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Abstract

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Keywords (separated by '-') Pulpotomy - Diode laser - Photobiomodulation - Low level laser therapy - Low power laser therapy - Deciduous molar - Primary dentition - Primary molar - Mineral trioxide aggregate

Footnote Information

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ORIGINAL ARTICLE

Clinical and radiographic effectiveness of mineral trioxide aggregate (MTA) partial pulpotomy with low power or high power diode laser irradiation in deciduous molars: a randomized clinical trial

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Abstract

This study investigated the clinical and radiographic effectiveness of MTA partial pulpotomy with low power or high power diode laser irradiation in primary molars. In this randomized single-blind clinical trial, 63 mandibular second molars were assigned into three groups ($n=21$). After pulp amputation and achieving hemostasis, MTA was placed over pulp stumps in group 1 (MTA). The patients in groups 2 (LLLT-MTA) and 3 (DL-MTA) underwent low level (660 nm, 200 mW) and high power (810 nm, 1 W) diode laser radiation prior to MTA placement, respectively. The occurrence of clinical failure (spontaneous pain, tenderness upon percussion, swelling, fistula, mobility) and radiographic failure (periodontal ligament widening, external or internal root resorption, periapical or furcal radiolucency) was recorded up to 18 months after therapy. MTA and LLLT-MTA groups showed clinical success rate of 100% throughout the experiment. The clinical success rate of DL-MTA group was 95.2%, 95.2%, and 87.5% after 6, 9, and 18 months. The radiographic success rates were 90.5%, 90.5%, and 87.5% in the MTA group; 100%, 95.2%, and 88.2% in the LLLT-MTA group, and 85.7%, 76.2%, and 68.7% in the DL-MTA group, at 6-, 9-, and 18-month follow-ups, respectively. No significant differences were found in the frequency of clinical or radiographic failure among the groups at any interval ($p>0.05$). MTA partial pulpotomy was a suitable technique for vital pulp therapy in deciduous teeth. The addition of low power or high power diode laser radiation to the procedure did not cause a significant difference in success rate values.

Keywords Pulpotomy · Diode laser · Photobiomodulation · Low level laser therapy · Low power laser therapy · Deciduous molar · Primary dentition · Primary molar · Mineral trioxide aggregate

Introduction

Preserving the teeth during childhood is of great importance, as the deciduous teeth play a major role in esthetics, mastication, and phonetics, and they also maintain arch length and integrity until the eruption of permanent successors into the oral cavity. It is assumed that 75% of primary teeth with deep caries would experience pulpal exposure during cavity preparation and require pulpal treatment [1]. In cases of reversible pulpal injuries, vital pulp therapy (VPT) is the more conservative and preferred option and may be performed through various therapeutic approaches. Indirect pulp treatment (IPT) is used in cases of deep dentinal cavities, whereas direct pulp capping (DPC) or pulpotomy is employed when the pulp exposure occurs [2]. Choosing the appropriate treatment modality is a challenging issue in primary molars with deep carious lesions [3]. Although DPC is not routinely performed in the clinical practice, a recent guideline of American Academy of Pediatric Dentistry (AAPD) states that IPT, DPC, and pulpotomy are all viable options of VPT in the primary dentition [3, 4]. It should be noted that the occurrence of saliva contamination during VPT may oblige the clinician to shift to a more aggressive pulp treatment such as pulpectomy of primary teeth.

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Pulpotomy is generally considered as the most popular and successful technique of VPT in deciduous molars [5]. Partial pulpotomy is a less invasive form of pulpotomy, with more biologic principles and conservative hypothesis to achieve better clinical outcomes [6]. Partial pulpotomy was first proposed by Cvek [7] in 1978 to treat traumatically exposed pulps of permanent incisors. This technique was later employed for conservative treatment of carious pulp exposures in which hemostasis could be obtained within a few minutes [8]. Partial pulpotomy involves removing 2 mm of inflamed coronal pulp adjacent to the exposure site and then covering the amputated pulp with a suitable covering agent to preserve the remaining coronal and radicular tissues [3, 6]. This treatment modality is associated with several advantages including preservation of healthy coronal pulp, creating a clean wound by removal of infected dentinal chips and injured odontoblasts, minimal loss of tooth structure, easier control of bleeding, and shorter surgical time [3, 6, 9]. The characteristics of the pulp covering agent has a great effect on the success of partial pulpotomy by providing improved strength and anti-microbial seal [6]. Various regenerative biomaterials including calcium hydroxide (CH), mineral trioxide aggregate (MTA), and calcium-enriched mixture (CEM) cement have been employed as capping agents for VPTs of primary teeth [9, 10].

Lasers are currently employed as adjuncts in various branches of dentistry including endodontic and pediatric procedures. High power lasers (> 500 mW) have cutting, hemostatic, antimicrobial, and even analgesic properties and can be used to induce a superficial zone of coagulation in an atraumatic and aseptic way [11–13], whereas low power (also called low level) lasers (< 500 mW) are generally applied for photobiomodulation (PBM) therapy. Photobiomodulation is a term used to describe photochemical reactions in biological systems induced by irradiation with light of low power intensity. A variety of light sources, especially low level lasers and light emitting diodes (LEDs), could be applied in this procedure. Low level laser therapy (LLLT) has been used in pulp therapy to stimulate dental pulp cells, reduce pulpal inflammation, provide analgesic effect, and enhance the wound healing process [14]. Previous studies evaluated the efficacy of high power and low power lasers in cervical pulpotomy of deciduous molars [11, 12, 14, 15]. In these cases, following pulp amputation and achieving hemostasis, the laser was irradiated to the openings of root canals to either induce blood coagulation or enhance the healing process.

There are few studies on the success rate of partial pulpotomy as a conservative approach of vital pulp therapy in primary molars with the use of MTA for pulp coverage. Furthermore, the literature contains heterogeneous reports concerning the effectiveness of different lasers in conventional pulpotomy of primary molars [16, 17], and the effect of low power and high power diode lasers on the outcomes of partial pulpotomy has not been assessed in previous investigations. The present randomized clinical trial was conducted to determine the clinical and radiographic effectiveness of partial pulpotomy with MTA sealing in primary molars over a period of up to 18 months and to investigate whether low level laser therapy (LLLT) or high power diode laser (DL) radiation could enhance the success rate of this procedure in vital pulps of lower primary second molars.

Materials and methods

Study design and ethics

This was a randomized, single-blind, controlled clinical trial. The study protocol was approved by the ethics committee of Mashhad University of Medical Sciences, and it was also registered in the Iranian Registry of Clinical Trials (IRCT) website under the identification number IRCT2015100524373N1. The possible risks and benefits of the procedure were explained thoroughly for the parents/guardians of the children, and informed consent forms were signed by them before the study commencement. A sample of consent form has been presented in Table 1.

Sample size and power calculation

The sample size was calculated considering the reported success rate of MTA pulpotomy with or without laser irradiation (100% for MTA pulpotomy [18] and 70.8% for laser-assisted MTA pulpotomy [11], considering the significance level of 5% and power of 80%. The sample size was calculated as $n = 18$ per group and then increased to 21 in order to compensate for the possible drop-outs of the patients throughout the follow-up periods.

Participants

The participants were selected from those attending the Department of Pediatric Dentistry at Mashhad University of Medical Sciences, Mashhad, Iran. The inclusion criteria involved healthy children aged 4 to 7 years who had at least one second primary molar in the lower jaw with deep caries, normal clinical findings (no history of spontaneous or nocturnal pain, no tenderness to percussion or palpation, no abscess, no fistula, and no mobility), and normal radiographic appearance (no widening of the periodontal ligament space, no pathologic external or internal root resorption, no periapical or furcal radiolucencies). The exclusion criteria involved subjects who used analgesic or sedative drugs as well as patients with systemic diseases, mental disability, allergy to the materials and medications used in the

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AQ1 **Table 1** The consent form used in this study

Patient Consent Form
To record a patient's consent to publication of information and images relating to them or a relative, in a journal
Name of patient: ……
Name of parent/guardian and relationship to patient: ……
Title of publication: Clinical and radiographic effectiveness of Mineral Trioxide Aggregate (MTA) partial pulpotomy with low power or high power diode laser irradiation in deciduous molars: a randomized clinical trial
Principal author: Professor Masoumeh Ebrahimi
Principal author's address: Department of Pediatric Dentistry, School of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran
I, [Name of parent/guardian ……..], give my permission to use clinical information/radiographic material relating to [Name of patient and relationship ……] in the publication identified above to be published by all media and languages throughout the world
This consent is given based on the verbal and written information provided. I am free to ask questions at any time. I have the option to decline to take part or to withdraw from the study at any time without incurring any penalty or loss of benefits otherwise available, including medical care at this institution. I understand that the information/radiographic material will be used only in educational publications intended for health professionals. The name of patient will not be published and she/he cannot be identified from the clinical information, other than in relation to identifiable material (such as radiographic material) for which I give consent
Signature of parent/guardian
Address
Date
Signature of professional obtaining permission
Address
Date

procedure, and suppressed immune system. Furthermore, teeth with no pulpal exposure after caries removal and those with large exposure sites or uncontrolled bleeding after exposure were excluded from the sample during treatment.

From the 174 teeth assessed for eligibility, 75 teeth in 64 children met the inclusion criteria and recruited for the study. Twelve teeth were excluded during treatment and received an alternative therapy such as cervical pulpotomy, pulpectomy, or restoration. Therefore, the final sample consisted of 63 teeth in 53 children. The participants were 24 boys and 29 girls with the mean age of 5.5 ± 0.91 years at the time of therapy.

Randomization and blinding

Sixty-three primary mandibular second molars were randomly assigned into three groups ($n = 21$), according to the partial pulpotomy procedure performed: group 1 (control), MTA; group 2, low level laser therapy (LLLT) + MTA; and group 3, diode laser (DL) + MTA. The block randomization was used for patient assignment in this study in order to achieve equal samples across the groups over time. Since there were six different ways to order the three groups, six blocks of size three were created and named from 1 to 6 (considering A, B, and C as the treatment groups, 1 = ABC, 2 = ACB, 3 = BAC, 4 = BCA, 5 = CAB, 6 = CBA). Using a random numbers table, a number in the range of 1 to 6 was chosen, and the sequence of treatment was set accordingly. In patients with right and left second primary molars, the left side was treated first, and the right side was scheduled as the next treatment. The patient assignment was performed by an independent person not involved in the study process.

All treatments were provided by a postgraduate student of pediatric dentistry, who was thoroughly trained about the details of the technique and procedures involved. The patients and their parents were blinded to the group assignment, but the operator was not, as the devices and procedures were different in the study groups. The statistician who performed the data analysis was also blinded to the group assignment. The study was carried out at the Department of Pediatric Dentistry at Mashhad University of Medical Sciences, Mashhad, Iran, between January 2015 to September 2015, and the follow-ups were set between July 2015 and March 2017.

Clinical interventions

The treatment was accomplished at a single visit. The carious molar was anesthetized through an inferior alveolar nerve block using 2% lidocaine with epinephrine 1:80,000. Following complete isolation by a rubber dam, the tooth surface was cleaned and disinfected with rubber cup and 5.25% sodium hypochlorite solution. Then, carious enamel was removed by means of a fissure diamond bur (#835/009; Tees Kavan Co., Tehran, Iran) at high speed under water spray, and dentin decay was completely excavated by a low-speed round carbide bur (#C1/023; Tees Kavan Co.).

When a pinpoint pulp exposure occurred at the final stage of caries removal, the very superficial inflamed layer of the pulp was gently removed to a depth of 2 mm using a

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sterile round diamond bur (#801/014; Tees Kavan Co.) and a water-cooled high-speed handpiece with light hand pressure. If pulp exposure diameter was large, multiple exposures occurred, or there was no pulpal exposure, the tooth was excluded from the study. Following pulp amputation, the wound surface was thoroughly irrigated with sterile normal saline solution until bleeding ceased. A dry sterile cotton pellet was then applied over the pulp stumps with light pressure to achieve normal hemostasis. In cases that hemostasis was not obtained within 4 min, it was considered that the pulp tissue was still infected and the tooth was excluded from the sample.

After achieving hemostasis, the treatment was continued in the study groups as follows:

Group 1 (MTA): This was considered as the control group of the study. Following hemostasis, the gray MTA (Angelus, Londrina, PR, Brazil) was prepared according to the manufacturer's instructions and placed over the amputated pulp stumps with a sterile amalgam carrier. Light pressure was applied with a moistened cotton pellet to adapt the paste with the exposure site. Because of its long setting time, the MTA material was covered by light-cured glass-ionomer cement (GC Fuji II, GC Corporation, Tokyo, Japan) to provide a firm foundation and stabilize the unset material. A stainless steel crown (3 M ESPE, St. Paul, MN, USA) was then fitted and cemented by glass-ionomer cement (GC Fuji I, GC Corporation, Tokyo, Japan) to serve as a final restoration.

Group 2 (LLLT-MTA): After hemorrhage control in this group, the pulp stumps underwent low level laser therapy (LLLT) by an indium-gallium-aluminum-phosphide (InGaAIP; Thor DD2 Control Unit, Thor, London, UK) diode laser. The device emitted a red light at the wavelength of 660 nm and was operated at the power of 200 mW and continuous wave mode. The laser probe was held stationary (immobile) in contact with the intact part of the occlusal surface of the tooth and at a distance of about 4 mm from the exposure site over a period of 10 s. Each tooth received energy of 2 J, and the energy density was calculated as 7.1 J/cm2, considering the spot size of 0.28 cm^2 at the 4-mm distance from the probe aperture (beam divergence 60°, circular spot shape). The MTA material was then placed over the exposure site by a sterile amalgam carrier and pressed gently with a moistened cotton pellet. The procedure was continued, as explained in the control group.

Group 3 (DL-MTA): After hemostasis in this group, the pulp tissue was ablated using a high power gallium aluminum arsenide (GaAlAs; ARC Laser GmbH, Nürnberg, Germany) diode laser (DL). The laser irradiated a wavelength of 810 nm and was set at the power of 1 W with a continuous wave mode. The beam was delivered through a 300-μm-diameter optical fiber in contact with the pulp tissue. The tip was cut before using for each patient and initiated before application. The energy density at the point of contact was calculated as 1428 J/cm^2. The laser handpiece was slowly moved (1–2 mm/s) over the exposure site for 10 s to prevent overheating of the underlying tissues. After that, the MTA material was placed over the wound surface and pressed gently with a moistened cotton pellet. The procedure was continued, as mentioned in the control group.

The treatments in groups 2 and 3 were made in a specially designed laser room with luminous laser signs. The devices were tested before application, using the power meter of the device in group 2 and using a fire test in group 3. Both patient and clinician wore safety glasses (optical density = 5) during treatment.

Follow-up examinations

The patients were followed-up at 6, 9, and 18 months after treatment, and the clinical and radiographic parameters were assessed to delineate the frequency of failures. The periapical radiographs were taken by the parallel technique. The assessments were made by two calibrated and experienced clinicians, and in cases of disagreement, the investigators were discussed until consensus was achieved.

The teeth were rated as clinical failures if they had any of the following criteria: 1, spontaneous pain; 2, tenderness upon percussion or palpation; 3, swelling or abscess; 4, fistula; or 5, mobility.

The radiographic signs indicating treatment failure were as follows: 1, periodontal ligament widening; 2, pathologic external root resorption; 3, internal root resorption; 4, periapical radiolucency; and 5, furcal radiolucency. The pulp calcification or pulp canal obliteration was not considered as a radiographic sign of failure.

At each checkup, the frequency of clinical or radiographic success was measured by subtracting the number of clinical or radiographic failures from the total number of evaluated cases. The failed cases were considered in calculation of success rate at all assessment intervals. The success rate (%) was then calculated by dividing the number of cases showing clinical or radiographic success by the total number of evaluated cases and multiplying the result by 100. The teeth that presented radiographic failure were monitored at regular intervals and those with clinical failure received an appropriate treatment such as pulpectomy or extraction.

Statistical analysis

The data were analyzed using SPSS 18.0 software (SPSS Inc, Chicago, IL, USA). The differences in age and gender among the groups were analyzed by one-way analysis of variance (ANOVA) and chi-square test. The Fischer's exact test was applied to find any significant difference in the frequency of failures among the study groups at different follow-up periods. The significance level was set at $p < 0.05$.

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Results

A total of 63 mandibular second molars from 53 children were treated. All cases returned at 6 and 9 months after therapy, but there was a 22% dropout in the total number of cases assessed at the 18-month visit. Five patients in the MTA group, 4 patients in the LLLT-MTA group, and 5 patients in the DL-MTA group did not refer at the last recall due to different reasons (disagreement of the guardians to come for further follow-ups or moving to another city). Figure 1 indicates a flowchart of the study protocol up to the 18-month follow-up. Table 2 presents the age and gender distribution of the participants in the study groups at the baseline examination. The study groups were well matched in age and gender at the start of treatment ($p > 0.05$; Table 2).

The results of clinical examination at the three follow-up periods

Table 3 presents the frequencies of clinical failure and success in the study groups at the three follow-up visits. At the 6-month checkup, all teeth were scored as clinically sound, except for one molar in the DL-MTA group that showed sensitivity to percussion, mobility, swelling, and fistula. This

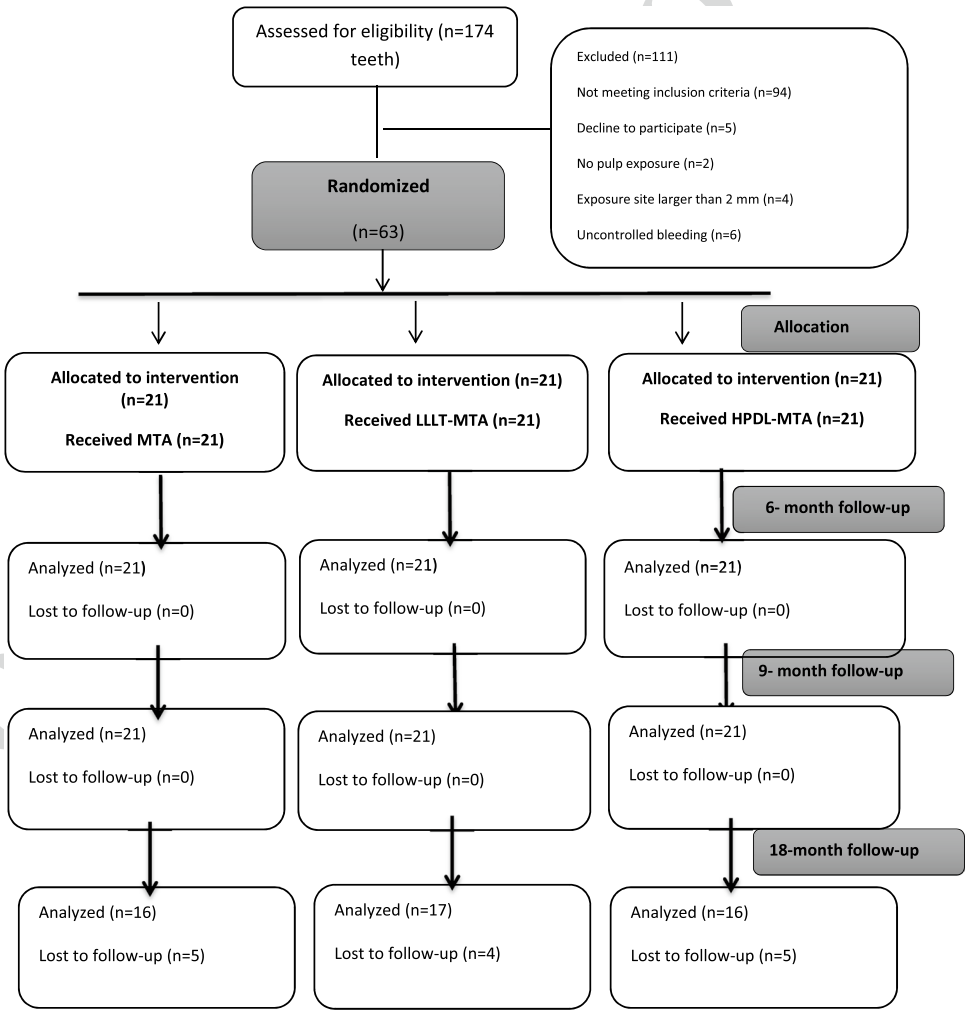

Fig. 1 A flowchart of the study protocol up to the 18-month follow-up

Table 2 Comparison of baseline characteristics of the participants in the study groups

Study groups		MTA	LLLT-MTA	DL-MTA	Significance
Age		5.39 ± 0.90	5.50 ± 0.93	5.72 ± 0.92	$p = 0.505$
Gender	Female	13 (61.9%)	7 (33.3%)	14 (66.7%)	$p = 0.064$
	Male	8 (38.1%)	14 (66.7%)	7 (33.3%)	

*The age has been shown by mean ± standard deviation (SD) and the gender distribution by frequency (%)

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Table 3 The frequency of clinical failure and the frequency (percentage) of clinical success in the study groups at different follow-up periods, as compared to the baseline examination

Follow-up	6-month		9-month		18-month	
Study groups	Clinical failure**	Clinical Success (%)	Clinical failure (%)	Clinical Success (%)	Clinical failure	Clinical success (%)
MTA	0	21 (100)	0	21 (100)	0	16 (100)
LLLT-MTA	0	21 (100)	0	21 (100)	0	17 (100)
HPDL-MTA	1	20 (95.2)	1	20 (95.2)	2	14 (87.5)
p value*	$p > 0.99$		P > 0.99		P = 0.204	

*$p < 0.05$ indicates a statistically significant difference among the study groups

**The criteria indicating clinical failure were spontaneous pain, tenderness upon percussion or palpation, swelling or abscess, fistula, and mobility

case was deemed a clinical failure. Therefore, the clinical success rate was 100% in the MTA and LLLT-MTA groups and 95.2% in the DL-MTA group.

At the 9-month checkup, no additional failure was observed in any of the study groups. The clinical success rate in the MTA, LLLT-MTA, and DL-MTA groups were 100%, 100%, and 95.2% at the 9-month follow-up.

After 18 months of therapy, one new case of clinical failure was found in the DL-MTA group due to spontaneous pain. Therefore, the clinical success rate at the 18-month follow-up was 100% in the MTA group, 100% in the LLLT-MTA group, and 87.5% in the DL-MTA group.

The Fisher's exact test revealed no significant difference in the frequency of clinical failure among the study groups at any of the assessment intervals ($p > 0.05$; Table 3).

The results of the radiographic examination at the three follow-up periods

Table 4 presents the frequencies of radiographic failure and success in the study groups at the three follow-up visits. At the 6-month checkup, radiographic evaluation demonstrated failure in two teeth in the MTA group. One tooth showed periodontal ligament widening, external root resorption, and furcal and periapical radiolucencies, whereas the next one had only furcal radiolucency. Furthermore, three teeth in the DL-MTA group showed radiographic failure. One tooth that was also rated as clinical failure showed periodontal ligament widening, furcal and periapical radiolucencies, and the next two had only furcal radiolucency (Table 4). No case of radiographic failure was observed in the LLLT-MTA group. The radiographic success rates in the MTA, LLLT-MTA, and DL-MTA groups were 90.5%, 100%, and 85.7%, respectively, at the 6-month checkup.

The 9-month radiographic examination demonstrated radiographic failure in one tooth in the LLLT-MTA group due to furcal radiolucency. Furthermore, two new cases of failure occurred in the DL-MTA group. These teeth exhibited periodontal ligament widening and furcal and periapical radiolucencies. At the 9-month follow-up, 90.5% of the MTA group, 95.2% of the LLLT-MTA group, and 76.2% of the DL-MTA group were found as radiographic success.

At the 18-month checkup, one new case of radiographic failure was observed in the LLLT-MTA group. This patient had PDL widening and furcal and periapical radiolucencies. The overall success rate at the 18-month checkup was 87.5%

Table 4 The frequency of radiographic failure and the frequency (percentage) of clinical success in the study groups at different follow-up periods as compared to the baseline examination

Follow-up	6-month		9-month		18-month	
Study groups	Radiographic failure**	Radiographic success (%)	Radiographic failure	Radiographic success (%)	Radiographic failure	Radiographic success (%)
MTA	2	19 (90.5)	2	19 (90.5)	2	14 (87.5)
LLLT-MTA	0	21 (100)	1	20 (95.2)	2	15 (88.2)
DL-MTA	3	18 (85.7)	5	16 (76.2)	5	11 (68.7)
p value*	$p = 0.354$		$p = 0.249$		$p = 0.418$	

*$p < 0.05$ indicates a statistically significant difference among the study groups

**The criteria indicating radiographic failure were periodontal ligament widening, pathologic external root resorption, internal root resorption, periapical radiolucency, and furcal radiolucency

for the MTA group, 88.2% for the LLLT-MTA group, and 68.7% for the DL-MTA group.

There were no statistically significant differences in the frequency of radiographic failure among the groups at any of the follow-up intervals ($p > 0.05$; Table 4). Some representative radiographs of successful and failed cases in the study groups are shown in Figs. 2, 3 AND 4.

Discussion

The present randomized controlled trial investigated the clinical and radiographic success of MTA partial pulpotomy either alone or combined with low power or high power diode laser radiation for treatment of deep carious lesions in primary molars. The primary mandibular second molars were employed to enhance the accuracy of radiographic examination, as overlapping of the roots of upper primary molars with underlying successors can make the detection of pathologic findings difficult. The long-term success of pulp treatment is greatly influenced by the suitability of final restoration to defeat against microleakage along the interfaces of restoration. Therefore, all teeth were restored with SS crowns in the present study. A rigorous method was employed for calculating the success rate, so that cases with any sign of clinical or radiographic failure were considered unsuccessful throughout the experiment, even if they did not refer at the last recall. Only two cases of clinical failure were observed in this experiment. One case reported sensitivity to percussion, mobility, swelling, fistula, and the other experienced spontaneous pain. The most frequent sign of radiographic failure was furcation involvement, which was observed in 9 teeth, followed by periapical radiolucency and PDL widening (observed in 5 teeth). It is believed that the radiographic signs of failure are not an indication for intervention as long as the tooth is free of clinical symptoms and the underlying permanent tooth has not been involved [19]. Therefore, different strategies should be selected upon facing clinical versus radiographic failures. In the current study, the cases with clinical failure underwent retreatment, whereas those with the sole radiographic failure were only observed annually to see whether any further treatment would be required.

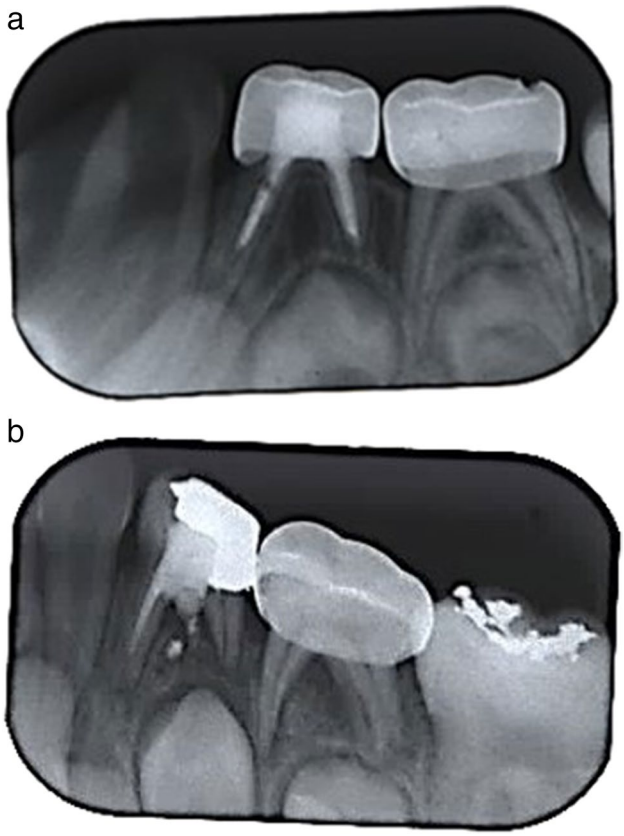

Fig. 2 The 18-month periapical radiographs in two patients after partial pulpotomy with MTA. **A** A successful result in tooth 75; **B** a failed outcome in tooth 75, displayed by widened PDL space and periapical and furcal radiolucencies

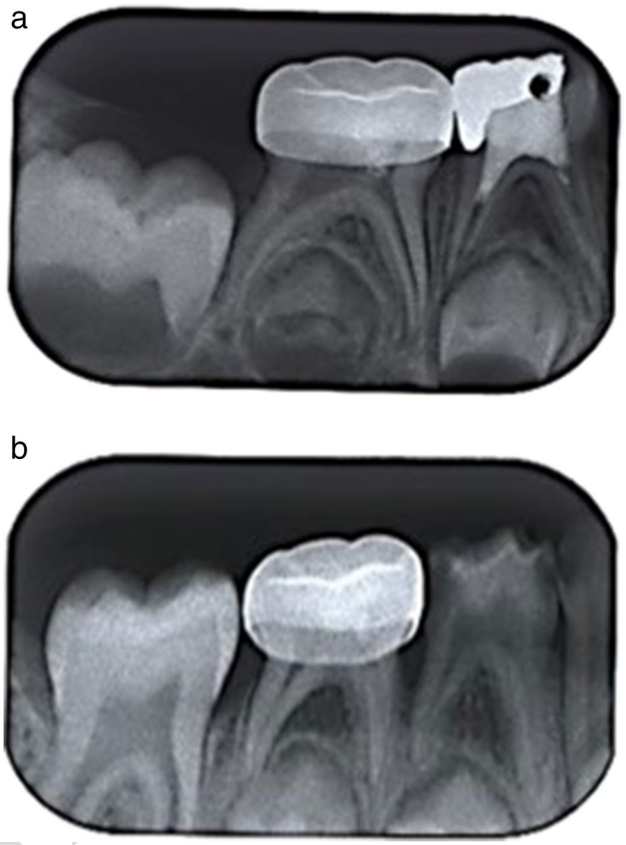

Fig. 3 The 18-month periapical radiographs in two patients after partial pulpotomy in the LLLT-MTA group. **A** A successful result in tooth 85; **B** a failed outcome in tooth 85, represented by furcal radiolucency

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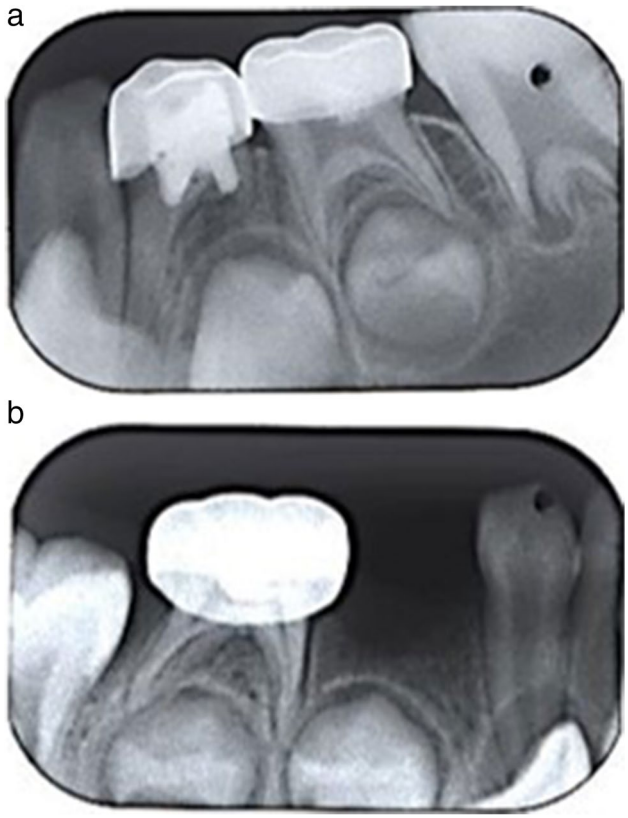

Fig. 4 The 18-month periapical radiographs in two patients after partial pulpotomy in the DL-MTA group. **A** a successful result in tooth 75; **B** a failed outcome in tooth 85, exhibited by widened PDL space and periapical and furcal radiolucencies

The mineral trioxide aggregate (MTA) was used as the pulp capping material in this study. MTA is a regenerative medicament with the capacity for promoting dentin formation, satisfactory antimicrobial properties, and superior biocompatibility [3, 11, 20, 21]. The clinical success rate of MTA partial pulpotomy (without laser irradiation) was 100% throughout the study. The radiographic signs of failure were observed in two cases after 6 months of therapy, and no new case of radiographic failure was observed at the 9- and 18-month intervals. Therefore, the radiographic success rate of partial pulpotomy with MTA was 90.5% at the 6- and 9-month follow-ups and 87.5% at the 18-month checkup. These findings imply that partial pulpotomy with MTA sealing can serve as a successful approach in deciduous molars, as demonstrated by several investigations [3, 9, 22]. Schröder et al. [22] demonstrated the success rate of 83% for partial pulpotomy over a 1-year period, which was not significantly different from the outcomes of cervical pulpotomy. The success rate values observed in this study were a little higher than those reported by previous authors [3, 9, 22]. This could be ascribed to the use of MTA instead of CH [22] as the pulp capping agent; to the use of a stainless steel crown for final restoration as opposed to the amalgam filling [22]; and to the immediate restoration instead of implementing it at the next visit [3].

The combination of MTA partial pulpotomy with LLLT caused the clinical success rate of 100% throughout the study. The radiographic failure was observed in one patient after 9 months and in another patient after 18 months of therapy. Therefore, the radiographic success rate of partial pulpotomy in the LLLT-MTA group was 100%, 95.2%, and 88.2% at the 6-, 9-, and 18-month follow-ups, respectively. The benefits of LLLT in increasing ATP synthesis, alleviating pain, modulating pulpal inflammation, enhancing angiogenesis, and accelerating the wound healing process have been demonstrated in several studies [15, 23–27]. Others suggested that the irradiation of low power lasers is capable to enhance the production activity of fibroblasts and promote the hard tissue barrier formation [14, 15, 28]. In the present study, the success rate in the LLLT-MTA group was similar to the control group. This implies that LLLT is associated with no adverse effect on dental pulp vitality, although any possible benefits of laser therapy on the partial pulpotomy procedure should be assessed in larger sample sizes and longer follow-up periods. The laser device used in this study emitted a 660 nm wavelength, and delivered the energy of 2 J with energy density of 7.1 J/cm^2 to the exposure site. It has been demonstrated that among the different wavelengths of low level lasers (600–1300 nm), a spectrum between 600 and 700 nm has high stimulatory effects on cellular proliferation of various cultured cell lines [29]. The energy density used in the present study was within the therapeutic window to produce biological effects, as proposed by Arndt-Schulz law (between 0.01 and 10 J/cm^2) [30] and recently modified by Cronshaw et al. (between 2 and 10 J/cm^2) [31].

Different kinds of high power lasers such as CO2, Nd:YAG, Er:YAG, and diode have been used in primary molar pulp therapy. The diode laser is more popular in dental offices due to its versatility, durability, a light weight, and suitable cost [32]. The wavelength of high power diode laser (808 to 980 nm) is highly absorbed by pigmented tissues such as hemoglobin and melanin, making it a suitable option in the vital pulp treatment. The diode laser is generally employed for the completion of pulp treatment in order to induce a superficial zone of coagulation necrosis [12, 33]. This layer can act as a biologic dressing, which is compatible with the underlying pulp tissues, and actually isolates the pulp from the restoration [12]. In the present investigation, the success rate in the DL-MTA group was lower than the other study groups, although this difference was not statistically significant. The clinical success rate of partial pulpotomy with diode laser was 95.2% after 6 and 9 months (one case of failure) and 87.5% after 18 months of therapy (two failures). The radiographic failures were observed in 3 patients at the

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6 month interval and 5 patients at the 9- and 18-month checkups. The higher rate of failure in the DL-MTA group was probably related to the blood coagulation effect of diode laser, which could mask a hyperemic pulp condition and lead to chronic inflammation over time [11]. Another factor that may cause a higher rate of failure is the induction of thermal damage to the surrounding tissues of the impact site. In the present study, the diode laser was radiated after 4 min of applying a wet sterile cotton pellet on the pulp stumps to ensure the detection of uncontrolled pulpal hemorrhage. Furthermore, the potential thermal damage was reduced by lowering the output power (1 W) and using scanning movement over a short period of time (10 s). Despite the procedures performed in this study to reduce the hemostatic and thermal effects of diode laser, it appears that the diode laser contributed to the higher frequency of failure in the DL-MTA group. The higher rate of failure in the DL-MTA group may have clinical implications in a larger sample size, and thus this technique should be used cautiously in pulp treatment of deciduous teeth.

The present study revealed no significant differences in the failure rates of partial pulpotomy when either low power or high power diode laser was applied as a supplement to the conventional procedure. Since there is no study concerning laser-assisted partial pulpotomy in deciduous teeth, the present outcomes are compared with those that implemented cervical pulpotomy with low or high power lasers. The results of this study are consistent with the findings of several investigations that reported no significant difference between the LLLT pulpotomy and conventional pulpotomy techniques, as demonstrated by similar success rate values [14, 15, 34]. The higher frequency of clinical and/or radiographic failure in the high power laser group than the control group has also been demonstrated in previous studies although the difference between groups was statistically insignificant [11, 35, 36]. Durmus and Tanboga [35] performed pulpotomy in 120 primary molars using formocresol (FC), ferric sulfate (FS), and diode laser (DL). They found a high rate of radiographic failure in the DL group, as compared to FC and FS pulpotomies [35]. The outcomes of the present study, however, are in contrast with those of several investigations [12, 14, 15, 37–39] that exhibited substantial benefits for additional laser radiation to the conventional technique of pulp therapy. Fernandes et al. [14] reported higher radiographic success rate in the pulpotomy group treated with low level laser followed by calcium hydroxide (LLLT + CH) as compared to the group treated by CH alone. Gupta et al. [12] treated 30 primary teeth with ferric sulfate (FS), electrosurgery (ES), and diode laser pulpotomy. After 12 months of therapy, the laser group (980 nm, 3 W) displayed clinical and radiographic success rates of 100%, which was significantly superior to both FS and ES groups (80%). The differences observed between the results of this study and those of previous investigations may be related to different laser parameters or the different techniques of VPT.

The limitations of this study were the relatively small sample size, single blindness, and the dropout rate of about 22% at the 18-month follow-up, which may compromise the validity of the results. We considered MTA partial pulpotomy as the control group in this study and did not compare the results with a more conventional technique such as cervical pulpotomy. Thus, further randomized clinical trials using larger patient samples and longer follow-up periods are warranted to determine the success rate of partial pulpotomy applied with low power or high power lasers as a suitable approach in vital pulp therapy of deciduous molars. Further studies should also be conducted to find the optimum laser parameters to decrease the chance of failure following the partial pulpotomy procedure.

Conclusion

Within the limitations of this study, it can be concluded the following:

1. The clinical success rate of MTA partial pulpotomy either alone or combined with a low power diode laser radiation was 100% during 18 months of follow-up. When a high power diode laser was added to the standard partial pulpotomy procedure, the clinical success rate reduced to 87.5% after 18 months of treatment.
2. At the 18-month checkup, radiographic failure was observed in 2 teeth treated by MTA partial pulpotomy, 2 teeth treated by MTA partial pulpotomy supplemented with low level laser therapy, and 5 teeth treated by MTA partial pulpotomy combined with high power diode laser radiation.
3. There was no significant difference in the success rate of MTA partial pulpotomy when either low power or high power diode laser was added to the procedure. Therefore, partial pulpotomy was a suitable technique for vital pulp therapy of primary molars. The addition of low power or high power diode laser radiation to the conventional procedure did not cause a significant difference in success rate values.
4. Despite the comparable success rate values, the frequency of clinical and radiographic failures was a bit higher in the high power diode laser group than the other groups, implying that this technique should be used cautiously in pulp treatment of deciduous molars.

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Declarations

Ethics approval The study protocol was approved by the ethics committee of Mashhad University of Medical Sciences, and it was also registered in the Iranian Registry of clinical Trials (IRCT) website under the identification number IRCT2015100524373N1.

Consent to participate The procedure was explained in detail for all the patients, and signed consents were taken before the study commencement.

Conflict of interest The authors declare no competing interests.

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