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A clinical evaluation of mineral trioxide aggregate for root-end closure of non-vital immature permanent incisors in children-a pilot study

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Abstract – The aim of this pilot study was to evaluate the clinical efficacy of mineral trioxide aggregate (MTA) as an apexification material when used in non-vital immature permanent incisors in children. Fifteen children with a mean age of 11.7 years and 17 non-vital permanent incisors were ajudged suitable for inclusion. Standard endodontic procedures were followed and an apical plug of 3–4 mm was created by using MTA after a calcium hydroxide intracanal dressing had been applied for at least 1 week. Final obturation was completed by using thermoplastisized Gutta–Percha (Obtura II) at least 1 week following MTA placement. Subjects were reviewed clinically and radiographically at 3-month intervals. Mean follow-up time for MTA was 12.53 months (± 2.94 SD). Of the total of 17 teeth treated, MTA placement was considered to be adequate in 13 teeth. The procedure showed clinical success in 94.1% of the cases, radiographic success was found to be 76.5% and in further three cases (17.6%) the outcome was considered to be uncertain. This is one of the very few studies that have reported the out coming of MTA as an apexification material in children with non-vital teeth and incomplete root development. However, larger clinical studies are required to evaluate the long-term success of this procedure.

It has been shown that approximately 20–30% of 12-year old children have suffered dental injuries (1). Although trauma may not directly affect the pulp, it may still result in a loss of vitality. If this occurs at a young age, when the root development is incomplete, the clinician faces a difficult case of an immature permanent tooth with thin dentine walls and a wide, open apex in need of endodontic treatment.

For many years the treatment of choice in these cases has been the apexification technique using calcium hydroxide (2–4). Calcium hydroxide is known to induce the formation of a hard tissue barrier in the apex (2), allowing for the obturation of the root canal to be completed. However, the apexification procedure may take many months and require multiple visits, making patient compliance a problem. It may also further weaken the teeth by the repetition of endodontic procedures during the replacement of the intracanal dressing (5, 6) and the prognosis may be compromised by the placement of a temporary coronal seal (7). To eliminate the disadvantages of the apexification technique, many alternative approaches have been suggested aiming mainly at developing a one-step procedure for the completion of the endodontic treatment. Some of these alternatives showed potential but were abandoned because of limitations in the availability of materials, while others proved to be unacceptable because of the lack of biocompatibility of the materials (8–11).

Recently, a new material has been developed for endodontics that appears to be a significant improvement over other materials used against bone. This material is mineral trioxide aggregate (MTA), which is a powder that consists of fine hydrophylic particles and sets in the presence of moisture in less than 4 h. MTA has been found to have impressive physical and chemical properties (12), while a number of animal and *in vitro* studies have shown a high degree of biocompatibility (13, 14). It is also known to provide a seal that is superior to any other material used in endodontics for the purposes of surgical or non-surgical treatment (15).

These properties make MTA a suitable material for many endodontic applications, such as pulp capping, repair of root perforations, root-end fillings and apexification (16, 17). Although numerous studies have been published regarding the use of MTA as a root-end filling material, in contrast, there is a little published information about its use in cases of immature teeth with open apices in humans. The very few studies that deal with this subject are mainly case reports, while the vast majority of the work regarding MTA in general has been produced by Torabinejad and colleagues (17–26) who were involved in the development of MTA. Therefore, there is a need for more controlled clinical studies on humans by independent researchers.

The purpose of this study was to evaluate the clinical efficacy of MTA in producing root-end closure of non-vital traumatized young permanent incisors in children.

Materials and methods

Before the main study was conducted, it was thought necessary to allow the investigators to familiarize themselves with the materials and to determine the details of the clinical procedures performed in the main study. For this purpose an *in vitro* testing of MTA (ProRoot™ MTA, Dentsply, Weybridge, UK) was carried out on five extracted premolars prepared to resemble immature incisors with open apices (Fig. 1).

An *in vivo* application of the material, which assisted in determining the details of the clinical procedure to be followed in the main study was also performed on the first four patients who consented to take part in the project. Standard endodontic procedures were used and the manufacturer's instructions were followed during mixing and application of MTA at the apex. Final obturation of the root canal was achieved by using thermoplasticized Gutta–Percha (Obtura II System, QED, Peterborough, UK), and sealer (Tubli-seal, Kerr Italia S.p.A., Salerno-Italy). Following the completion of the *in vitro* and *in vivo* placement of the material, the investigators were able to gain experience in handling the MTA and to proceed with the main study.

The population group for the main study consisted of children who attended the Trauma Clinic of the Department of Paediatric Dentistry at Leeds Dental Institute between May 2002 and July 2003. Altogether, 15 children aged 7–17 years old were found to be suitable for inclusion in this study. The inclusion and exclusion criteria used are shown in Table 1.

A written informed consent was obtained for every child from either the parent or guardian. This took the form of an explanatory information sheet and a consent form. The patient's dentist was also informed in writing

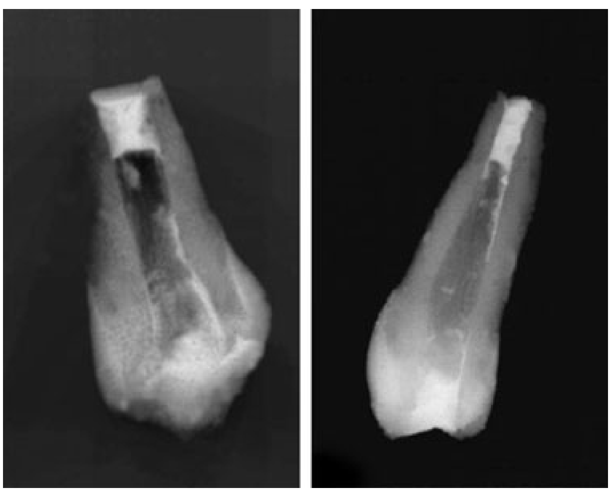

Fig. 1. Digital radiograph of two premolars used during the training of the researchers in using mineral trioxide aggregate (MTA) showing correct placement of MTA.

Table 1. Inclusion and exclusion criteria of the main clinical study

Inclusion criteria
Fifteen children were chosen from the Trauma Clinic of the Leeds Dental Institute according to the following criteria:
Fit and healthy
Suffered loss of vitality following trauma of at least one permanent incisor resulting In an incomplete root development and open apex
Failed attempts at generating a hard tissue barrier with calcium hydroxide
Needed a final root canal obturation which could be achieved with the thermoplasticized technique
Exclusion criteria
Children were excluded from the study if:
They were medically compromised and suffering from a condition for which endodontic treatment was contraindicated
Their parents/guardians had not signed an informed consent
Loss of vitality of one or more permanent incisors was as a result of caries
The tooth/teeth had also suffered root fracture
There were signs of active pathological root resorption
Treatment under local analgesia was not possible due to poor co-operation of the patient
Prognosis of the tooth/teeth was poor and required extraction
Isolation with a rubber dam was not possible

of the nature of the treatment planned. During the initial screening a medical and dental history was completed. A clinical and radiographic examination was carried out to assess the suitability of the children for inclusion in the study. On clinical examination the following signs and symptoms were recorded:

- Tenderness to percussion,
- Tenderness to palpation of the apical area,
- Presence of a sinus tract or abscess related to one or more of the traumatized permanent incisors,
- Presence and description of pain originating from one or more traumatized permanent incisors,
- Need for use of analgesics to control symptoms,
- Presence of bad taste in the mouth,
- Discolouration of one or more permanent incisors,
- Pathological mobility.

The examination also included pulp sensibility testing using both thermal and electrical stimulation. Radiographic examination included a periapical radiograph, using the parallel technique. The radiographs were then examined by two examiners and recorded in the patient's dental records.

It was agreed that the treatment would be completed in three visits. On the first visit, the root canal was accessed and prepared by using standard endodontic procedures. Clinically, the stage of root development was assessed during the root canal preparation. Teeth suitable for MTA, i.e. with open apices, were identified after the insertion of a large endodontic file (size 60) beyond the working length without any resistance at the apical portion. The working length was determined by a conventional radiograph. Second visit, the root canal was re-accessed and MTA was mixed according to the manufacturer's instructions. It was then carried into the root canal using the MTA carrier suggested by the manufacturer (Dovgan MTA Carrier, Maillefer Instruments, Dentsply, Weybridge, UK). The formation of the apical plug was achieved by gentle condensation using appropriate endodontic pluggers. The pluggers were premeasured 4 mm short of the working length by using rubber stoppers to establish the correct thickness of the MTA plug. A conventional periapical radiograph was used to confirm correct placement of the material. If the apical barrier proved to be inadequate, the root canal was re-accessed and the material was washed out by thorough irrigation and instrumentation in order to be replaced. A moist cotton pellet using sterile water was finally placed inside the pulp chamber followed by a dry cotton pellet and the access cavity was sealed with a glass-ionomer restorative material (Ketac-Fil).

During the third visit, the final obturation of the root canal was achieved with the use of thermoplasticized Gutta–Percha (Obtura II) and the access cavity was sealed with a composite resin material. A periapical radiograph was taken to assist in the evaluation of the root filling. All clinical procedures were recorded in the patient's dental records on each visit.

The study population was reviewed at three month intervals and clinical and radiographic assessment was carried out. Radiographs were assessed from the time of the initial screening until the most recent available radiograph taken on the last review visit.

A special data capture form was used to transfer all the information from the patients' dental notes. The principal investigator who had carried out the root treatment performed all clinical assessments. The following clinical parameters were specifically assessed:

- Pain or discomfort immediately after or since the root canal obturation,
- Use of any analgesics for the relief of pain,
- Tenderness to palpation or obvious signs of abscess formation (sinus),
- Tenderness to percussion.

Presence of any of the above signs and symptoms was considered clinical failure, while absence of them was recorded as clinical success. Periapical radiographs were assessed by using the criteria published by the European Society of Endodontology (27) and recorded as success, uncertain outcome and failure according to the criteria discussed below. In addition, the quality of the MTA apical plug and the root canal obturation was also recorded, as well as the stage of root development prior to the commencement of treatment. All radiographic findings were recorded in the special data capture form. The criteria for radiographic assessment are given below:

a) Success:
- Radiographic evidence of normal periodontal ligament space,
- Decrease in the size of the periapical lesion as compared with preoperative radiographs,
- No evidence of inflammatory external root resorption.

In cases where an existing extensive periapical lesion had healed but had left a locally widened periodontal ligament space, this defect was considered to be scar tissue rather than a sign of persisting disease. The root treatment in such situations was considered a success.

b) Uncertain outcome:
- If the periapical radiolucent area had remained the same and had not diminished in size.

c) Failure:
- Evidence that an existing periapical lesion had increased in size,
- Evidence of a new lesion, that had appeared subsequent to the placement of the root filling,
- Signs of continuing root resorption or hypercementosis.

The quality of the MTA placement was originally assessed by the operator during the second visit, when a decision was made whether it was necessary to be replaced. The criteria for correct placement of MTA were as follows: (an example of correct placement of MTA is shown in Fig. 2)

- The apical plug corresponded to the radiographic apex and did not over-extend into the periapical area or appear to underfil the apical 3 mm of the root,
- There was no space between the material and the walls of the canal,
- The apical barrier did not show any signs of displacement following final obturation of the canal as compared with the radiograph taken during the initial placement of the material,
- There appeared to be no leakage of sealing or obturation material into the periapical area.

The quality of the root canal obturation was checked from the periapical radiograph (Fig. 3). The quality of the seal was recorded as *adequate* if:

- there was no space between the root filling material and the root canal walls,
- there was no canal space visible beyond the end of the root canal filling.

The quality of the seal was recorded as *inadequate* if:

- space was evident between root filling and root canal wall,
- the root filling over-extended through the apex,

Fig. 2. Periapical radiograph showing a permanent incisor after the correct placement of mineral trioxide aggregate apical plug.

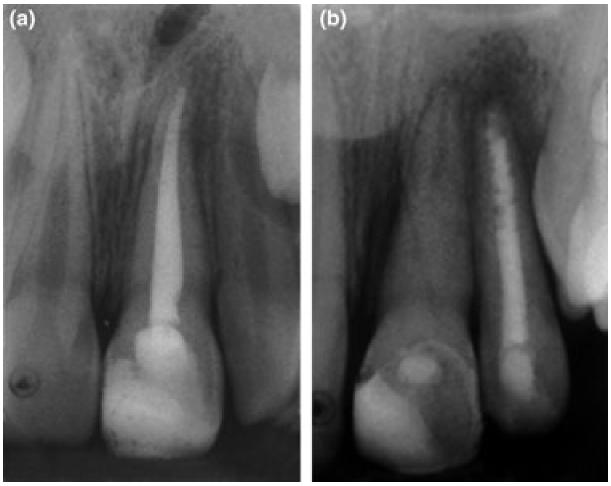

Fig. 3. Periapical radiographs showing examples of adequate (a) and inadequate (b) obturation of the root canal of permanent incisors.

- the root canal was under-filled as evident by space between the end of root filling and the MTA barrier.

The stage of root development was recorded according to the classification system described by Andreasen et al. (28).

Treatment was carried out by one investigator but two examiners assessed the radiographs independently. The examiners met before the assessments and agreed the criteria to be used. The radiographs were viewed on the light-box viewer using a magnification by a factor of two. The two examiners recorded the radiographic findings in the data capture form. At the end of the study both examiners met and in cases of disagreement tried to obtain a uniform decision.

The data were entered into a computer software package (SPSS, Version 10.1, SPSS Inc., Chicago, IL, USA). Results were tabulated and descriptive statistics were used to analyse the data. For the graphical presentation of the results MICROSOFT EXCEL® (VERSION 10) WAS USED.

Results

The study population consisted of children who attended the Trauma Clinic of the Department of Paediatric Dentistry at Leeds Dental Institute between May 2002 and July 2003. Altogether, 19 children were found to be suitable for inclusion in this study, four children of the 19 were treated using the MTA apexification technique prior to the commencement of the main study of to determine the details of the clinical procedures to be followed and their results were excluded.

Fifteen children took part in the main study. The sample comprised of 12 males (80%) and three females (20%). Their mean age was 11.7 years (±2.33 SD). Overall, 17 permanent incisors were treated, of which 15 (88.2%) were upper central incisors and two (11.8%) were upper laterals. Figure 4 demonstrates the distribution of teeth according to the stage of root development.

Mean values and descriptive statistics of follow up (clinical and radiographic) and total treatment time are shown in Table 2. Mean total treatment time was calculated from the time of MTA placement until the final obturation of the canal.

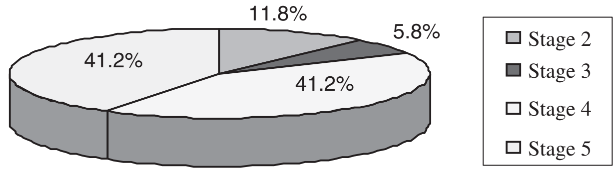

Fig. 4. Distribution of teeth treated with MTA according to stage of root development.

All variables recorded in the data capture form were tabulated and statistical calculations were performed. No teeth were found to cause any pain following the placement of MTA. No analgesics were used and prior to the obturation of the root canal no tenderness to palpation or percussion (TTP) was reported, apart from one case (TTP following MTA placement). Pain following the final obturation was reported in 2 of 17 teeth (11.7%) on the first follow-up visit and analgesics were used for this reason. Tenderness to palpation was observed in three teeth (17.6%) and TTP in two patients, one of which had to use analgesics for pain control. This same patient was the only one to present with an acute abscess related to the tooth treated with MTA 1 month following the final obturation. The MTA plug was considered inadequate (extruded) in this case. Table 3 summarizes the number of cases, which presented with symptoms in relation to the quality of the final obturation of the root canal.

Radiographic success was assessed in all cases following MTA placement and final obturation and also at 3-month intervals wherever possible. Review times varied between 6 months and 16 months in total. In thirteen cases (76.5%) the treatment was rated as successful based on the radiographic evidence, while three of the teeth were described as having an uncertain outcome (17.6%). One case was unsuccessful (Table 4). The quality of MTA was recorded as adequate in 13 of 17 teeth (76.5%) and the final obturation was considered inadequate in only two cases (11.8%).

The quality of MTA plug appeared to affect the treatment outcome, however no statistical analysis could be preformed because of the small number of subjects. In most cases where the MTA placement was inadequate, the outcome was considered to be uncertain based on radiographic criteria.

The relationship between the radiographic outcome and the presence of symptoms following obturation is demonstrated in Table 5.

Overall success was determined by the number of teeth demonstrating absence of signs and symptoms of periapical pathology or abscess formation following completion of treatment. Radiographic evidence of successful endodontic treatment was based on the criteria set in the beginning of the study (see Fig 5.)

Discussion

The present study was undertaken to test the clinical efficacy of a new material currently suggested for use in

Table 2. Follow-up and total treatment time of MTA placement

	n	Minimum	Maximum	Mean	SD
Review after MTA (months)	17	6	16	12.53	±2.94
Total treatment time (days)	17	7	70	21.47	±17.58

One case was lost in follow up, which can explain the minimum review time following MTA placement.
MTA, mineral trioxide aggregate.

Table 3. Distribution of teeth presenting with symptoms in relation to the quality of the root canal obturation

	Quality of obturation			
	Adequate		Inadequate	
	n	%	*n*	%
Pain/obturation†				
Yes	2	11.8	0	–
No	13	76.4	2	11.8
Analgesics/obturation				
Yes	2	11.8	0	–
No	13	76.4	2	11.8
TTpalp.‡/obturation				
Yes	2	11.8	1	5.9
No	13	76.4	1	5.9
TTP§/obturation				
Yes	1	5.9	1	5.9
No	14	82.3	1	5.9

n, number of teeth.
†Following obturation.
‡Tenderness to palpation.
§Tenderness to percussion.

Table 4. Distribution of teeth at different stages of root development in relation to the radiographic success

	Radiographic assessment			
Stages of root development	Success	Uncertain outcome	Failure	Total
Stage 2	–	2	–	2
Stage 3	1	–	–	1
Stage 4	7	0	–	7
Stage 5	5	1	1	7
Total	13	3	1	17

Table 5. Distribution of teeth presenting with symptoms following final obturation in relation to radiographic outcome

	Pain		Analge-sics		Tender-ness to palpation		TTP	
Radiographic assessment	Yes	No	Yes	No	Yes	No	Yes	No
Success	1	12	1	12	2	11	1	12
Uncertain outcome	–	3	–	3	–	3	–	3
Failure	1	–	1	–	1	–	1	–
Total	2	15	2	15	3	14	2	15

multiple endodontic procedures, including one-visit apexification procedure.

MTA is a relatively new material which is known more to specialists in endodontics since it was first introduced for surgical endodontic procedures (apicectomies and retrograde root-end fillings) and as a repair material in root perforations. In the present study, before any clinical procedure was attempted, it was considered important that the operator of the study was familiar with the material's handling properties. For this purpose, extracted human premolars were used, and were prepared to resemble immature teeth with an open apex. To create an apical stop, wax was used to cover the apex. This model does not resemble the clinical situation. First, visual access to the apex and root canal is more direct than it is in the mouth. This fact made the assessment of MTA placement easier than under clinical conditions. Furthermore, the apical stop made of wax provided an actual hard physical barrier against which the MTA could be safely condensed. Under clinical conditions an actual barrier does not exist and the material cannot be condensed, but should be lightly pressed into position to avoid extrusion into the periapical tissues. Especially in cases with a wide-open apex (i.e. stages 1–3 of root development), no resistance can be felt until the MTA plug reaches a thickness of approximately 3 mm and extrusion of the material can easily occur. To overcome this problem it has been suggested to create a physical apical barrier prior to MTA placement (29). This can be achieved with several materials, including various collagen-type materials such as collatape (Centerpulse Dental, Carlsbad, CA, USA) and calcium sulphate (Class Implant, Rome, Italy). The advantage of these materials is that they are resorbable and therefore can allow the induction of cementoblast activity by MTA shown in several studies (13, 20, 22, 30, 31).

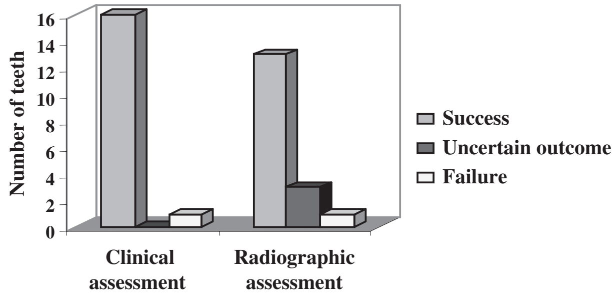

Fig. 5. Frequency of clinical and radiographic success of the root canal treatment.

An assessment of the delivery system into the root canal and placement of the material at the apex was performed at this stage. For this purpose the MTA bendable applicators recommended by the manufacturer were used. However, because of the thickness of the applicator, MTA could only be carried a few millimetres beyond the entrance of the root canal. The material was then carefully pushed down and the remnants of it were scrapped from the root canal walls to reach the apex. On occasions, dehydration of the mixed material occurred which made the placement of MTA difficult. The manufacturer suggests that the working time of MTA is approximately 5 min. For the creation of an apical barrier three to four applications are often required, making the procedure lengthier. Digital radiographs taken of the four premolars after the placement of MTA

(Fig. 1), showed some of the material remaining on the dentinal walls. This may cause some weakening of the tooth resistance to fracture by the interaction of MTA with dentine (32) and may produce a narrow root canal following the setting of the material, making the final obturation of the root canal difficult to achieve.

Hachmeister et al. (33) have also identified the problem in their study and characterized the procedure as being technique-sensitive. They claimed that when MTA is placed in an orthograde manner, direct visualization of the apex is not possible and therefore predictable placement of MTA cannot be assured. This is not always true, as the use of magnification loops and microscopes in endodontics has increased the visual accuracy of the operator significantly. However, radiographic assessment is still required and the operator needs to be familiar with the use of equipment such as microscopes.

In the present study, the teeth were obturated with thermoplastisized Gutta–Percha following the MTA placement. The efficacy of this technique has been established by many investigators (34, 35). However, in the case of a traumatized immature incisor, with paper thin walls and an unfavourable crown-root ratio, perhaps a different technique would be more appropriate to increase the strength of the root canal walls and improve the long-term prognosis of these teeth, which have been shown to be prone to cervical root fractures (5). The combination of apical MTA and an internal bonded composite (flow-able dual cure composite) appears to have a more favourable prognosis than Gutta–Percha (36), there are no composite resin materials for endodontic use currently available, and the ones that are suggested for this purpose have been manufactured for restorative applications.

In this study the mean follow-up time for the MTA (both clinical and radiographic) was 11.94 months ($\pm$4.11 SD). The review time can be considered an advantage in a clinical trial assessing the efficacy of an endodontic procedure. In order to identify changes in the periapical area a radiographic review should be undertaken at least every 3 months following completion of treatment. In this study, the radiographic assessment was conducted based on the radiographs taken at the initial screening and the last radiographic view available following the placement of MTA.

Because of the small number of subjects no statistical analysis of the results could be performed and no associations between variables could be identified. However, it appeared that the quality of MTA plug might have had an effect on the treatment outcome. In most of the cases that MTA was assessed as inadequate (four cases), the radiographic outcome was considered to be uncertain. These were cases where because of either time constraint or patient limitations MTA replacement was not possible.

No clinical association could be found between the stage of root development and the treatment outcome or the quality of MTA placed, although during the clinical application of the material it was felt that in wide open apices (i.e. stages 1–3 of root development) the creation of an adequate seal using MTA was not as predictable as in teeth with more advanced root development (stages 4 and 5). In these cases, extrusion of the material can easily occur and the marginal adaptation of MTA on the dentinal walls of the apex and consequently the sealing ability may not be as good as presented in some *in vitro* studies (15, 24, 25), where MTA was assessed as a root-end filling material. There are only two studies assessing the bacterial leakage demonstrated with MTA when used as an apexification material (33, 36). In the Hachmeister et al. study (33) MTA demonstrated more bacterial leakage when placed with the orthograde technique than when placed as a root-end material. According to the authors, this could be attributed to the delivery system and not the material itself. Further research is required to establish whether the sealing ability and the marginal adaptation of MTA are compromised when placed for the creation of an apical barrier through the orthograde route.

In two cases cervical discolouration was noticed following the placement of MTA. In the present study the original Pro-Root^{TM} MTA was used, which has a dark grey shade. This type of MTA may result in discolouration of the tooth, which has been identified and mentioned in the literature previously (17). For this reason, a white formula of MTA has been produced, with the claim that the properties of the material remain the same, although the ability to stain the teeth is diminished. However, the biocompatibility of white MTA is controversial. Some researchers have shown that the white MTA is not as biocompatible as the grey MTA (37), while others show no difference (38). Further research is required to establish whether the white formula can be safely used for endodontic purposes.

Radiographic success was seen in 86.6% of the cases. However, because of the limitations of this pilot study, such as the small number of teeth, these results should be interpreted with caution. An interesting finding was the presence of what seemed as continued root development and a hard tissue barrier formation over the MTA at the apex. This could be the result of the prolonged treatment of these teeth with calcium hydroxide, which is known for its osteogenic potential (39), or the effect of MTA on the cementoblasts. MTA has been shown to be biocompatible and a constant finding on most studies is the induced cementogenesis (13, 20, 22, 30, 31). The mechanism of the induction of cementoblast activity by MTA is not clear yet, and further research is required to establish this.

The findings of this study cannot be considered as conclusive because of the small number of subjects. However, this was a pilot study and multi-centre clinical studies to test the efficacy of MTA for apexifications in larger number of children are required. As there are no similar clinical trials and only some anectodal case reports, no comparison can be made with the present study. More controlled clinical studies are required to evaluate the clinical success of this one-step apexification procedure. MTA does appear to offer some advantages over the conventional treatment with calcium hydroxide. However, although MTA may be cost effective in the long-term, the increased cost in the short-term and the difficulty in the handling of the material may restrict its wide use for the various applications for which it is recommended. Further research is also required to establish whether the white formula can be safely used for the same applications as the grey formula and to determine the composition and properties of the white formula.

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