studies were pooled in the meta-analysis. However, the limited number of included studies and relatively small sample sizes may reduce the generalizability of the findings. There were also differences in treatment parameters, time points for pain assessment, methods for healing assessment, and follow-up duration, which hindered direct comparisons between studies. Furthermore, methodological weaknesses such as unclear allocation concealment and lack of blinding of participants, treatment providers, and outcome assessors were frequent, and could have contributed to bias.

Clinical Implications

Despite the differences in the results of the individual studies and the methodological issues of the research, the overall conclusion points to the fact that both cryosurgery and diode laser are effective in the treatment of gingival pigmentation. Meanwhile, the diode laser seems to be slightly safer and more comfortable in terms of post-intervention side effects, although it shows comparable aesthetic results. As a result, from the clinical perspective, it might be beneficial to opt for less invasive approaches, such as diode laser, to increase the rate of patient satisfaction without compromising therapeutic efficacy. Both cryosurgery and diode laser can appear as a viable method in periodontal aesthetic dentistry for their relative safety, availability, and predictable outcomes. A patient-centered, evidence-based approach combined with proper technique selection and appropriate follow-up will result in the best esthetic outcomes achieved in the gingival depigmentation therapy.

Future Recommendations

Randomized controlled trials with larger sample sizes and standardized interventions are required to confirm the validity of the results. Standardized criteria for pain assessment, healing and pigmentation recurrence would facilitate more meaningful comparison between studies.

Long-term follow-up trials are necessary to evaluate the healing process and to determine if depigmentation is permanent. Furthermore, the effects of different wavelengths, cryogens and treatment regimens on the outcome of the procedure should be analyzed in detail to identify the most effective and predictable approach. Finally, data on patient-reported outcomes such as esthetic satisfaction, quality of life and cost-effectiveness should be included in the study.

CONCLUSION

This systematic review shows that both cryosurgery and diode laser were effective methods in reducing gingival pigmentation and that there was a preference for the diode laser over the cryosurgery as it caused less discomfort during and after the procedure, and caused less repigmentation in some studies. However, the difference between the two techniques in the pooled meta-analysis of pain scores was not statistically significant, indicating that current evidence is insufficient to establish clear superiority of one approach over the other. Either method works well, and the choice can be based on the type of equipment, the operator experience, patient preference and clinical setting (private practice, academic or hospital-based). Further, large-scale, well-designed randomized controlled trials using more advanced assessment methods with longer follow-up are needed to confirm these findings and provide a more definitive guide for clinical decision making in gingival depigmentation treatment.

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