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A comparative evaluation of four regenerative materials for pulpotomy in primary molars: An *in vivo* study

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ABSTRACT

Background: Preservation of pulpal vitality is of paramount importance as the vital functioning pulp is capable of initiating a unique reparative capacity. The present study aimed to evaluate and compare four regenerative materials for pulpotomy in primary molars.

Materials and Methods: This *in vivo* study included a total of 120 primary molars from 30 healthy children aged 3–9 years for regenerative pulpotomy procedure. The teeth were then divided by the lottery method (chits with names of materials on it) into four groups so that each child received all four of the regenerative materials; Group I: Biodentine (BD)™, Group II: Mineral Trioxide Aggregate Plus (MTA Plus™), Group III: Retro MTA (Retro MTA®), and Group IV: Calcium Enriched Mixture (CEM) cement. All the primary molars (Ist/2nd molars) were evaluated clinically and radiographically at 6, 12, 18, and 24 months. Data were subjected to the statistical analysis using the Chi-square test. The level of significance was considered as $P < 0.05$.

Results: Clinical evaluation showed 100% success with BD™ and CEM cement; whereas 96.2% success was seen with MTA Plus™ and Retro MTA®. On radiographic evaluation, MTA Plus™ and CEM cement showed 96.2% success, whereas BD™ and Retro MTA® showed 92.59% success rate.

Conclusion: All four regenerative materials showed high success in the pulpotomy of primary molars.

Key Words: Mineral trioxide aggregate, primary teeth, pulpotomy, tricalcium silicate

INTRODUCTION

Retaining primary molars is of prime requisite for mastication, preserving arch length, growth of jaws, and also protect from developing oral habits. Hence, essential pulp treatment focus to treat reversible pulpal injuries, in which tooth is affected by caries, injury, or any restorative procedures. Pulpotomy is as yet comprehensively performed treatment for cariously involved pulp in asymptomatic primary molars.[1]

Pulpotomy materials are classified according to devitalization, preservation, and regeneration. Formocresol a devitalizing agent used for pulpotomy was introduced by Sweet in 1932. It was a successful material with some disadvantage. There has been the plenty of literature about the suitability and well-being of utilizing this aldehyde-based material in pediatric dentistry.[2]

Since the introduction of mineral trioxide aggregate (MTA), there has been a keen interest

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in regenerative endodontics.[3] Newer regenerative materials with bioinductive, biocompatible, and bactericidal properties have been launched. These preserve the healthy radicular pulp tissue.

Although MTA has been used extensively, the material has some inherent limitations that include high solubility, difficult handling characteristics, presence of toxic elements in the composition, higher cytotoxicity in its freshly mixed state (ISO 10993-5) (ISO 10993-3),[4,5] and high pH during setting. This inflicted to the evolution of newer improved MTA-based products (such as MTA Plus, Retro MTA, ortho MTA, Endocem MTA, MTA Fillapex, Endoseal.) MTA Plus (MTA Plus™) (Prevest Denpro Limited, Jammu, India; lot. 41001 Avalon Biomed Inc.) was introduced with a finer particle size to improve the handling characteristics of MTA. A new bioceramic material, Retro MTA® (BioMTA, Seoul, Korea) was also introduced to upgrade the properties of MTA. RetroMTA contains zirconia, a radiopacifying agent, which does not cause discoloration and is fast setting.[6]

Biodentine™ (Septodont, Saint-Maur-des-Fosses, France) is a tricalcium silicate (Ca3SiO5) based inorganic restorative cement and is used as an alternative to MTA.[7] It is also known as "bioactive dentine substitute" and has higher mechanical properties.[8] BD™ has an advantage over MTA, besides its biocompatibility, mechanical, and physical properties are better.

Calcium enriched mixture (CEM) cement (Bionique Dent, Tehran, Iran) is a calcium silicate-based material.[9] The sealing ability of CEM is comparable to MTA.[10] With its smaller particle size, CEM can promote hydroxyapatite and also induce hard-tissue formation.[11] It also shows a superior antibacterial effect and improved handling.[9] Several studies have compared MTA with other materials for pulpotomy in primary teeth.[12-15] Most studies on pulpotomy compared regenerative materials with devitalizing and preservative materials.[16,17]

Hence, the aim was to evaluate the clinical and radiographic success of MTA-based materials (MTA Plus™ and RetroMTA®) and compare with BD™ and CEM cement as pulpotomy medicament in deciduous molars.

MATERIALS AND METHODS

In this interventional study design, normal, healthy, and cooperative children were selected from the patients attending the Department of Pedodontics and Preventive Dentistry, The Oxford Dental College, Bengaluru, India. Permission was obtained from institutional ethical review board (222/2014-15, 430/2015-16). The dental health of the child and treatment required was discussed with the parents of the children. Prior written consent was obtained from the parents for carrying out the pulpotomy procedure, and the importance of periodic follow-up visits was explained.

One hundred and twenty teeth were chosen in 30 children aged 3–9 years, who had no medical condition that would contraindicate pulp therapy. As it an open-label trial, the participants were aware of regenerative materials placed in their teeth. Four primary molars were involved in the study, thus each participant had to have at least four primary molars (first and/or second mandibular and maxillary primary molars), requiring pulpotomy. A brief history was recorded, and the teeth were exposed to the clinical examination and radiographic evaluation before the beginning of the study.

Vital primary molars with probable carious pulp exposure, absence of spontaneous pain or persistent pain, no clinical symptoms or evidence of pulp degeneration such as pain on percussion, history of swelling or sinus tracts, hemorrhage from the amputation site is bright red and easy to control and teeth that could be restored with stainless steel crowns.[18,19]

Radiographic criteria: No evidence of physiologic root resorption, absence of furcal and/or periapical radiolucency, absence of internal or external root resorption, absence of pathologic root resorption.[18,19]In this split-mouth study design (complex randomization), four primary molars were allocated by the lottery method to four groups in each participant. The teeth requiring pulpotomy were selected based on the above-mentioned criteria. Once the child is made to sit on the dental chair for the treatment, according to lottery method, the chits of materials name written on it were placed in the box and children were allowed to pick the chits. Thus, the child had to pick four chits one after other so that all the materials are selected once. The selected materials were randomly placed onto the tooth.

- Group I: BD™ (Septodont, Saint-Maur-des-Fosses, France)
- Group II: MTA Plus™ (MTA-P) (Prevest Denpro, Avalon Biomed Inc., Jammu, India; lot. 41001)

Figure 1: Internal root resorption and external root resorption seen with biodenitne and mineral trioxide aggregate plus.

Figure 2: Radiograph showing furcal radiolucency with molar treated with RetroMTA.

Figure 3: Periodontal ligament space widening with calcium enriched mixture cement.

- Group III: RetroMTA®, (R-MTA) (BioMTA, Seoul, Korea)
- Group IV: Calcium Enriched Mixer cement (CEM cement®, BioniqueDent, Tehran, Iran).

A conventional pulpotomy procedure was performed on the selected teeth. Following the administration of local anesthesia (LOX 2% adrenaline 1:200,000, 30 ml, NEON laboratories limited, Mumbai, India) rubber dam (GDC rubber dam kit, GDC Fine Crafted Dental Pvt Ltd.) isolation was carried out. All dental caries and overhanging enamel were removed with a No. 330 FG high-speed small diamond bur (0.9 mm Diameter, 2.8 mm Length, Midwest® Dentsply Sirona) with water spray. Removal of all carious dentin was carried out. A sterile No. 4 RA (diameter 1.4 mm, length 1.4 mm DENTSPLY) or 8 RA (diameter 2.3 mm, length 2.3 mm DENTSPLY) round slow-speed diamond bur was used to remove entire coronal pulp. The pulp stumps were excised until the canal orifices seen clearly with no tags remaining on the pulpal floor. Irrigation of the pulp chamber was done using normal saline. After completion of the amputation, hemorrhage was controlled within 3–5 min using slightly moistened cotton pellets placed against the pulp stumps at the orifices of the root canals.[18,19]

In group I, BD™ (Septodont, Saint-Maur-des-Fosses, France) five drops of liquid from the pipette were added to the capsule containing 0.7 g of powder, as per the manufacturer's instruction. The content of the capsule was then triturated for 30 s at 4200 rpm. A plastic carrier (provided by the manufacturer) was used to transfer the mix, to standardize the quantity of material placed. The material was condensed over the root canal orifices using an amalgam carrier and moistened cotton pellet. The pulp cavity was filled with BD™. The material was condensed lightly using a cylindrical amalgam condenser to confine the placement of the material at the root canal orifices.[20]

In Group II, MTA Plus™ (MTA P) (MTA Plus (Prevest Denpro, Avalon Biomed Inc, Jammu, India; lot. 41,001) 1 scoop of powder was dispensed on a glass slab and 1 drop of the liquid anti-washout gel was added to the powder and mixed on a glass slab with a cement spatula. The powder/gel ratio was 2.5:1 by weight. The thick mix of MTA Plus™ was then placed at the root canal orifices using a plastic filling instrument and condensed lightly using an amalgam cylindrical condenser.[21]

In Group III, RetroMTA® (R-MTA) (BioMTA, Seoul, Korea) the cap was opened and 0.3 g of powder from

the pouch was dispensed into the floor of the cap. The plastic pipette was cut with scissors and three drops of liquid (distilled water) were added onto it. An agate spatula was used for wetting the powder with liquid for 20 s. To standardize the quantity of the material used, an MTA carrier was used to transfer the RetroMTA® to the root canal orifices. The material was condensed with proper pressure using a cylindrical condenser to confine the material placement at the root canal orifices.[22]

In Group IV, CEM cement (CEM cement®, BioniqueDent, Tehran, Iran) powder and the liquid were dispensed onto a mixing pad at a ratio of 1:1 by weight according to manufacturer's instructions. Gradually, the liquid was incorporated into the powder using plastic spatula for 15–30 s to ensure that all powder particles were hydrated. More liquid was added to achieve a thick and creamy consistency. A wet gauze pad was used to cover the mixed material to prevent evaporation, hence increasing the working time. The CEM cement was carried to the root canal orifices using a plastic filling instrument and adapted to the orifices with dry cotton pellets using gentle pressure.[9]

In all the teeth, following placement of the regenerative agents, the pulp chamber was filled with GC Miracle Mix® (GC Corporation, Tokyo, Japan) following rubber dam removal, the occlusion was checked for high points using articulating paper. Final restoration with a stainless-steel crown (3M ESPE, Dental Products, St. Paul, MN, USA) was given following the pulpotomy procedure.[23]

The patients were recalled for clinical and radiographic evaluation at 6, 12, 18, and 24 months. Clinical evaluation was done by noticing any signs and symptoms in the tooth treated. Radiographically, an intraoral periapical radiograph was taken for the evaluation. Radiographically, X-rays were evaluated under the X-ray viewer by three examiners and findings were noted separately for each child and each material. The examiners were aware of the materials placed. Participants were also instructed to report to the department on the development of any signs and symptoms regarding the treated teeth, during the intervening period. At the end of 2 years follow-up, 27 children were available, as 2 children relocated to other states and one child's parents did not give consent for continuing the study at 2 months period.

Statistical analysis

Data obtained were subjected to the statistical analysis using SPSS (Statistical Package for the Social Sciences) for Windows version 22.0 Released 2013. Armonk, NY, USA: IBM Corp. The Chi-square Test was used to compare the clinical and radiological parameters between different study groups at 18 months and 24 months of follow-up periods. The level of significance was set at $P < 0.05$.

RESULTS

At the end of the study period, 27 children and 108 teeth were available [Tables 1 and 2]. Clinically and radiographically, all teeth were rated successful until the 12-months follow-up period. In the 18th month, clinically one failure was seen with

Table 1: Distribution of the primary molars according to pulpotomy material

Materials	1st primary molars		2nd primary molar		Total (number of primary teeth)
	Maxillary (*n*)	Mandibular (*n*)	Maxillary (*n*)	Mandibular (*n*)	
Biodentine	7	17	2	4	30
MTA plus	10	6	9	5	30
Retro MTA	4	12	4	10	30
CEM cement	6	5	8	11	30

MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Table 2: Distribution of teeth at 24 months (3 children dropped out)

Materials for pulpotomy	1st primary molars		2nd primary molar		Total (number of primary teeth)
	Maxillary (*n*)	Mandibular (*n*)	Maxillary (*n*)	Mandibular (*n*)	
Biodentine	6	15	2	4	27
MTA plus	8	6	8	5	27
Retro MTA	4	11	4	8	27
CEM cement	6	5	6	10	27

MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Group II [Table 3]. In the 24th month, one more failure was seen with Group III (P = 0.86) [Table 4] with the Chi-square value χ^2 = 0.750. At 18th month, radiographically, one failure was observed in Group I and Group II groups, whereas no failure was observed in Group III and Group IV [Table 5] with Chi-square values $\chi^{2:}$ 10.500, P = 0.31. At the 24-month follow-up, one radiographic failure was observed in Group I and Group IV; two failures were observed in Group III [Table 6] with Chi-square values $\chi^{2:}$ 10.500, P = 0.31. The percentage of radiographic failures and clinical failure showed were 92.5% in Group I and Group II, 88.8% in Group III, and 96.5% in Group IV at the end of the study thus there was no statistically significant difference seen between the groups (P = 0.05) [Table 7].

DISCUSSION

A short procedural period is critical to reduce the likelihood of disruptive behavior among pediatric patients. Nowadays, newer materials which are biologically acceptable are considered superior in dentistry, as the priority has changed from preservation to regeneration. Hence, materials with better biologic properties such as improved antibacterial activity, ability to form odontoblast like cells, less cytotoxic activities and few mechanical properties like improved radiopacity, no microleakage, fracture resistant, increased shear bond strength and faster setting time has been introduced. These properties of the materials help enhance the success rate of the treatment done in primary teeth. In present study, regenerative materials like BD™ MTA-based cements (MTA Plus™, Retro MTA®) and CEM cement® were assessed clinically and radiographically in pulpotomy procedure. These materials have got improved biological and mechanical properties.[20-23]

Pulpotomy was regarded as successful with no clinical signs and radiographic failures. The pulp in primary teeth is more cellular and has a greater blood supply which can play an important role in the success rate of pulpotomy.

In the present study, Group I (BD™) showed the clinical success of 100% during the overall study period. The absence of clinical signs and symptoms may be due to the inherent property of BD™ itself. The setting and hardening of the cement happened because of the ability of calcium silicate that has interacted with water. Tricalcium silicate mixed with the liquid component leads to the formation of a hydrated calcium silicate gel and calcium hydroxide. BD™ forms hydroxyapatite crystals at the surface. The sealing ability at the interface of the material

Table 3: Clinical failures in pulpotomized primary molars till 18 months' follow-up

Parameters	A	B	C	D	E	F	Total	
							Number of failure teeth	Number of successful teeth
Biodentine	-	-	-	-	-	-	0	27
MTA plus	1	-	-	-	-	-	1	26
Retro MTA	-	-	-	-	-	-	0	27
CEM cement	-	-	-	-	-	-	0	27

A: Pain symptoms; B: Tenderness to percussion; C: Swelling; D: Pathologic mobility; E: Fistulation; F: Premature exfoliation; MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Table 4: Clinical failures in pulpotomized primary molars at the end of the study (24 months)

Parameters	A	B	C	D	E	F	Total	
							Number of failure teeth	Number of successful teeth
Biodentine	-	-	-	-	-	-	0	27
MTA plus	-	-	-	-	-	-	0	26
Retro MTA	-	1	-	-	-	-	1	26
CEM cement	-	-	-	-	-	-	0	27

χ^2=0.750, P=0.86. A: Pain symptoms; B: Tenderness to percussion; C: Swelling; D: Pathologic mobility; E: Fistulation; F: Premature exfoliation; MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Table 5: Radiographic failures in pulpotomized primary molars till 18 months

Parameters	G	H	I	J	K	Total	
						Number of failure teeth	Number of successful teeth
Biodentine	-	-	-	1	-	1	26
MTA plus	-	-	-	-	1	1	26
Retro MTA	-	-	-	-	-	0	27
CEM cement	-	-	-	-	-	0	27

χ^2=10.500, P=0.31. G: PDL space widening; H: Periapical radiolucency; I: Furcal radiolucency; J: External root resorption; K: Internal root resorption; MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Table 6: Radiographic failures in pulpotomized primary molars till 24 months

Parameters	G	H	I	J	K	Total	
						Number of failure teeth	Number of successful teeth
Biodentine	-	-	1	-	-	1	25
MTA plus	-	-	-	-	-	0	26
Retro MTA	-	-	1	1	-	2	25
CEM cement	1	-	-	-	-	1	26

χ^2=10.500, P=0.31. G: PDL space widening; H: Periapical radiolucency; I: Furcal radiolucency; J: External root resorption; K: Internal root resorption; MTA: Mineral trioxide aggregate, CEM: Calcium enriched mixture

Table 7: Overall success of all the four regenerative materials placed in primary molars at the end of 24 months follow-up

Materials for pulpotomy	Clinical success	Radiographic success	Overall success
Biodentine	100% (0 failure)	92.59% (2 failure)	92.59% (2 failure)
MTA plus	96.2% (1 failure)	96.2% (1 failure)	92.59% (2 failure)
Retro MTA	96.2% (1 failure)	92.5% (2 failure)	88.8% (3 failure)
CEM cement	100% (0 failure)	96.2% (1 failure)	96.2% (1 failure)

and dentinal walls increased by these crystals. BD™ is mechanically stronger, less soluble with increased compressive strength, decreased porosity which gives a tighter seal.[24,25]

BD™ also inhibits the growth of streptococcus mutans and *Enterococcus faecalis*. Thus, the antibacterial property of BD™ is proved to be better as compared to MTA.[26] This property is very significant for the clinical success of any restorations. The above-mentioned properties of BD™ could also be one of the contributing factors for the clinical success observed throughout the evaluation period. El Meligy *et al*. reported 100% success rate with BD clinically and radiographically in primary molars in a 12 months randomized controlled trial.[27]

Radiographically, at 18 months of evaluation period in Group I, External root resorption [Figure1] one primary molar which was considered as a failure. The reason for this can be individual immunological response to the regenerative agent. Gonçalves *et al*.[28] reported that the teeth treated with pulpotomy procedure were approximately three times more likely to have a periapical lesion, a finding which follow with that reported by Aminabadi *et al*.,[29] who reported that root resorption was the second most common finding with the teeth undergone with pulpotomy procedure. Thus, root resorption can be due to errors in the diagnosis or due to failures in the performing the pulpotomy procedures. Nasseh *et al*. reported that BD™ showed highest clinical and radiographic success with the primary molars with root resorption. Thus, the study concluded that BD™ is better material as pulpotomy agent.[30]

At 24 months, furcal radiolucency was observed in one tooth with the first primary mandibular molar in Group I. Furcal radiolucency was observed to occur more frequently in first primary molars, probably due to their anatomic feature such as smaller crown size and highly situated pulpal horns.

In Group II (MTA Plus™), clinical success was 100% at 6 and 12 months, whereas at 18 months, one clinical failure was observed, and the tooth was discarded. At 24 months, 96.67% success was observed wherein, one patient complained of pain and tenderness to percussion with respect to the primary second molar.

Radiographically, at 6 and 12 months, pulpotomized teeth were 100% successful. An 18-month radiographic evaluation, one tooth presented with Non perforated internal root resorption [Figure1] which did not cause any clinical symptoms. The tooth was asymptomatic and was kept under observation. As it is not considered as failure[31] but as resorption was progressing with clinical symptoms observed as a sign of pulpotomy failure.

The cause for the progress of inflammation may be assigned to various factors. Such as microbial stimulus, pulp coronal to the resorption must be partially or completely necrotic, allowing microbial antigens to invade the healthy pulp and alkalinity of the material; the calcium oxide in MTA Plus™ that forms calcium hydroxide could cause metaplasia within the pulp leading to osteoclastic activity.[29] Hence, the bacterial toxins which have entered the tissue cannot be detected through general examinations.

In Group III (RetroMTA®), clinical success which was observed until 18 months had suggested that the material property proved to be better clinically with the success rate of 96.7% with one failure at 24 months. The reason for the clinical success can be attributed to the short setting time, reduced the possibility of material washout, no leaching of cytotoxic substances.[22] Radiographically,the two primary molars showed furcal radiolucency and extral root resorption ,the reason can be the amount of pulpal involvement cannot be determined by the radiographic criteria [Figure 2]. Time elapsed since the caries exposure and pulpotomy procedure performed.[28] Kang *et al*. reported RetroMTA reported 100% success rate clinically as a pulpotomy agent when compared to orthoMTA and ProRootMTA.[16]

In Group IV (CEM cement), clinically, all the pulpotomized molars showed 100% success, the reason could be its antibacterial activity of cement. CEM cement has a 0.5–2.5 μm fine particle which is smaller than the diameter of a dentinal tubule (2–5 μm). Therefore, they can seal the dentinal tubules by providing hydraulic tree by going

into tubules and a high local pH which can also result in more effective antibacterial activity.[32,33] Biocompatibility of CEM cement is correlated with calcium ions released during setting, these ions bind with phosphorus to form hydroxyapatite crystals and there is a cellular enzymatic activity which changes permeability to facilitate healing.[34,35]

CEM cement as pulpotomy agent shows reduced inflammation [Figure 3], better quality, and thickness of calcified bridge. Odontoblastic cell morphology is comparable to calcium hydroxide. It helps in cessation of internal resorption and healing of condensing apical periodontitis.[36-38]

At 24 months of the evaluation period widening of the periodontal space was observed in one of the second primary mandibular molar which was considered as a sign of pulpotomy failure [Figure 3]. Studies comparing these regenerative materials are very scarce. In our study, all the groups showed better results with no significant difference between them. Accurate diagnosis of pulp status and proper techniques are essential for the success of pulpotomy and if some doubts about condition of pulp exist, the other methods such as pulpectomy or extraction must be considered.[39] Thus, further studies evaluating the histopathologic findings of treated teeth with these agents should be conducted.

Limitations that should be considered include: The children were followed up by investigators who were part of the clinical study. Even though the treated teeth were evaluated fairly according to the set study criteria, clinician bias cannot be completely excluded, whereas there was a high chance of bias while making different decisions by both the observer.

CONCLUSION

All the four regenerative materials can be successfully used as pulpotomy agents in primary teeth.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

REFERENCES

1. Pulp therapy for primary and immature permanent teeth. Pediatr Dent 2017;39:325-33.
2. Holan G, Eidelman E, Fuks AB. Long-term evaluation of pulpotomy in primary molars using mineral trioxide aggregate or formocresol. Pediatr Dent 2005;27:129-36.
3. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. J Endod 1993;19:541-4.
4. Ko H, Yang W, Park K, Kim M. Cytotoxicity of mineral trioxide aggregate (MTA) and bone morphogenetic protein 2 (BMP-2) and response of rat pulp to MTA and BMP-2. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;109:e103-8.
5. Kim EC, Lee BC, Chang HS, Lee W, Hong CU, Min KS. Evaluation of the radiopacity and cytotoxicity of Portland cements containing bismuth oxide. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:e54-7.
6. Souza LC, Yadlapati M, Dorn SO, Silva R, Letra A. Analysis of radiopacity, pH and cytotoxicity of a new bioceramic material. J Appl Oral Sci 2015;23:383-9.
7. Bachoo IK, Seymour D, Brunton P. A biocompatible and bioactive replacement for dentine: is this a reality? The properties and uses of a novel calcium-based cement. Br Dent J. 2013;214:E5.
8. Laurent P, Camps J, De Méo M, Déjou J, About I. Induction of specific cell responses to a Ca3SiO5-based posterior restorative material. Dent Mater 2008;24:1486-94.
9. Asgary S, Shahabi S, Jafarzadeh T, Amini S, Kheirieh S. The properties of a new endodontic material. J Endod 2008;34:990-3.
10. Sahebi S, Moazami F, Sadat Shojaee N, Layeghneghad M. Comparison of MTA and CEM cement microleakage in repairing furcal perforation, an *in vitro* study. J Dent (Shiraz) 2013;14:31-6.
11. Amini Ghazvini S, Abdo Tabrizi M, Kobarfard F, Akbarzadeh Baghban A, Asgary S. Ion release and pH of a new endodontic cement, MTA and Portland cement. Iran Endod J 2009;4:74-8.
12. Aeinehchi M, Dadvand S, Fayazi S, Bayat-Movahed S. Randomized controlled trial of mineral trioxide aggregate and formocresol for pulpotomy in primary molar teeth. Int Endod J 2007;40:261-7.
13. Silva LL, Cosme-Silva L, Sakai VT, Lopes CS, Silveira AP, Moretti Neto RT, *et al*. Comparison between calcium hydroxide mixtures and mineral trioxide aggregate in primary teeth pulpotomy: A randomized controlled trial. J Appl Oral Sci 2019;27:e20180030.
14. Liu H, Zhou Q, Qin M. Mineral trioxide aggregate versus calcium hydroxide for pulpotomy in primary molars. Chin J Dent Res 2011;14:121-5.
15. Noorollahian H. Comparison of mineral trioxide aggregate and formocresol as pulp medicaments for pulpotomies in primary molars. Br Dent J 2008;204:E20.
16. Kang CM, Kim SH, Shin Y, Lee HS, Lee JH, Kim GT, *et al*. A randomized controlled trial of ProRoot MTA, OrthoMTA and RetroMTA for pulpotomy in primary molars. Oral Dis 2015;21:785-91.
17. Moretti AB, Sakai VT, Oliveira TM, Fornetti AP, Santos CF, Machado MA, *et al*. The effectiveness of mineral trioxide aggregate, calcium hydroxide and formocresol for pulpotomies in primary teeth. Int Endod J 2008;41:547-55.
18. Hargreaves K, Cohen S. Pathways of the Pulp. 10th ed. St. Louis: Elsevier; 2011. p. 822-31.

19. Mathewson RJ, Primosch RE. Fundamentals of Pediatric Dentistry. 3rd ed. Chicago: Quintessence; 1995. p. 265-74.
20. Available from: https://www.septodont.fr/fichiers_upload/biodentinescientificfile.pdf. [Last accessed on 2020 Aug 24].
21. Available from: http://www.prevestdenpro.com/prevestadmin/files/20197201618230.pdf. [Last accessed on 2020 Aug 24].
22. Available from: http://www.biomta.com/shop/eng/product_5.php, https://drive.google.com/file/d/10ZsG-wLAZuY8LZnanXR33GcyMSgcvlca/view. [Last accessed on 2020 Aug 24].
23. Rajasekharan S, Martens LC, Cauwels RG, Anthonappa RP. Biodentine™ material characteristics and clinical applications: A 3-year literature review and update. Eur Arch Paediatr Dent 2018;19:1-22.
24. Ozbay G, Kitiki B, Peker S, Kargul B. Apical sealing ability of a novel material: analysis by fluid filtration technique. Acta Stomatol Croat 2014;48:132-9.
25. Allen AJ, Thomas JJ, Jennings HM. Composition and density of nanoscale calcium-silicate-hydrate in cement. Nat Mater 2007;6:311-6.
26. Koruyucu M, Topcuoglu N, Tuna EB, Ozel S, Gencay K, Kulekci G, *et al*. An assessment of antibacterial activity of three pulp capping materials on *Enterococcus faecalis* by a direct contact test: An *in vitro* study. Eur J Dent 2015;9:240-5.
27. El Meligy OAES, Alamoudi NM, Allazzam SM, El-Housseiny AAM. BiodentineTM versus formocresol pulpotomy technique in primary molars: A 12-month randomized controlled clinical trial. BMC Oral Health. 2019;19:3.
28. Gonçalves VA, Lopes DC, Azevedo AL, Silva ML, Letícia RJ. Inflammatory root resorption in primary molars: Prevalence and associated factors. Braz Oral Res 2012;26:335-40.
29. Aminabadi NA, Farahani RM, Gajan EB. A clinical study of formocresol pulpotomy versus root canal therapy of vital primary incisors. J Clin Pediatr Dent 2008;32:211-4.
30. Nasseh HN, El Noueiri B, Pilipili C, Ayoub F. Evaluation of biodentine pulpotomies in deciduous molars with physiological root resorption (Stage 3). Int J Clin Pediatr Dent 2018;11:393-4.
31. Smith NL, Seale NS, Nunn ME. Ferric sulfate pulpotomy in primary molars: A retrospective study. Pediatr Dent 2000;22:192-9.
32. Asgary S, Eghbal MJ, Parirokh M. Sealing ability of a novel endodontic cement as a root-end filling material. J Biomed Mater Res A 2008;87:706-9.
33. Asgary S, Eghbal MJ, Parirokh M, Torabzadeh H. Sealing ability of three commercial mineral trioxide aggregates and an experimental root-end filling material. Iran Endod J 2006;1:101-5.
34. Ghoddusi J, Tavakkol Afshari J, Donyavi Z, Brook A, Disfani R, Esmaeelzadeh M. Cytotoxic effect of a new endodontic cement and mineral trioxide aggregate on L929 line culture. Iran Endod J 2008;3:17-23.
35. Asgary S, Parirokh M, Eghbal MJ, Ghoddusi J. SEM evaluation of pulp reaction to different pulp capping materials in dog's teeth. Iran Endod J 2006;1:117-23.
36. Tabarsi B, Parirokh M, Eghbal MJ, Haghdoost AA, Torabzadeh H, Asgary S. A comparative study of dental pulp response to several pulpotomy agents. Int Endod J 2010;43:565-71.
37. Asgary S, Ehsani S. Permanent molar pulpotomy with a new endodontic cement: A case series. J Conserv Dent 2009;12:31.
38. Asgary S, Eghbal MJ. Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: A multi-center randomized controlled trial. Acta Odontol Scand 2013;71:130-6.
39. Parisay I, Ghoddusi J, Forghani M. A review on vital pulp therapy in primary teeth. Iran Endod J 2015;10:6-15.