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Efficacy Of Bioactive Materials In Laser Assisted Vital Pulp Therapy: A Systematic Review And Meta-Analysis

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Abstract

Aim: The aim of this systematic review and meta-analysis was to evaluate the efficacy of bioactive materials used in conjunction with laser-assisted vital pulp therapy (VPT) in mature permanent teeth, with respect to clinical success rate, dentin bridge formation, and failure rate.

Methodology: This study protocol was registered in PROSPERO and a systematic literature search was conducted across multiple electronic databases, including MEDLINE (PubMed), Cochrane Library, and Google Scholar, covering articles published from January 2014 to February 2025. Randomized clinical trials evaluating bioactive materials with or without adjunctive laser application in mature permanent teeth were considered for inclusion. The primary outcomes assessed were clinical success rate, dentin bridge formation, and failure rate. A total of seven randomized clinical trials were included in the qualitative and quantitative analysis.

Result: The meta-analysis demonstrated favourable clinical outcomes with laser-assisted VPT using bioactive materials, with improved dentin bridge formation and higher clinical success rates compared with conventional therapy alone. The adjunctive use of lasers may enhance pulpal healing through antimicrobial, hemostatic, and biostimulatory effects. However, heterogeneity among the included studies and limited long-term evidence were observed.

Conclusion: Laser-assisted VPT with bioactive materials appears promising for preserving pulpal vitality in mature permanent teeth. Further well-designed randomized clinical trials with standardized protocols and longer follow-up are required to establish its long-term effectiveness.

Keywords: Biodentin, dentin bridge formation, laser-assisted pulp therapy, , mineral trioxide aggregate, vital pulp therapy

Introduction

Vital pulp therapy (VPT) has emerged as a conservative and biologically based approach for the management of deep carious lesions and pulp exposures. Unlike conventional root canal treatment, VPT aims to preserve the vitality and function of the dental pulp by maintaining its reparative and defensive potential. Procedures such as indirect pulp capping, direct pulp capping, partial pulpotomy, and full pulpotomy are included under the spectrum of VPT. [1,2]

Preservation of vital pulp tissue enables retention of proprioceptive function, innate immune defense mechanisms, and physiologic stress distribution within the tooth structure, thereby reducing the risk of fracture and improving long-term tooth survival. [2,3]

Recent evidence suggests that VPT can achieve clinical outcomes comparable to root canal treatment while being less invasive and technically simpler. The success of VPT depends on factors such as hemorrhage control, bacterial elimination, and the sealing ability and biocompatibility of the pulp capping material used. [4]

In recent years, lasers have been introduced as adjuncts to conventional VPT procedures because of their antimicrobial, hemostatic, and biostimulatory properties. Diode lasers (810–980 nm) are widely used for bacterial disinfection, coagulation, and stimulation of tissue repair. Er:YAG and Er,Cr:YSGG lasers assist in cavity preparation, smear layer removal, and dentinogenesis, whereas Nd:YAG lasers penetrate dentinal tubules and enhance pulp disinfection and coagulation. [5,6]

Laser-assisted VPT has shown promising outcomes by promoting minimally invasive and bacteria-free healing while improving postoperative pulpal repair and regeneration. The use of lasers has demonstrated improved clinical results due to direct blood coagulation, antimicrobial effects of irradiation, and stimulation of pulpal healing. [5]

Another critical determinant of VPT success is the choice of bioactive material. An ideal pulp capping material should possess excellent biocompatibility, antibacterial activity, adequate sealing ability, dimensional stability, and the capacity to induce reparative dentin formation. [4,7]

Mineral trioxide aggregate (MTA) has long been considered the gold standard material for VPT because of its superior biocompatibility and bioactivity. However, disadvantages such as difficult handling properties, long setting time, and discoloration potential have led to the introduction of newer calcium silicate–based materials such as Biodentin. [4,7]

Biodentin has gained considerable attention due to its improved handling characteristics, shorter setting time, and ability to stimulate odontoblastic differentiation and dentin bridge formation. Several studies have demonstrated favorable outcomes with both MTA and Biodentin in VPT procedures, particularly when combined with laser-assisted protocols. [6,7]

Although numerous studies have independently evaluated lasers and bioactive materials in VPT, evidence regarding their combined efficacy remains limited and fragmented. Therefore, this systematic review and meta-analysis aims to evaluate the efficacy of bioactive materials used in laser-assisted vital pulp therapy with respect to clinical success, radiographic outcomes, dentin bridge formation, and pulpal healing.

Materials and Methods

Protocol and Registration

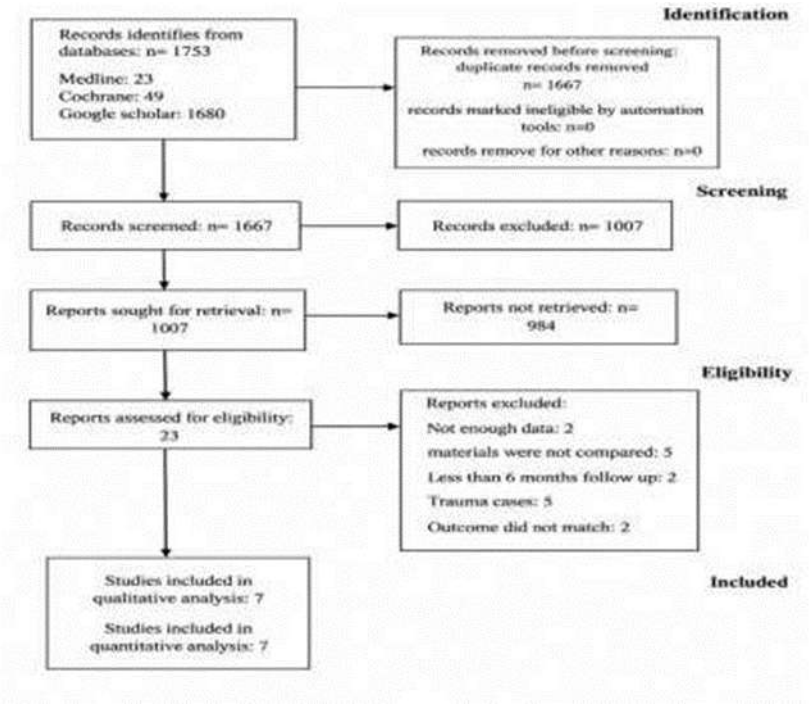
This systematic review and meta-analysis were conducted according to the Preferred Reporting Items for Systematic Reviews and Network Meta-Analyses (PRISMA-NMA) guidelines.[1] It was registered in the Prospectively Registered Systematic Reviews (PROSPERO) database (CRD420251003189).

Search Strategy

An electronic literature search was conducted using MEDLINE (PubMed), Cochrane Library, and google scholar. The following search key was used: ((((((vital pulp therapy) AND (pulp capping)) AND (laser)) AND (mta)) OR (biodentine)) AND (permanent teeth) and (randomised clinical trial) vital pulp therapy AND pulp capping AND laser AND mta OR biodentine AND permanent teeth and randomised clinical trial ((((((vital pulp therapy) AND (pulp capping)) AND (laser)) AND (mta)) OR (biodentine)) AND (permanent teeth) and randomised clinical trial.(Figure1)

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Figure 1: Preferred Reporting Items for Systematic Reviews and Meta analyses flowchart



PICO question and eligibility criteria

The PICOS framework was used. The clinical question was: Is there a significant difference in the success rates of different biomaterials when used with laser in vital pulp therapy?

- P: Mature permanent teeth treated with vital pulp therapy
- I: Bioactive materials, laser with bioactive materials
- C: Comparison of different bioactive materials with or without use of laser
- O: Success rate

Study Selection

Inclusion Criteria for Studies

Randomized controlled trials were included. Studies with preoperative diagnosis, a description of the clinical procedure, biomaterials and lasers, and studies with diagnosis of irreversible pulpitis were included.

The failure of VPT was defined as having clinical symptoms, pain, sensitivity to cold and percussion tests, and/or signs of periapical inflammation. The minimum follow-up period was six months.

Exclusion Criteria for Studies

Case reports, cohort studies, case-control studies, review articles, animal studies, conference abstracts, non-English papers, studies involving primary dentition, immature permanent teeth, and trauma cases were excluded.

Data Collection and Extraction

Two independent observers evaluated all articles based on title, abstract, and full text. Conflicts were resolved through discussion. A third reviewer was consulted in case of disagreement.

Data extracted included publication details, demographics, pulpal diagnosis, type of VPT, materials used, follow-up periods, and success or failure rates. Pooled analysis was performed separately for all treatment modalities at 6, 12, and 24 months follow-up intervals.

Risk of Bias Assessment

The Cochrane Risk of Bias tool helped to determine the Risk of Bias (RoB) in the studies that have been reviewed and makes consideration of five areas reporting bias, performance bias, detection bias, incomplete outcome data bias, and random sequence generation bias. This review has been evaluated by two reviewer and if any discrepancy is found third reviewer has been consulted.

Results

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Literature search:

The systematic search revealed 1753 records from various databases. After removal of duplicates and screening, 7 studies underwent full-text assessment, of which seven studies fulfilled the inclusion criteria and were included in the qualitative and quantitative analysis.The included studies evaluated various combinations of bioactive materials and laser systems including diode lasers, low-level laser therapy, Biodentin, and MTA. Follow-up periods ranged from 6 months to 24 months.

Baseline characteristics of the 7 included studies are presented in (Table 1). The number of treated and lost patients and the successful and unsuccessful cases in every follow-up period, funding source, and conflict of interest were recorded.

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Table 1: Data Extraction

Data	Type of therapy	Diagnosis	Materials	Investigated follow up periods	6 months follow up			12 months follow up			Clinical evaluation	
					Sample size	Number of success cases	Number of failed cases	Sample size	Number of success cases	Number of failed cases	Tenderness	Pain
Swetha et al.	Full pulpotomy	irreversible pulpitis	Diode laser + Biodentin	48hrs, 6,12, 18months	43	42	1	32	29	3	1	3
	conventional crown pulpotomy		Biodentine		43	42	1	28	23	5	1	5
Mishra, et al.: 2024	Full pulpotomy	irreversible pulpitis	Biodentine	1 week, 3 week, 1 months, 3 months, 6months, 12 months	51	51	0	47	43	4	4	0
			Biodentine + platelet		52	52	0	44	41	3	3	0
			Biodentin+ low level laser therapy		50	48	2	45	42	3	3	2
Kerman shah et al 2020	direct pulp capping	irreversible pulpitis	Pro root MTA	3,6 months	14	13	1	13	13	0		
			Er: YAG laser - Pro root MTA		12	9	3	9	9	0		
Aditee et al 2024	direct pulp capping	irreversible pulpitis	DIODE Laser+ Light cure calcium hydroxide	7th day, 1,6,12 months	N/A not mentioned			20	17	3		
			Laser +MTA					20	19	1		
			Laser +PRF					20	20	0		
			Light cure calcium hydroxide					20	10	10		
			MTA					20	15	5		
			PRF					20	16	4		
Sharma et al	indirect pulp capping	irreversible pulpitis	RMGIC	3, 6, 12 months	seven	7	0	7	7	0		
			Laser+ RMGIC		seven	7	0	7	7	0		
			Biodentine		seven	7	0	7	7	0		
			Laser + Biodentine		seven	7	0	7	7	0		
Ahmed, et al. 2024	direct pulp capping	irreversible pulpitis	MTA	3,6,12 months	16	14	2	16	14	2		
			Diode laser+ MTA	3,6,12 months	16	14	2	16	14	2		
Nammour S et al 2023,	direct pulp capping	irreversible pulpitis	Calcium hydroxide	12,24,36 months				379	302	77		
			Biodentine					279	163	116		
			Co2 + calcium hydroxide					1147	1033	114		
			Diode laser + calcium hydroxide					124	100	24		
			Er: YAG LASER+ calcium hydroxide					69	41	28		

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Risk of Bias Assessment

Risk of bias assessment was performed using the Cochrane Risk of Bias tool, revealing an overall predominance of low risk across the included studies, with performance bias representing the most common high-risk domain, while attrition and other bias were frequently rated as unclear (Table 2)

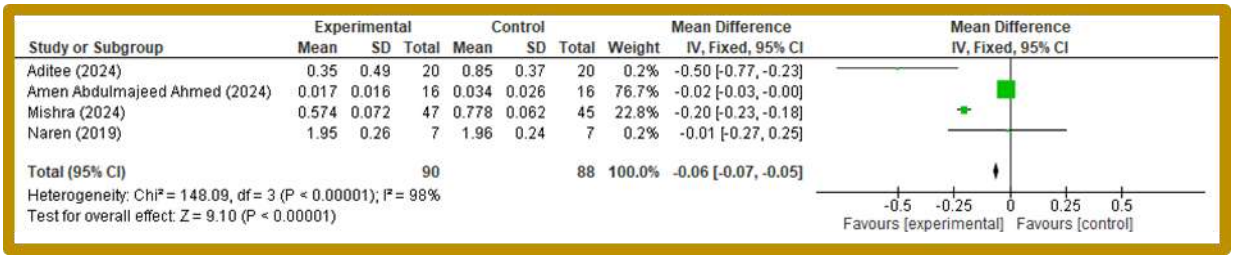
Table 2: Risk of bias Assessment

	Selection bias	Performance bias	Detection bias	Attrition bias	Reporting bias	Other bias
Swetha et al.	Low risk	High risk	Low risk	High risk	Low risk	Unclear
Mishra et al.	Low risk	Low risk	Low risk	Low risk	Unclear	Low risk
Kermanshah et al.	Low risk	High risk	Low risk	Unclear risk	Low risk	Low risk
Agrawal et al.	Low risk	High risk	Low risk	Low risk	Low risk	Unclear risk
Sharma et al.	Low risk	High risk	Low risk	High risk	Low risk	Low risk
Ahmed et al.	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Nammour et al	Low risk	High risk	Low risk	Unclear risk	Low risk	Unclear risk

Meta-analysis Findings

The forest plot analysis demonstrated improved dentin bridge formation and success rate in laser-assisted groups compared with bioactive materials alone.

Figure 2: Forest Plot of Dentin Bridge Formation



The forest plot compared dentin bridge formation between the Laser and bioactive material group and the bioactive material alone group. Four studies were included in the analysis(Figure 2). Ahmed et al [7]and Mishra et al [3] demonstrated results favoring the experimental group, while Aditee et al [5] and Naren et al [6] showed minimal differences between the groups.

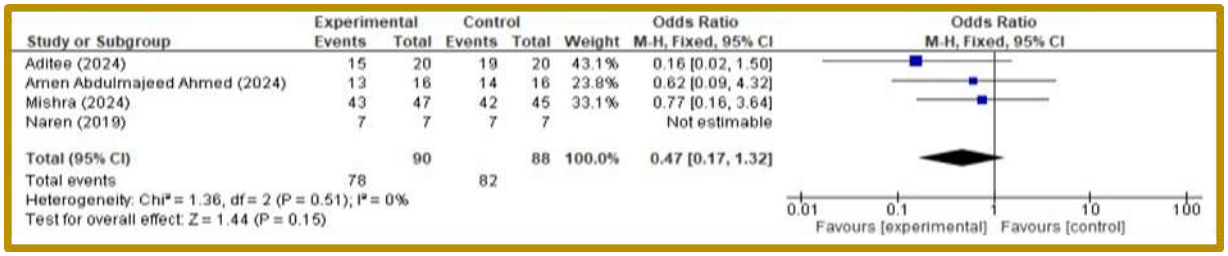
The pooled analysis demonstrated an overall mean difference of −0.06 (95% CI: −0.07 to

−0.05), favoring the Laser and bioactive material group, and the overall effect was statistically significant (P < 0.00001). However, heterogeneity among the studies was considerably high (I^2

= 98%), indicating substantial variation in the study results. Overall, the addition of laser therapy significantly improved dentin bridge formation compared with bioactive materials alone.

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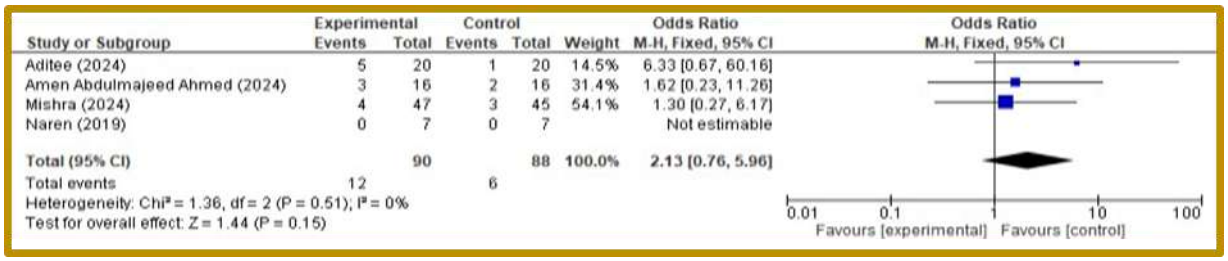
Figure 3: Forest Plot of Success Rate



The forest plot compared the success rate between the Laser and bioactive material group and the bioactive material alone group(Figure 3). Four studies were included in the analysis. Aditee et al [5], Ahmed et al [7], and Mishra et al [3] showed odds ratios below 1, favoring the experimental group; however, all confidence intervals crossed 1, indicating non-significant results. Naren et al [6] was not estimable because all cases were successful in both groups.

The pooled analysis demonstrated an overall odds ratio of 0.47 (95% CI: 0.17–1.32), suggesting a higher success rate in the Laser + bioactive material group compared to bioactive material alone, although the difference was not statistically significant (P = 0.15). Heterogeneity was absent (I^2 = 0%), indicating good consistency among the included studies. Overall, the addition of laser therapy did not significantly improve the success rate compared with bioactive materials alone.

Figure 4: Forest Plot of Failure Rate



The forest plot compared the failure rate between Laser and bioactive material and bioactive material alone. Four studies were included in the analysis(Figure 4). Aditee et al [5], Ahmed et al [7], and Mishra et al [3] showed higher odds of failure in the experimental group; however, their confidence intervals crossed 1, indicating non-significant results. Naren et al[6] was not estimable due to the absence of failure events in both groups.

The pooled analysis showed an overall odds ratio of 2.13 (95% CI: 0.76–5.96), suggesting a higher failure rate in the Laser + bioactive material group, but the difference was not statistically significant (P = 0.15). Heterogeneity was low (I^2 = 0%), indicating consistency among the included studies. Overall, the addition of laser therapy did not significantly influence the failure rate compared to bioactive materials alone.

Discussion

The present systematic review and meta-analysis aimed to determine whether significant differences exist in the success rates of different biomaterials when used in combination with laser therapy during vital pulp therapy (VPT). The overall findings suggest that laser-assisted VPT produced favorable clinical and radiographic outcomes irrespective of the biomaterial used. However, among the evaluated materials, bioactive calcium silicate-based cements, particularly Biodentin and mineral trioxide aggregate (MTA), consistently demonstrated higher success rates because of their superior sealing ability, excellent biocompatibility, and capacity to induce reparative dentin formation. [8–11]

The success of VPT depends on effective bacterial control, adequate hemostasis, preservation of pulp vitality, minimal pulpal inflammation, and stimulation of tissue regeneration. Laser therapy has emerged as a

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valuable adjunct in VPT because of its antimicrobial, hemostatic, anti-inflammatory, and photobiomodulatory properties. By reducing the bacterial load at the exposure site, achieving rapid coagulation, and stimulating cellular proliferation and angiogenesis, laser irradiation creates a favorable biological environment for pulp healing. When combined with bioactive materials capable of releasing calcium ions and inducing mineralization, these effects may act synergistically to improve treatment outcomes. [2,3,8-10]

The meta-analysis demonstrated improved dentin bridge formation in laser-assisted groups compared with conventional treatment groups. This enhanced reparative response may be attributed to the ability of laser irradiation to stimulate odontoblastic differentiation, increase the expression of growth factors, and promote tertiary dentin formation. Histological studies have consistently reported reduced pulpal inflammation and more organized dentinal bridge formation following laser-assisted pulp capping. Suzuki et al.[12] demonstrated that CO_2 laser irradiation during direct pulp capping resulted in continuous dentin bridge formation with minimal inflammatory cell infiltration, while Hasheminia et al. reported superior histological healing and more organized reparative dentin formation in laser-assisted pulp capping procedures compared with conventional techniques. [5,8]

Although both MTA and Biodentin exhibited excellent clinical performance when combined with laser therapy, Biodentin demonstrated certain biological and handling advantages. Biodentin has a shorter setting time, improved mechanical properties, greater calcium ion release, and enhanced bioactivity, all of which facilitate faster hard tissue formation and reduce the risk of material displacement during clinical procedures. Conversely, MTA has a well-established record of long-term clinical success but is associated with limitations such as prolonged setting time, difficult handling characteristics, and the potential for tooth discoloration. These differences may partially explain the slightly higher success rates reported with laser-assisted Biodentin in some included studies, although the pooled analysis did not demonstrate a statistically significant superiority of one calcium silicate cement over the other.[4–6,8,11,13]

The high clinical success observed across laser-assisted groups may also be explained by the synergistic interaction between laser therapy and bioactive materials. Laser irradiation effectively disinfects the exposure site and provides immediate hemostasis, while calcium silicate-based biomaterials seal the exposure, release bioactive ions, and stimulate reparative dentinogenesis. This combination minimizes bacterial leakage, preserves pulp vitality, and enhances regenerative healing, ultimately contributing to favorable clinical outcomes. [4,5,8,14]

Among the various laser systems, diode lasers and CO2 lasers appear to provide superior outcomes because of their efficient hemostatic and antibacterial properties. Er:YAG lasers also demonstrated favorable outcomes due to smear layer removal and dentinogenesis stimulation. However, variations in laser parameters among studies contributed to heterogeneity in clinical outcomes. [4,8,12,14]

Nevertheless, the available evidence should be interpreted cautiously. The included studies varied considerably with respect to laser wavelength, power settings, irradiation protocols, pulp exposure type, follow-up duration, restorative protocols, and the biomaterials evaluated. Most studies compared laser-assisted treatment with conventional techniques rather than directly comparing different biomaterials under identical laser conditions. [2–8]

The choice of bioactive material also plays a critical role in VPT success. MTA remains the gold standard because of its superior sealing ability and bioactivity, whereas Biodentin offers improved handling characteristics and a shorter setting time. Several studies included in this review demonstrated favorable outcomes with Biodentin combined with laser therapy. [5,6,8,11

13] Consequently, although Biodentin and MTA appear to perform similarly well in laser-assisted VPT, the current evidence remains insufficient to conclusively establish the superiority of one biomaterial over another.

Therefore, well-designed long-term randomized clinical trials with standardized laser parameters and direct head-to-head comparisons of contemporary bioactive materials are required to establish standardized treatment protocols and determine whether significant differences truly exist in their

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clinical success when used in conjunction with laser therapy.

[2–8, 9]

Limitation

The findings of this review should be interpreted with caution due to the limited number of included studies and the heterogeneity in laser type, wavelength, power settings, irradiation protocols, biomaterials used, pulpal diagnosis, and follow-up periods. These variations limited direct comparisons between different biomaterials and may have influenced the pooled outcomes.

Conclusion

Laser-assisted vital pulp therapy using bioactive materials demonstrates favorable clinical and radiographic outcomes. The adjunctive use of lasers appears to improve dentin bridge formation, enhance pulpal healing, and increase the overall success rate of VPT procedures. Among the bioactive materials, MTA and Biodentin remain the most promising because of their excellent regenerative potential. Further long-term randomized clinical trials are required to validate these findings.

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