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Assessment of a novel alternative to conventional formocresol-zinc oxide eugenol pulpotomy for the treatment of pulpally involved human primary teeth: diode laser-mineral trioxide aggregate pulpotomy

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Summary. *Objective.* The purpose of this study was to investigate whether a diode laser pulpotomy with mineral trioxide aggregate (MTA) sealing could be an acceptable alternative to the conventional formocresol pulpotomy and zinc oxide eugenol (ZOE) sealing in human primary teeth.

Methods. A randomized, single-blind, split-mouth study was used with a sample of 16 children aged from 3 to 8 years (mean age = 5·10 years). A total of 26 pairs of teeth from these 16 patients were selected based on clinical and radiographic criteria. One tooth from each pair was randomly assigned to either the laser-MTA pulpotomy group or the formocresol-ZOE pulpotomy group. All teeth were followed up clinically and radiographically at 2·3, 5·2, 9·5 and 15·7 months. All extracted failures were sectioned and photographed to assess possible reasons for this.

Results. A total of seven laser-MTA-treated teeth were deemed to be radiographic failures (mean time until failure = 9·1 months) compared to three formocresol-ZOE treated teeth (mean time until failure = 12·5 months). These results were not significant using Fisher's exact test ($P > 0{\cdot}05$). Six of the laser-MTA failures and all three formocresol-ZOE failures exhibited furcal and/or periapical radiolucencies with or without pathologic root resorption. One of the laser-MTA failures displayed premature root resorption and is being observed for exfoliation. Analysis of photographs of teeth available for extraction revealed errors in clinical technique in addition to expected signs of a disease process such as the presence of granulation tissue and areas of pathologic root resorption.

Conclusions. The laser-MTA pulpotomy showed reduced radiographic success rates compared to the formocresol-ZOE pulpotomy at 15·7 months; however, these results were not statistically significant. Improved success rates among a larger patient sample and a longer follow-up period would be required for the laser-MTA pulpotomy to be considered a routine alternative to the conventional formocresol-ZOE procedure. Meticulous restorative techniques must be followed to ensure the success of laser-MTA pulpotomies.

Introduction

The aim of pulpotomy therapy is to maintain a carious primary tooth until natural exfoliation by removing the coronal portion of the infected pulp while preserving the uninfected radicular tissue. To

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date, there are several techniques for pulp treatment in primary teeth with a range of protocols and medicaments suggested for different clinical situations [1]. However, the use of formocresol pulpotomy in the treatment of primary teeth is widely accepted as the treatment of choice, both among North American predoctoral paediatric dentistry programmes [2] and among paediatric dentistry specialists in Canada [3]. Several clinical studies investigating the long-term success rates of formocresol pulpotomy have justified its use [4–7]. However, additional studies have demonstrated the potential for the local and systemic distribution of formocresol with attendant potentially toxic effects [8,9]. These systemic manifestations must be considered a possibility since formocresol is a material that is toxic to cells and tissues [10]. In addition, animal studies have suggested that the use of formocresol may have both mutagenic and carcinogenic effects in humans [11–13]. Finally, it is debated whether the use of formocresol in the treatment of primary teeth has an effect on the enamel structure of their permanent successors [14]. It is for the above reasons that more biocompatible treatment alternatives have been sought, including glutaraldehyde [15], ferric sulphate [16], electrosurgery [17] and laser irradiation [18].

Zinc oxide eugenol (ZOE) is widely used as a base in pulpotomies because of its antibacterial and analgesic properties [19]. Furthermore, ZOE provides an effective seal, thereby limiting microleakage and subsequent recurrent infection [20]. Nevertheless, direct placement of eugenol over vital pulp tissue can damage it [21]. However, if the pulp tissue is fixed with an agent like formocresol, it will not be affected by eugenol [20].

Lasers, including the diode laser, have found wide application in general and oral surgery procedures involving soft tissues [22,23]. The diode laser potentially offers the following treatment benefits: minimal or no bleeding, faster healing, reduced postoperative infection, and minimal or no anaesthesia. The diode laser uses nearly microscopic chips of gallium-arsenide or other precious semiconductors to generate coherent light in a very small package. The energy level differences between the conduction and valence band electrons in these semiconductors provide the mechanism for laser action. The diode laser has a much higher overall efficiency and, therefore, is more practical [24]. The diode laser emits an infrared light beam that is capable of producing well-localized ablation of soft tissue through conversion of the laser energy to heat. This interaction is most frequently accompanied by peripheral thermal damage to the tissue, and charring of the tissues at the impact site [25,26]. Nevertheless, with appropriate (water) cooling of the tissues, charring can be prevented [27]. The diode laser is most suited for the pulpotomy technique because of the high absorbance of the wavelength (980 nm) at which energy is produced in tissues such as dental pulp which have a very high water content. Furthermore, since this laser is a contact laser, only the soft tissues in immediate contact (micrometer range) with the laser-emitting tip are affected, leaving the remaining tissue unaffected. The laser will have no effect on hard tissues. Previous studies evaluating the use of carbon dioxide and erbium: yttrium-aluminium-garnet lasers in pulp treatment have demonstrated moderate degrees of success [18,28,29]. However, the carbon dioxide laser has also shown the negative attribute of causing medium-extent peripheral thermal damage to the surrounding pulp tissue [25]. Early histopathological studies of various diode lasers have demonstrated reduced thermal damage of pulpal tissue and accelerated pulpal wound healing [30,31]. Based on these characteristics, the diode laser appears to have promise as an alternative for pulpotomy therapy.

Mineral trioxide aggregate (MTA; ProRoot™ Dentsply, Tulsa, OK, USA), a relatively new material currently being used in pulp therapy, has been demonstrated to provide an enhanced seal over the vital pulp and is nonresorbable [32,33]. Furthermore, MTA has been reported to have superior biocompatibility and is less cytotoxic than other materials currently used in pulp therapy [34].

The purpose of this study was to investigate whether a diode laser pulpotomy with MTA sealing is an acceptable alternative to the conventional formocresol pulpotomy and ZOE sealing in human primary teeth. The MTA base was used in conjunction with the laser pulpotomy so as to provide superior sealing ability whilst preventing the tissue-damaging effects of ZOE when placed in direct contact with the nonfixed pulp.

Subjects and methods

This was a randomized, single-blind, split-mouth study approved by the University of Toronto Health Sciences Ethics Review Committee. Eight males and eight females from 3 to 8 years of age who attended the University of Toronto Faculty of Dentistry paediatric clinic were recruited for study based on the following criteria:

Clinical criteria

1 Appropriate guardians provided free and informed written consent and the child patient provided assent for treatment as per university-approved ethics guidelines. Potential risks to the patient, including early tooth loss as a result of pulpotomy failure, were discussed.
2 The children required pulpotomies in a primary first or second molar in at least two of four quadrants.
3 All teeth displayed carious exposure of pulp on clinical and radiographic examinations, but were asymptomatic.
4 Teeth showed no clinical evidence of excessive mobility or a sinus tract.
5 Teeth were vital.
6 Teeth were deemed restorable with a stainless steel crown.

Radiographic criteria

1 There was an absence of furcal or periapical radiolucencies.
2 There was an absence of pathologic root resorption.
3 No more than one-third physiologic root resorption had occurred.
4 No pathology of the succedaneous follicle was noted.

Subjects participating in this study underwent formocresol pulpotomy treatment in one quadrant and laser pulpotomy treatment in a second quadrant. Random assignment of a given quadrant to either treatment group was determined by a coin toss. Treatment was provided by one of seven paediatric dental residents, including the primary investigator (B.S.), who all participated in a training course detailing both pulpotomy techniques.

All teeth treated were anaesthetized using 2% lidocaine with 1:100 000 epinephrine. The teeth were then isolated with a rubber dam and dried with a sterile gauze pad. All teeth exhibiting carious pulp exposures were initially prepared for the placement of a stainless steel crown (SSC) and gross decay was removed prior to pulpal access. Initial occlusal access was prepared using a high-speed dental hand-piece and a #245 bur under water spray. In the formocresol pulpotomy group (FC-ZOE), pulp amputation was completed with a #4 slow-speed round bur and spoon excavator, followed by copious irrigation with saline. After haemostasis was achieved, a cotton pellet dampened with full-strength formocresol was placed in contact with the pulp for 5 min, followed by the placement of a zinc oxide and eugenol base. A SSC (3M Iso-Form, 3M Dental Products, St Paul, MN, USA) was fitted and cemented in place using glass-ionomer cement (GIC; Ketac, 3M-ESPE AG, Seefeld, Germany).

In the experimental diode laser pulpotomy group (L-MTA), the pulp was ablated to the level of the root canal orifice using the 980-nm diode laser (BioLitec, East Longmeadour, USA) set at 3 W of power with a continuous pulse. All patients and clinical staff wore appropriate eye protection during application of the laser. The laser energy was delivered through a 0·5-mm-diameter optical fibre in contact with pulp tissue. Multiple applications were administered until the pulp was ablated and haemostasis was achieved. A MTA base was placed on the amputated pulp stumps. Since MTA (ProRoot™, Dentsply, Tulsa, OK, USA) has a long setting time, light-activated GIC (Vitrebond, 3M Dental Products) was placed over the MTA base to achieve a firm foundation and prevent disturbance of the unset MTA material. A SSC was cemented in place using GIC.

All teeth in both categories were to be followed up clinically and radiographically at 1, 3, 6, 12 and 24 months. The outcome of success or failure was determined by the following clinical and radiographic criteria:
1 teeth remained asymptomatic;
2 absence of a sinus tract;
3 absence of furcal radiolucencies, pathologic resorption and/or damage to succedaneous follicle; and
4 premature tooth loss.

Clinical outcome assessments were made by the primary investigator (B.S.) at each follow-up visit, while radiographic outcome assessments were made by the primary investigator and one independent experienced clinician who was blind to the treatment. Both judges were calibrated prior to initiation of the trial through independent evaluation of 10 randomly chosen radiographs. Inter-rater agreement was measured for the radiographic criteria outlined above using Cohen's kappa.

Gross photographs were taken of all teeth which were extracted as a result of deemed failures. These teeth were embedded in acrylic, sectioned and photographed again to determine a possible clinical–pathological correlation, and to assess the reason(s) for the failure.

Results

The mean age of the 16 subjects treated in this study was 5·1 ± 1·2 years with a range of 3·5–7·5 years. From these subjects, a total of 26 pairs of primary first ($n = 28$) and second molars ($n = 24$) were treated. Subjects contributed between one and four pairs of teeth depending on treatment needs. Fifteen subjects representing 48 teeth were available for a first follow-up visit at 2·3 ± 2·1 months post-treatment. Thirteen subjects representing 41 teeth were available for a second follow-up visit at 5·2 ± 1·9 months post-treatment. Twelve subjects representing 38 teeth were available for a third follow-up visit at 9·5 ± 2·3 months post-treatment. Seven subjects representing 20 teeth were available for a fourth follow-up visit at 15·7 ± 3·0 months post-treatment. Finally, one subject representing four teeth (two FC-ZOE-and two L-MTA-treated teeth) was unable to be contacted post-treatment and was listed as lost to follow-up.

Clinical findings

All teeth were assessed as clinically sound at each follow-up visit.

Radiographic findings

Inter-rater reliability for all radiographic measurements was very good ($\kappa = 0{\cdot}81$). The results for each follow-up visit can be found in Table 1. At the first follow-up, 4·2% (1/24) of the L-MTA-treated teeth were deemed a failure compared to 0·00% (0/24) of the FC-ZOE-treated teeth. These results were not found to be significant ($P > 0{\cdot}05$) using Fisher's exact test. The L-MTA failure, consisting of a furcal radiolucency and pathologic root resorption, occurred at 1·1 months and was treated by extraction (Fig. 1a).

At the second follow-up, 5·3% (1/19) of the L-MTA-treated teeth were deemed to have failed compared to 0·0% (0/20) of the FC-ZOE-treated teeth. There were no significant differences found between the two groups ($P > 0{\cdot}05$) using Fisher's exact test. The L-MTA failure, consisting of a furcal radiolucency and pathologic root resorption, occurred at 5·6 months and resulted in extraction (Fig. 2).

At the third follow-up, 22·2% (4/18) of the L-MTA-treated teeth were deemed a failure compared to 5·3% (1/19) of the FC-ZOE-treated teeth. These results were not found to be significant ($P > 0{\cdot}05$) using Fisher's exact test. From the L-MTA group, three of these failures, consisting of furcal radiolucencies and pathologic root resorption, occurred at 9·7 months and resulted in extraction (Fig. 3a). The other failure, consisting of premature root resorption, occurred at 9·1 months and is being monitored for exfoliation (Fig. 4). The single failure from the FC-ZOE group, consisting of furcal and periapical radiolucencies and pathologic root resorption, occurred at 9·7 months and was recommended for extraction (Fig. 5a).

At the fourth follow-up, 28·6% (2/7) of the L-MTA-treated teeth were deemed a failure compared to 15·4% (2/13) of the FC-ZOE-treated teeth. These results were not found to be significant ($P > 0{\cdot}05$) using Fisher's exact test. One of the failures from the L-MTA group displayed furcal and periapical radiolucencies in addition to pathologic root resorption at 18·8 months and was recommended for extraction. The second L-MTA failure was initially labelled as such at the third follow-up because of premature root resorption, but it continues to be observed. The two failures from the FC-ZOE group displayed furcal radiolucencies at 13·9 months and were recommended for extraction (Fig. 6).

All teeth were treated by one of seven paediatric dental residents, with the majority of those teeth

Table 1. Comparison of successes and failures among both treatment groups at each follow-up visit: (FC-ZOE) formocresol and zinc oxide eugenol; and (L-MTA) laser-mineral trioxide aggregate.*

	Follow-up							
	(1) 2·3 months		(2) 5·2 months		(3) 9·5 months		(4) 15·7 months	
Success/failure	FC-ZOE	L-MTA	FC-ZOE	L-MTA	FC-ZOE	L-MTA	FC-ZOE	L-MTA
Sound	24	23	21	19	19	14	11	5
Failure	0	1	0	1	1	4	2	2
Total	24	24	21	20	20	18	13	7
Significance	$P > 0{\cdot}05$		$P > 0{\cdot}05$		$P > 0{\cdot}05$		$P > 0{\cdot}05$	

*The mean time at which follow-up occurred is listed in months. Significance was measured using Fisher's exact test.

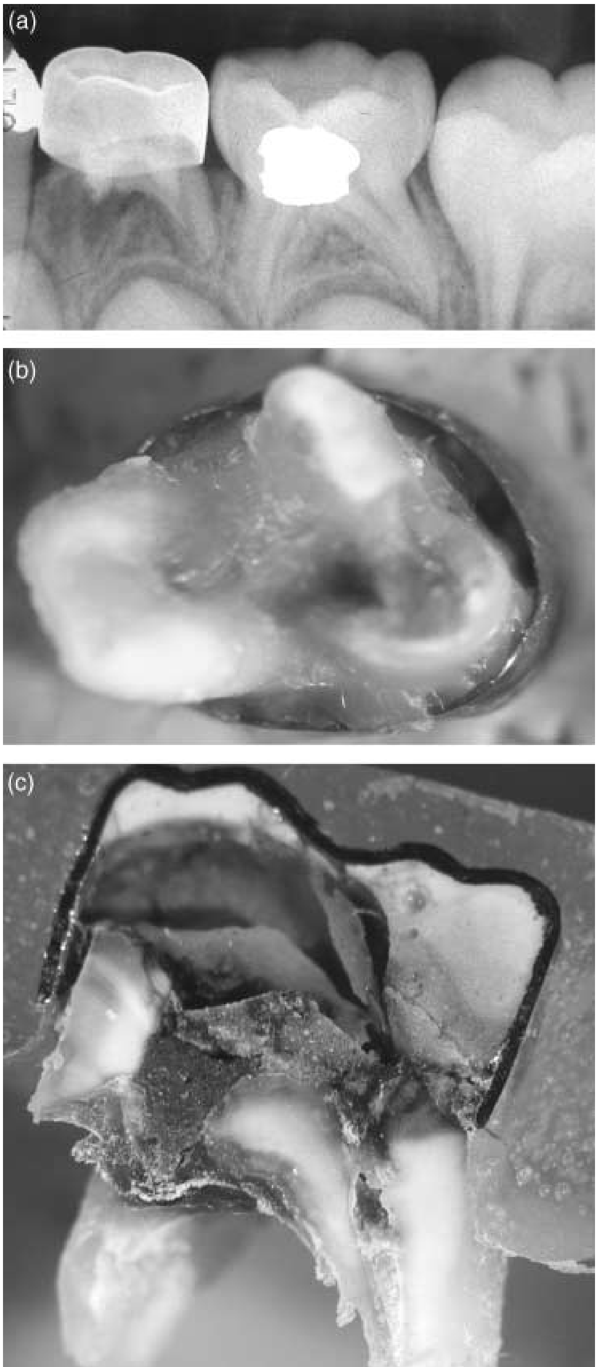

Fig. 1. (a) Laser-mineral trioxide aggregate (MTA)-treated tooth 74 displaying furcal radiolucency and pathologic root resorption at 34 days. (b) Laser-MTA-treated tooth 74 with a poorly adapted stainless steel crown (SSC) displaying resorption and necrosis at the mesial root. (c) Laser-MTA-treated tooth 74 displaying a poorly adapted SSC, thin MTA base and void within the cement.

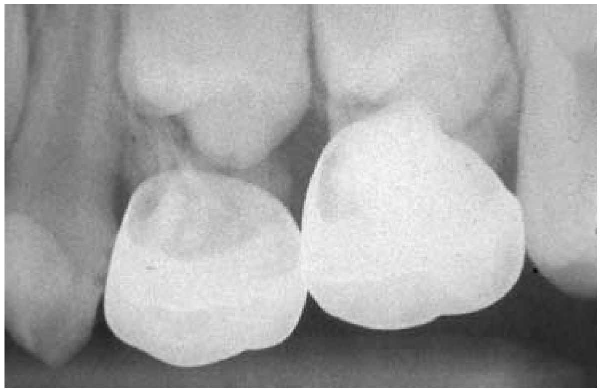

Fig. 2. Laser-mineral trioxide aggregate-treated tooth 64 displaying furcal radiolucency and pathologic root resorption at 5 months and 18 days.

(70·8%) treated by the primary investigator (B.S., operator 1). The distribution of teeth available for follow-up per operator, including radiographic outcomes, is shown in Table 2.

Overall, 29·16% (7/24) L-MTA-treated teeth were considered failures compared to 12·50% (3/24) FC-ZOE-treated teeth (Table 3). The mean time until failure for L-MTA-treated teeth was 9·1 ± 5·3 months, while the mean time until failure for FC-ZOE-treated teeth was 12·5 ± 2·4 months. The average age of the subjects at the time of pulpotomy failure was 5·6 ± 1·0 years.

There was no significant difference between the age of the patient, the treatment operator or the type of tooth treated amongst and across both treatment groups. In addition, there was no significant difference between patients contributing single or multiple pairs of teeth ($P > 0{\cdot}05$). Interestingly, all seven L-MTA failures occurred amongst male patients, while all three FC-ZOE failures occurred amongst female patients.

Clinical–pathological correlation

A total of seven teeth, including six L-MTA-treated teeth and one FC-ZOE-treated tooth, were available for sectioning and photographic assessment following extraction. All remaining teeth from both treatment groups will be similarly evaluated following natural exfoliation or extraction if deemed necessary.

Current photographic evaluation of the available extracted teeth revealed various iatrogenic errors in addition to expected pathology consistent with the radiographic findings. Pathologic findings included

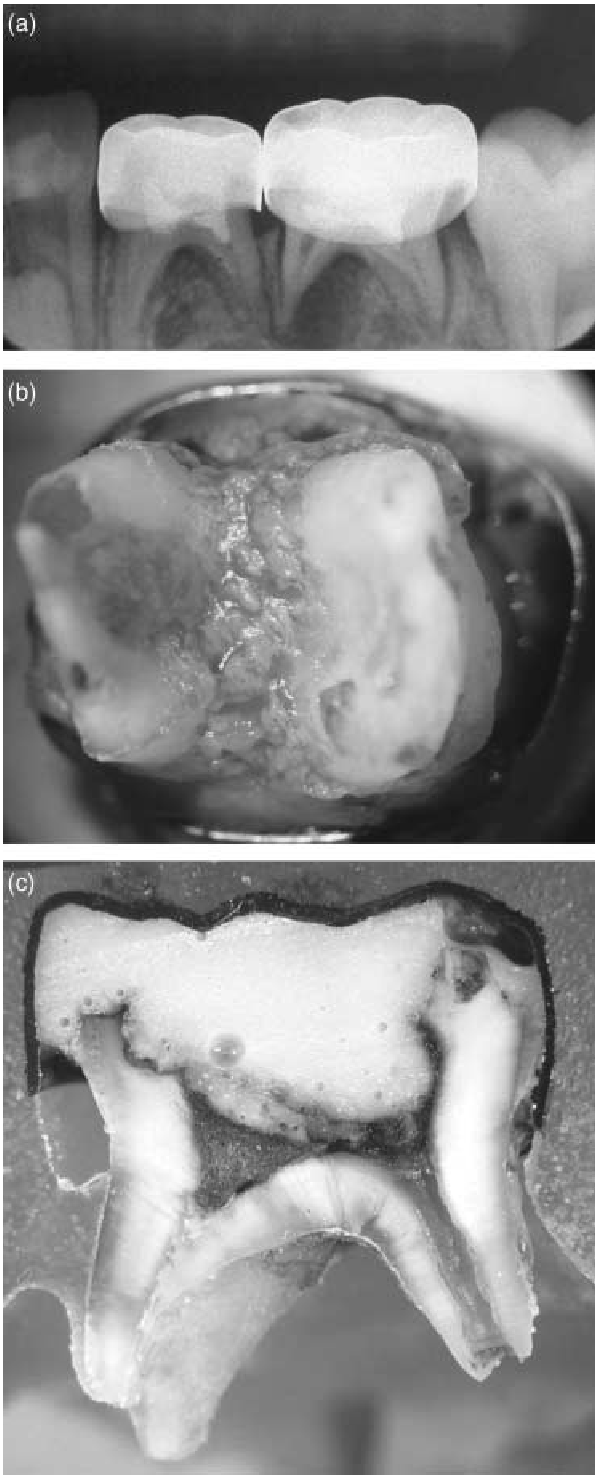

Fig. 3. (a) Laser-mineral trioxide aggregate (MTA)-treated teeth 74 and 75 displaying furcal radiolucencies and pathologic root resorption at 10 months and 6 days. Note the poorly adapted stainless steel crown (SSC) on tooth 75. (b) Laser-MTA-treated tooth 75 displaying furcal granulation tissue. Again, note the poorly adapted SSC. (c) Mesiodistal section of laser-MTA-treated tooth 75 displaying a poorly adapted SSC, a thin MTA base and residual coronal pulp tissue in addition to widened root canal space.

Fig. 4. Laser-mineral trioxide aggregate (MTA)-treated treated tooth 65 displaying premature root resorption at 9 months and 3 days in a 6·5-year-old child.

widening of the root canal spaces, deposits of furcal granulation tissue, significant areas of root resorption and necrosis, and evidence of pulpal hyperaemia (Figs 1b,c, 3b,c and 5b,c).

Iatrogenic findings included the presence of poorly adapted SSCs, thin placement of the MTA base, voids within the cement, excess cement extruding beyond crown margins and areas of residual coronal pulp tissue (Figs 1b,c, 3b,c and 5b). No extracted tooth was free of one or more of these iatrogenic findings.

Discussion

The small sample size used in this study was in accordance with the recommendations of the University of Toronto Health Sciences Ethics Review Committee, given the experimental use of the laser in children. In order to maximize recruitment, seven paediatric dental residents were trained to provide both pulpotomy procedures. Following this initial trial period, the sample size will be increased to at least a total of 32 patients (16 male and 16 female), who will undergo treatment as per the original protocol.

All teeth in both treatment groups were deemed clinically successful at each follow-up visit. In addition, all patients were free of pain following treatment, and no patient presented with clinical signs or symptoms of infection associated with pulpotomy failure.

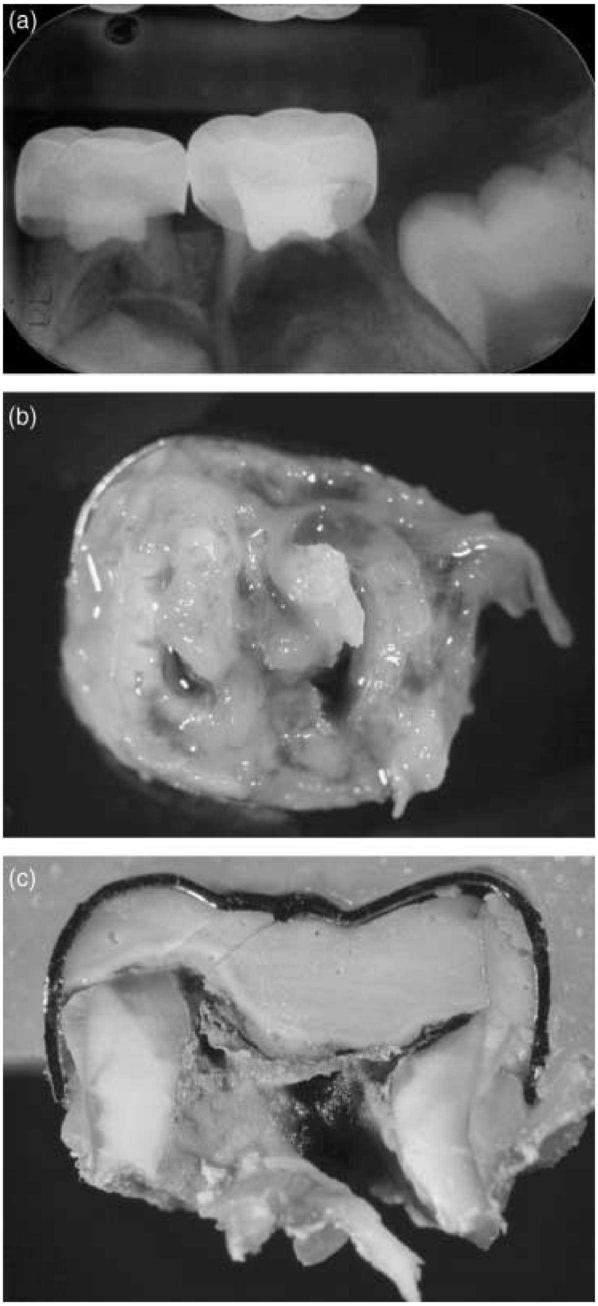

Fig. 5. (a) Formocresol and zinc oxide eugenol (ZOE)-treated tooth 75 displaying a furcal radiolucency and pathologic root resorption at 9 months and 21 days in a 5-year-old child. (b) Gross photograph of extracted tooth 75 displaying a well-adapted stainless steel crown, excess cement, and resorptive pitting of the mesial and distal roots. (c) Sectioned tooth 75 displaying areas of necrosis, root resorption, ZOE dissolution and staining of ZOE suggesting pulpal hyperaemia.

Radiographic assessment at 15·7 months revealed no significant difference between treatment types ($P > 0{\cdot}05$), although the FC-ZOE pulpotomy displayed a radiographic success rate of 87·5% compared to

Fig. 6. Formocresol and zinc oxide eugenol-treated teeth 84 and 85 displaying furcal radiolucencies and areas of pathological root resorption at 13 months and 27 days in a 5·5-year-old child.

Table 2. Distribution of all treatment outcomes per operator at 15·7 months: (FC-ZOE) formocresol and zinc oxide eugenol; and (L-MTA) laser-mineral trioxide aggregate.

	FC-ZOE		L-MTA		
Operator	Sound	Failure	Sound	Failure	Total
1	11	2	15	6	34
2	2	0	0	0	2
3	2	0	1	0	3
4	0	1	1	0	2
5	1	0	0	0	1
6	1	0	0	1	2
7	4	0	0	0	4
Total	21	3	17	7	48

Table 3. Radiographic outcomes among both treatment groups at 15·7 months: (FC-ZOE) formocresol and zinc oxide eugenol; and (L-MTA) laser-mineral trioxide aggregate.

Success/failure	FC-ZOE	L-MTA	Total
Sound	21	17	38
Failure	3	7	10
Total	24	24	48

the L-MTA pulpotomy, which displayed a radiographic success rate of 70·8%. This percentage difference may have clinical implications among a larger sample. The clinical and radiographic success rates for the FC-ZOE technique reported in this study are consistent with those reported in previous studies [5–7,35–37].

The clinical and radiographic success rates of the L-MTA pulpotomy reported in this study are consistent with other previously studied pulpotomy alternatives [38,39]. The only available laser pulpotomy study for the purpose of outcome comparison was conducted by Elliot *et al*. [18]. That prospective study, comparing a CO_2 laser-ZOE pulpotomy to the FC-ZOE technique, revealed a radiographic success rate of 86·7% for 15 laser-treated, caries-free primary canines at 90 days post-treatment. It is questionable as to whether those results could be reproduced in the caries-active primary molar at a longer duration of follow-up. Lastly, the clinical and radiographic success rates of the L-MTA pulpotomy may, in fact, approach those of the FC-ZOE pulpotomy if one discounts failures potentially arising from technique errors.

Detailed analysis of failures is seldom reported following *in vivo* clinical trials of pulpally treated human teeth. In this study, photographic assessment of sectioned teeth revealed a number of iatrogenic errors, which may have contributed to the failure rate among the L-MTA group. While it may be argued that these errors are likely to occur in both the experimental and the control groups, it is quite possible that the L-MTA pulpotomy is more sensitive to operator technique. Poorly adapted SSCs, a thin base, voids within cement, and areas of residual caries or coronal pulp tissue may have a more detrimental effect on the long-term success of the technique-sensitive L-MTA pulpotomy compared to the FC-ZOE pulpotomy. This might be the case, especially since the L-MTA does not provide a sustained bactericidal and fixative effect as afforded by formocresol. To date, only one of the three FC-ZOE failures was available for photographic assessment (Fig. 5a–c). This extracted tooth 75 did not reveal any obvious iatrogenic errors which may have contributed to treatment failure; however, it did display some haematopoetic staining of the ZOE base, which may be evidence of pulpal hyperaemia at the time of treatment. If this evidence is assumed to be correct, then FC-ZOE-treated tooth 75 should not have been selected for participation in this study because of the presence of uncontrollable pulpal haemorrhage at the time of treatment.

The ability to detect an uncontrollable pulpal haemorrhage in the FC-ZOE technique, as outlined by Levine *et al*. [40], provides a significant diagnostic advantage over the L-MTA pulpotomy [40]. The act of pulpal ablation through successive applications of the diode laser results in pulp stumps free of haemorrhage, and therefore, may mask a truly hyperaemic pulp. This fact may have resulted in the inappropriate selection of hyperaemic teeth for pulpotomy therapy, contraindicated by Levine *et al*. [40], which may in turn have contributed to the lower success rates found in the L-MTA treatment group. Previous literature describing pulpal haemorrhage and its relationship to pulpal vitality is limited in predictive value [41]. Future studies investigating this relationship would be of significant benefit to the clinician in search of additional diagnostic information.

It is also interesting to note that five of the seven experimental group failures occurred amongst the very first five L-MTA-treated teeth. This fact may indicate a learning curve associated with the new technique, which might lead to an improvement in overall successes with each additional tooth treated. With that caveat, long-term analysis of all naturally exfoliating teeth from both treatment groups, in addition to analysis of any future failures, is necessary to determine the effect of iatrogenic operator errors on pulpotomy technique.

However, these errors may not be the sole reason for failure in the L-MTA pulpotomy group. The diode laser itself may produce medium-extent peripheral thermal damage to the surrounding pulp tissue similar to that produced by the carbon dioxide laser studied by Miserendino *et al*. [25]. Potential thermal damage may be prevented by reducing the wattage of power emitted through the laser tip by reducing the pulse frequency, or by reducing total laser application time in addition to the use of copious water irrigation during laser application. Future *in vitro* studies with histological analysis, as suggested by Kimura *et al*. [42], may be necessary to determine the appropriate settings for the diode laser when treating pulpally involved human primary teeth.

It is also important to recognize that the success rates found in this study do not approach the reported success rates of MTA when used alone as a pulpotomy agent. Eidelman *et al*. reported 100% clinical and radiographic success rates for 17 primary molars treated with an MTA pulpotomy at a mean follow-up time of 13 months (range = 6–30 months) [43]. Because of the design of the present study, it is difficult to tell whether the diode laser or the MTA is having the primary affect on treatment outcomes. One cannot rule out that the diode laser may actually be responsible for the reduced success rates seen in this study, and in fact, may be unnecessary if the MTA pulpotomy continues to show high success rates in future studies. Further studies should compare the diode laser with formocresol and formocresol with MTA so that direct comparisons of similar techniques can be more readily evaluated.

Lastly, one must consider the costs associated with the various pulpotomy procedures. The cost of the diode laser used in this study is approximately \$30 000·00 CDN, while a single MTA application used in this study is approximately \$20·00 CDN. Only with a continued reduction in material and equipment prices could the L-MTA pulpotomy become acceptable when compared to the other relatively inexpensive treatment alternatives.

Overall, equivocal results have been observed using the diode L-MTA pulpotomy at 15·7 months. A larger sample size and long-term follow-up is necessary in order to appropriately compare the two treatment modalities. An improvement in operator technique, specifically with respect to the L-MTA pulpotomy, may result in an improvement in long-term success rates.

What this paper adds
- There were no significant differences between diode laser-mineral trioxide aggregate pulpotomy for primary teeth compared to formocresol-zink oxide eugenol after 16 months.
- Of all pulpotomies performed using diode laser-mineral trioxide aggregate, 29% were considered as failures.

Why this paper is important to paediatric dentists
- Improved success rates and additional studies using larger patient samples are required if diode laser-mineral trioxide aggregate pulpotomy is to be considered as an alternative to conventional pulpotomy.

Conclusions

The laser-MTA pulpotomy showed reduced radiographic success rates compared to the FC-ZOE pulpotomy at 15·7 months follow-up; however, these results were not statistically significant. Improved success rates among a larger patient sample and a longer follow-up period would be required for the laser-MTA pulpotomy to be considered as a routine alternative to the conventional FC-ZOE procedure. Meticulous restorative techniques must be followed to ensure the success of laser-MTA pulpotomies.

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Résumé. *Propos.* Cette étude a eu pour objectif d'étudier sur les dents temporaires humaines si une pulpotomie au laser à diode avec scellement au MTA peut être une alternative acceptable à la pulpotomie conventionnelle au formocrésol et pâte ZOE.
Méthodes. Une étude randomisée en simple aveugle a été menée en *split mouth* chez 16 enfantsâgés de 3 à 8 ans (âge moyen 5,10 ans). Un total de 26 paires de dents a été sélectionné chez ces 16 patients sur la base de critères radiographiques et cliniques. Une dent de chaque paire a été assignée au hasard au groupe LASER-MTA ou au groupe formocrésol-ZOE. Toutes les dents ont été suivies cliniquement et radiographiquement à 2, 3, 5,2, 9,5 et 15,7 mois. Toutes les dents extraites pour cause d'échec ont été sectionnées et photographiées pour évaluer les motifs possibles d'échec.
Résultats. Un total de 7 dents traitées au LASER-MTA ont été estimées comme des échecs par radiographie (temps moyen avant échec = 9,1 mois) contre 3 traitées au formocrésol-ZOE (temps moyen avant échec = 12,5 mois). Ces résultats n'étaient pas significatifs d'après le test exact de Fisher ($p > 0,05$). Six des échecs LASER-MTA et les 3 échecs formocrésol-ZOE présentaient des zones radio-claires à la furcation et/ou périapicales, avec ou sans résorption radiculaire pathologique. Un des échecs LASER-MTA a montré une résorption radiculaire prématurée et est surveillée durant son exfoliation. L'analyse des photographies des dents extraites a révélé des erreurs de technique clinique en plus des signes attendus de processus pathologique tels que la présence de tissu de granulation et des zones de résorption pathologique radiculaire.
Conclusion. La pulpotomie LASER-MTA a montré à 15,7 mois un taux de succès radiographique réduit comparé à la pulpotomie formocrésol-ZOE. Ces résultats ne sont cependant pas statistiquement significatifs. Une amélioration du taux de succès dans un groupe plus important de patients et sur une période de temps plus longue serait nécessaire pour que la pulpotomie LASER-MTA soit considérée comme une alternative de routine à la procédure conventionnelle formocrésol-ZOE. Des techniques de restauration méticuleuses doivent être appliquées pour assurer le succès des pulpotomies LASER-MTA.

Zusammenfassung. *Ziel.* Ziel dieser Studie war es zu untersuchen, ob eine Diodenlaser-MTA Methode

eine akzeptable Alternative zur konventionellen Formokresol Pulpotomie mit ZOE Abdeckung bei menschlichen Milchzähnen.
Methoden. Eine randomisierte, einfach verblindete Halbseitenstudie wurde durchgeführt bei einer Stichprobe von 16 Kindern (Alter 3 bis 8 Jahre, mittleres Alter 5.10 Jahre). Es wurden insgesamt 26 Zahnpaare von diesen 16 Patienten ausgewählt basierend auf klinischen und röntgenologischen Kriterien. Ein Zahn aus jedem Paar wurde zufällig entweder der Diodenlaser-MTA-Gruppe oder der Formokresol-ZOE zugeordnet. Alle Zähne wurden klinisch und röntgenologisch nach 2.3, 5.2, 9.5 und 15.7 Monaten nachuntersucht. Alle extrahierten Misserfolge wurden geschnitten und photographiert, um mögliche Ursachen zu ermitteln.
Ergebnisse. Insgesamt 7 Laser-MTA Zähne wurden als Misserfolge eingestuft (nach einer mittleren Zeit von 9.1 Monaten) im Vergleich zu 3 Misserfolgen bei Formokresol-ZOE Zähnen (nach einer mittleren Zeit von 12.5 Monaten). Die Ergebnisse waren nicht statistisch signifikant bei Analyse anhand des Fischers exaktem Test ($p > 0.05$). Sechs der Laser-MTA Misserfolge und alle drei Formokresol-ZOE Misserfolge wiesen im Röntgenbild interradikuläre und/oder periapikale Aufhellungen auf mit oder ohne pathologische Resorptionen. Ein Zahn der Laser-MTA Misserfolge wies pathologische Resorptionen auf, die zur vorzeitigen Exfoliation führten. Die Analyse der Photographien der extrahierten Zähne brachten Behandlungsfehler zutage sowie absehbare Zeichen der daraus resultierenden Prozesse wie Granulationsgewebe oder Areale von pathologischer Wurzelresorption.
Schlussfolgerung. Die Laser-MTA Pulpotomie zeigte röntgenologisch eine geringere Erfolgsrate als Formokresol-ZOE Pulpotomie nach 15.7 Monaten, auch wenn diese Ergebnisse nicht statistisch signifikant waren. Verbesserte Erfolgsraten in einem größeren Kollektiv und eine längere Nachbeobachtungszeit wären erforderlich, um die Laser-ZOE Pulpotomie als Routine-Alternative zur konventionellen Laser-MTA Pulpotomie in Betracht zu ziehen. Exakte Restaurationstechniken müssen befolgt werden, um den Erfolg der Laser-Pulpotomie sicherzustellen.

Resumen. *Objetivo.* El propósito de este estudio fue investigar si una pulpotomía con LASER diodo y sellada con MTA podía ser una alternativa aceptable a la pulpotomía convencional con formocresol y sellada con OZE en dientes humanos primarios.
Métodos. Se hizo un estudio randomizado, a simple ciego, en boca partida, con una muestra de 16 niños entre 3 y 8 años de edad (edad media de 5,10 años). En estos 16 pacientes se seleccionó un total de 26 pares de dientes, basados en criterios clínicos y radiográficos. Se asignó aleatoriamente un diente de cada par, tanto para el grupo de pulpotomía LASER-MTA o para el grupo de pulpotomía formocresol–OZE. Todos los dientes se siguieron clínica y radiográficamente a los 2,3, 5,2, 9.5 y 15,7 meses. Todos los fallos extraídos se seccionaron y fotografiaron para valorar posibles razones del fallo.
Resultados. Se señalaron como fallos radiográficos un total de 7 dientes tratados por LASER-MTA (tiempo medio hasta el fallo = 9,1 meses) comparados con 3 dientes tratados con formocresol-OZE (tiempo medio hasta el fallo = 12,5 meses). Estos resultados no fueron significativos usando el test exacto de Fisher ($p > 0,05$). Seis de los fallos de LASER-MTA y los 3 fallos de formocresol-ZOE mostraban radiolucencias furcales y/o periapicales con o sin reabsorción radicular patológica. Uno de los fallos de LASER-MTA mostró reabsorción radicular prematura y está siendo observado hasta su exfoliación. El análisis de las fotografías de los dientes disponibles por la extracción reveló errores en la técnica clínica además de los signos esperados del proceso de una lesión tales como la presencia de tejido de granulación y de áreas de reabsorción radicular patológica.
Conclusiones. La pulpotomía de LASER-MTA mostró porcentajes de éxito radiográfico reducidos comparados con la pulpotomía de formocresol-OZE; sin embargo, a los 15,7 meses estos resultados no fueron estadísticamente significativos. Se requerirían mejores porcentajes de éxito con una muestra más grande de pacientes y un período de seguimiento más largo de la pulpotomía LASER-MTA para ser considerada una alternativa rutinaria al procedimiento convencional formocresol-OZE. Deben seguirse técnicas restauradoras meticulosas para asegurar el éxito de las pulpotomías con LASER-MTA.

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