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Long-term treatment outcomes in immature permanent teeth by revascularisation using MTA and GIC as canal-sealing materials: a retrospective study

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Background. Pulp revascularisation with MTA sealing has been accepted as an alternative treatment for non-vital immature permanent teeth. Successful revascularisation cases with GIC sealing were also reported, but lack of long-term researches.

Aim. To evaluate long-term outcomes of revascularisation using MTA and GIC as canal-sealing materials in non-vital immature permanent teeth.

Design. Clinical and radiographic data of 60 non-vital immature permanent teeth treated with revascularisation (36.8 ± 12.4 months of follow-up) were reviewed. Of these, 28 teeth were sealed with MTA, and 32 with GIC. Tooth survival, success rate, and increases in root length and dentine wall thickness were evaluated.

Results. Teeth in MTA group showed a similar survival rate (96%) to GIC group (100%). The success rate in MTA group (93%) was greater than that in GIC group (59%). Eight of fourteen failed teeth due to recurrent apical disease (seven teeth in GIC group and one in MTA group) achieved complete root development. There was no statistically significant difference in root length or dentine wall thickness increase between the groups.

Conclusions. Long-term outcome of revascularisation in non-vital immature permanent teeth sealed with GIC was not as good as that with MTA. Although more recurrent apical disease developed, results on root development were acceptable in GIC sealed cases.

Introduction

A novel revascularisation treatment of non-vital immature teeth was introduced by Banchs and Trope in 2004[1]. Many case reports have since shown favourable outcomes after the eradication of bacteria from the root canal system, formation of a scaffold in the canal space, and creation of a bacteria-tight coronal seal[2–5]. Although following a similar concept of revascularisation, treatment protocols used in other reports vary in terms of irrigants[4,6,7], intracanal disinfectant medications[1,2,7], scaffolds in the canal[5,8,9], and sealing materials used[2,6,7,10]. The search for an optimal protocol for revascularisation is an ongoing and likely long-term process. No reported study has yet shown clinical outcomes among cases using different canal-sealing materials.

The importance of a bacteria-tight coronal seal for the success of revascularisation is well documented[1]. A mineral trioxide aggregate (MTA) plug has been used in most case reports to seal over the blood clot formed inside the canal at the cementoenamel junction (CEJ)[1,3,4,6,8,9] due to its excellent sealing ability and biocompatibility[11]. MTA also, however, has drawbacks, including high cost, difficult handling, and post-operative crown discoloration[12]. Glass ionomer cement (GIC) is an alternative sealing material to prevent coronal microleakage[13], especially in developing countries, for its affordability, easy handling, good biocompatibility[14], and lack of discoloration.

Two reported clinical studies and one case report have demonstrated the successful use

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of GIC or resin-modified GIC to seal over blood clots in revascularisation treatments[7,10,15]. With evidence still limited supporting the use of GIC in revascularisation and a lack of reports with long-term follow-up, the efficacy of GIC as an intracanal coronal sealing material in revascularisation treatment needs further evaluation. Thus, the aim of this retrospective study was to evaluate and compare the long-term clinical outcomes of revascularisation using GIC and MTA as canal-sealing materials for immature permanent teeth with non-vital pulp.

Materials and methods

Subjects

This retrospective study was performed in the Department of Paediatric Dentistry, Peking University School and Hospital of Stomatology. The study protocol was approved by the Ethics Committee of Peking University School and Hospital of Stomatology (ref. PKUSSIRB 201311107).

Dental records and radiographs were reviewed to identify children who had a revascularisation procedure performed on at least one tooth from September 2009 to September 2012. The inclusion criteria for the subject tooth included (1) diagnosis of pulp necrosis confirmed by a thermal test and an electrical pulpal vitality test using a vitality scanner (SybronEndo, Glendora, CA, USA) and operative findings; (2) a periapical lesion and an open apex (stages 1–4 according to Cvek's criteria[16]); (3) a revascularisation procedure completed as described below in *clinical protocol;* and (4) a minimum 12-month follow-up period. Cases with inadequate documentation, including a lack of post-operative radiographs, were excluded.

Clinical protocol

All revascularisation procedures in the study period were performed by eight faculty members of the department following the protocols after standardised training. During the first treatment visit, the access cavity was prepared under rubber dam isolation using 4% articaine with epinephrine 1:100,000. The root canal was irrigated with 5.25% sodium hypochlorite solution (20 mL) with minimal or no instrumentation. The canal was then dried with sterile paper points, and a mixed antibiotic paste of ciprofloxacin, metronidazole, and minocycline, based on a method described previously[17], was placed with a lentulo spiral instrument into the root canal space. The access cavity was then sealed with Coltosol F (Coltène/Whaledent, Altstätten, Switzerland). Then, 1–4 weeks later, when the patient was symptom-free and the tooth was not sensitive to palpation or percussion, the canal was re-entered, and the revascularisation process was completed. If the patient remained symptomatic, fresh antibiotic paste was placed in the canal until the patient became asymptomatic. After removing the temporary filling material and any remaining antibiotic paste under rubber dam isolation using 2% lidocaine without vasoconstrictor, the root canal was irrigated with 5.25% sodium hypochlorite solution (10 mL) and dried with sterile paper points. A size #30K-file was then introduced into the root canal and pushed beyond the apex towards the periapical tissue to create bleeding into the canal. A tight cotton pellet was inserted into the canal to allow formation of a blood clot at the CEJ when bleeding flushed exceeding the canal. 10-15 min later, when the blood clot formed, conventional Fuji IX GIC (Fuji Corporation, Osaka, Japan) was placed over the blood clot at the level of CEJ, followed by phosphoric acid etching for 30 s, a single-bond adhesive agent, and placement of Filtek Z250 composite resin (3M ESPE, Irvine, CA, USA). In some cases, instead of GIC, mixture of ProRoot MTA (Dentsply Tulsa Dental, Johnson City, TN) with 3 mm of thickness was placed at the level of the CEJ, followed by a wet cotton pellet and Coltosol F. Then, 3–7 days later, the Coltosol F was removed, and Filtek Z250 composite resin was then used to seal the access, following the manufacturer's instruction. All patients were asked to return for evaluation at 6-month intervals. Treatment outcomes were assessed with clinical and radiographic examinations at each follow-up visit.

Evaluation of treatment outcomes

Treatment outcomes were assessed using both survival and success. Tooth survival was defined as the tooth's remaining in the arch throughout the study period. Clinical success was defined as survival of the tooth with resolution of the periapical lesion and the absence of any clinical sign or symptom. Failure was defined as either loss of tooth, or presence of the periapical lesion or clinical sign or symptom. Treatment outcomes were evaluated by two independent reviewers, who were both paediatric dentists. When the result of an evaluation was not unanimous, consensus was reached through discussion.

Changes in root dimensions between the preoperative and final post-operative images were evaluated by measuring and calculating the changes in root length and dentine wall thickness. According to method described by Bose *et al.*[18], preoperative and final post-operative images in JPEG format were transferred to the ImageJ software (ver. 1.41; National Institutes of Health, Bethesda, MD), mathematically corrected using the TurboReg plug-in (Biomedical Imaging Group, Swiss Federal Institute of Technology, Lausanne Switzerland), and calibrated according to the type of the image. The root length and dentine wall thickness for both the preoperative and recall images were measured (Fig. 1). Changes in the post-operative values for root length and dentine wall thickness are reported in terms of percentage changes from preoperative values. The values were calculated as follows:

$$\text{Percentage increase in root length} = (\text{post-operative length} - \text{preoperative length}/\text{preoperative length}) \times 100;$$

$$\text{Percentage increase in dentine wall thickness} = (\text{post-operative thickness} - \text{preoperative thickness}/\text{preoperative thickness}) \times 100.$$

Each measurement was performed in duplicate, and results were averaged.

Other clinical findings, such as crown discolouration and restoration failure, were recorded according to the case records. Severe canal calcification leading to canal obliteration present in post-operative radiographs was also evaluated.

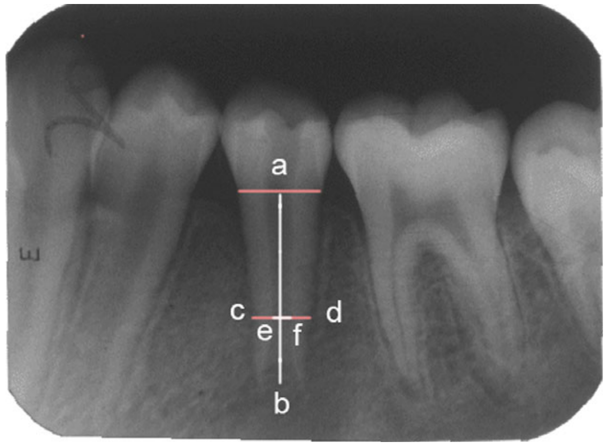

Figure 1. a: The mid-point of a straight line between the mesial and distal cementoenamel junction. b: The mid-point of the radiographic apex. Root length measurements were made along the straight line from a to b. The straight line from c to d indicates root width at the level of two-thirds the preoperative root canal length. The straight line from e to f is the pulp space width at the same level. Dentine wall thickness measurements were calculated by subtracting ef from cd.

Data collection and statistical analyses

Data collected included demographic information, contributory aetiologies and diagnoses, teeth types and developmental stage, variations in details of clinical treatment, follow-up periods, treatment outcomes, any change in tooth colour, and any other treatment of the tooth. Dental data were converted into Microsoft Excel format. All radiographs related to study cases were scanned and saved in JPEG format.

Data were imported from Excel into the software SPSS (Statistical Packages for the Social Sciences 20.0; IBM, Armonk, NY, USA) for analyses. Differences in continuous variables between groups were analysed using *t*-tests. Differences in categorical variables were evaluated using Fisher's exact test. Percentage changes in the root length and dentine wall thickness were analysed with the Mann–Whitney *U*-test. *P*-values <0.05 were considered to indicate statistical significance. Mean values are reported.

Results

Study sample

In total, 92 teeth that underwent revascularisation treatment were identified in the archives of the Department of Paediatric Dentistry, Peking University School and Hospital of Stomatology, from September 2009 to September 2012. A total of 72 cases met the inclusion criteria. A total of 12 cases were excluded due to lack of detailed documentation of recall and/or less than 12-month follow-up and/or requiring apexification treatment because of the persistent apical periodontitis within the first 12 month (recall rate = 83%). A total of 60 cases from 57 patients (38 boys and 19 girls, aged 10.8 ± 1.9 years) were included. The average follow-up period was 36.8 ± 12.4 (13–63) months. Of the 60 teeth, in 32 teeth, Fuji IX GIC was used (GIC group) as the canal-sealing material. In the other 28 teeth, MTA was used as canal-sealing material (MTA group). Table 1 summarises the patient demographics and clinical characteristics of the two groups. No significant difference in the other variables, such as average age, sex, distribution of teeth type, aetiology or diagnosis, root development stage, or follow-up period, was found between the groups (all $P > 0.05$).

Tooth survival and clinical success

Teeth in MTA group had similar survival rates (27 of 28, 96%) to the teeth in the GIC group (32 of 32, 100%; $P > 0.05$). Only one premolar tooth in MTA group was extracted because of a fracture in the cervical area 16 months after treatment.

Teeth in the MTA group showed a greater success rate (26 of 28, 93%) than teeth in the GIC group (19 of 32, 59%; $P < 0.05$). In MTA group, one tooth failed because of root fracture and the other tooth failed because of recurrent apical disease with radiolucency in radiographic film at 27 months after revascularisation. In the GIC group, 13 teeth were deemed failure after an average of 33.2 ± 13.0 (13–63) months of follow-up all because of recurrent apical disease with either clinical or radiographic signs and symptoms of apical periodontitis (Table 2). All failed teeth had at least one follow-up visit with resolution of the periapical lesion radiographically. Of the 14 failed teeth with recurrent apical disease, 12 showed various levels of root development with apex closure or near closure. Moreover, seven teeth in the GIC group (Fig. 2) and the one tooth in the MTA group (Fig. 3) achieved complete root development, and the root wall thickness increased.

Table 1. Demographics and clinical characteristics.

Variable	GIC group *n* = 32	MTA group *n* = 28
Age, (years)	10.8 ± 1.6	10.7 ± 2.2
Sex, *n* (%)*		
Male	23 (72)	15 (54)
Female	9 (28)	13 (46)
Teeth type, *n* (%)		
Anterior	3 (9)	6 (21)
Premolar	29 (91)	22 (79)
Cause, *n* (%)		
Anatomic [&]	27 (85)	22 (79)
Caries	2 (6)	1 (3)
Trauma	3 (9)	5 (18)
Diagnose, *n* (%)[#]		
AAA	13 (41)	14 (50)
CAA	7 (22)	5 (18)
SAP	12 (37)	9 (32)
Stage of root development	3.0 ± 0.6	3.0 ± 0.9
Follow-up period, (months)	38.0 ± 14.6	34.3 ± 10.0

*Each tooth is treated as an individual case for analysis.
&Anatomic anomaly: dens invaginatus or evaginatus.
#SAP, symptomatic apical periodontitis; AAA, acute apical abscess; CAA, chronic apical abscess.

Changes in root dimensions

Four cases from the MTA group and four from the GIC group were excluded from this part of the study because no quantified radiograph could be used for measurements. Thus, for radiographic outcomes, the average follow-up time was 30.2 ± 6.9 months ($n = 24$) for the MTA group and 35.6 ± 10.1 months ($n = 28$) for the GIC group.

Table 2. Distribution of teeth with recurrent apical disease (TRAD).

Number of TRAD (*n*)	12–24	25–36	>36 (months)
GIC group	3	7	3
MTA group	0	1	0

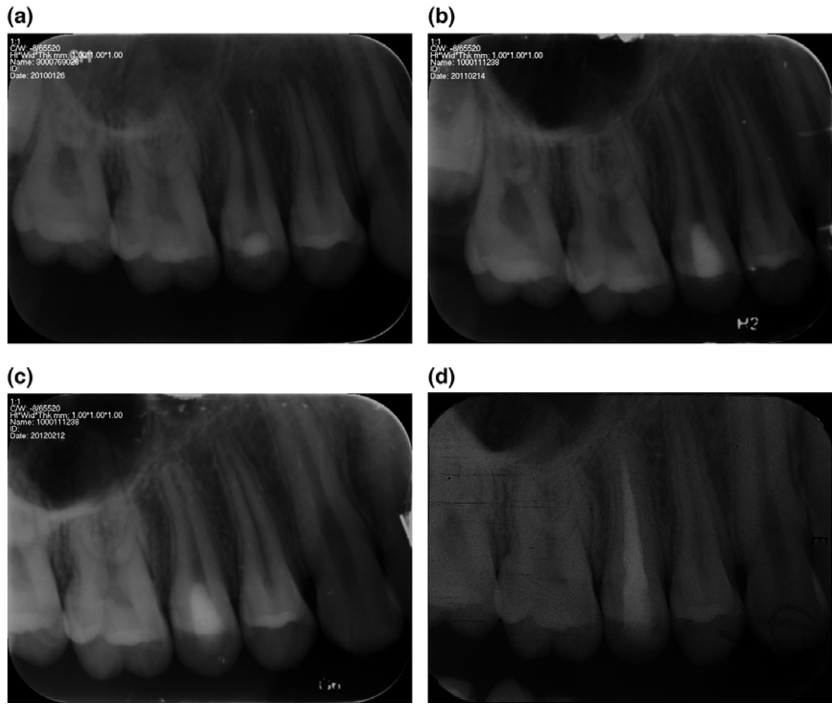

Figure 2. (a) Periapical radiograph of tooth #15 with a wide-open apex and an apical radiolucent area. (b) At the 12-month follow-up after revascularisation with GIC, healing of the periapical lesion and continued root development of #15 were evident. (c) At the 24-month follow-up, a periapical radiograph showed #15 with apex closure and a narrowed canal space. (d) At the 26-month follow-up, tooth #15 was re-entered and subjected to root canal treatment for pain while biting.

In terms of radiographic changes, cases in MTA group generally showed a slightly greater change in the root length (11.0%) compared with cases in the GIC (10.5%) group, and a slightly greater change in the dentine wall thickness (30.7% in the MTA group and 26.3% in the GIC group; Fig. 4). These measured radiographic differences in root dimension, however, were not statistically significant (Mann–Whitney *U*-test, $P > 0.05$).

Other clinical and radiographic findings

During the follow-up period, post-operative crown discoloration was recorded in 19 MTA and four GIC cases. Restoration lost was found in one MTA case and restoration marginal defect in one MTA and three GIC cases. All three GIC cases developed recurrent apical disease, whereas neither MTA case did.

Pulp canal obliteration was observed in 29% (8 of 28) of cases in the MTA group and 31% (10 of 32) of cases in the GIC group.

Discussion

In this retrospective study, we found that recurrent apical periodontitis occurred in 14 of 60 teeth during the follow-up period of 13–63 months. Of the 14 failed teeth, eight teeth (seven in GIC group and one in MTA group) developed recurrent disease after complete root maturation. This should caution clinicians that complete root development is not the final point of success in pulp revascularisation treatment.

Recurrent apical periodontitis is that the apical lesion reoccurs after having healed, which is one kind of post-treatment apical periodontitis[19]. It is recognised that the major reason for recurrent apical periodontitis is coronal leakage[20], whereas residual bacteria within the root canal system could not be rule out especially in revascularisation cases[21,22].

In our study, the initial resolution of the apical lesion and root maturation in most (12 of 14) failed cases indicated the initial elimination of bacteria from the root canal and newly formed tissue growing into the root canal after revascularisation; however, apical lesion occurred again. Restoration failure in three teeth suggested the possibility of coronal leakage; however, recurrent apical lesions were associated with teeth with intact restorations as well. The observation that there were more recurrent infection cases in

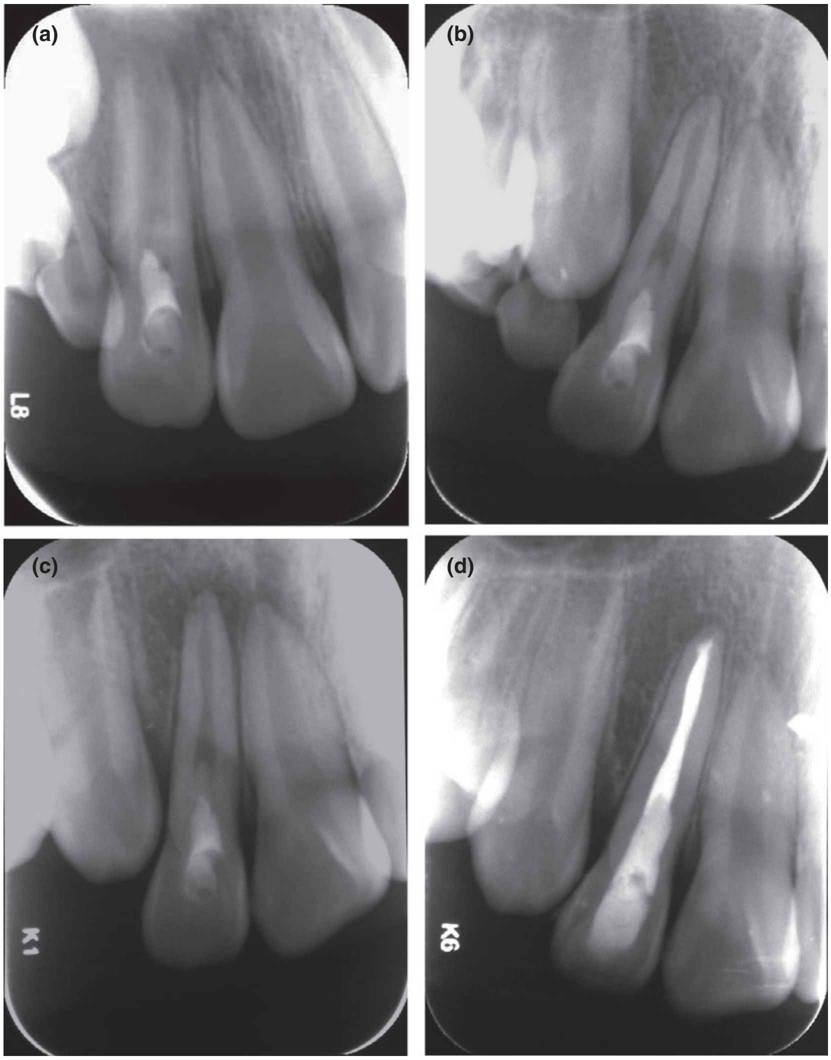

Figure 3. (a) Periapical radiograph of #12 showing a wide-open apex and an apical radiolucent area. (b) At the 24-month follow-up after revascularisation with MTA, there was the evidence of resolution of the periapical lesion and complete root development. (c) At the 27-month follow-up, a periapical radiograph of #12 showing a radiolucency around the apex. (d) Tooth #12 was treated with root canal treatment.

the GIC group than in the MTA group regardless of the restoration condition suggested the importance of the optimal seal provided by canal-sealing material during revascularisation. The canal-sealing material could offer a second defence against the bacterial leakage besides final restorations[13]. MTA had better sealing ability than GIC in *in vitro* studies[23], especially under moist circumstances. In addition, MTA had excellent biocompatibility. It is reported that MTA could release sufficient calcium ions reacting with environmental phosphate and produce hydroxyapatite crystals on the surface of MTA[24]. An animal study on revascularisation showed that cemental bridges formed beneath MTA[25]. The biological seal beneath MTA may further prevent bacterial invasion. In our study, with increasing observation time, only one reinfected case without defective restoration was observed in the MTA group. Although not as good as MTA, GIC+ composite resin could provide effective coronal sealing in 2-year follow-up period as few recurrent diseases occurred and root development accomplished under such circumstances. Recently, a case report showed that coronal leakage could occur in a tooth with MTA as the canal-sealing material and a defective filling 2 years after the completion of revascularisation, with inflammatory cells being observed primarily in the coronal area of the revascularised tissue[26]. The author questioned the sealing ability of MTA in resisting bacterial penetration based on this finding. The canal-sealing ability of the materials used in revascularisation may determine the long-term prognosis.

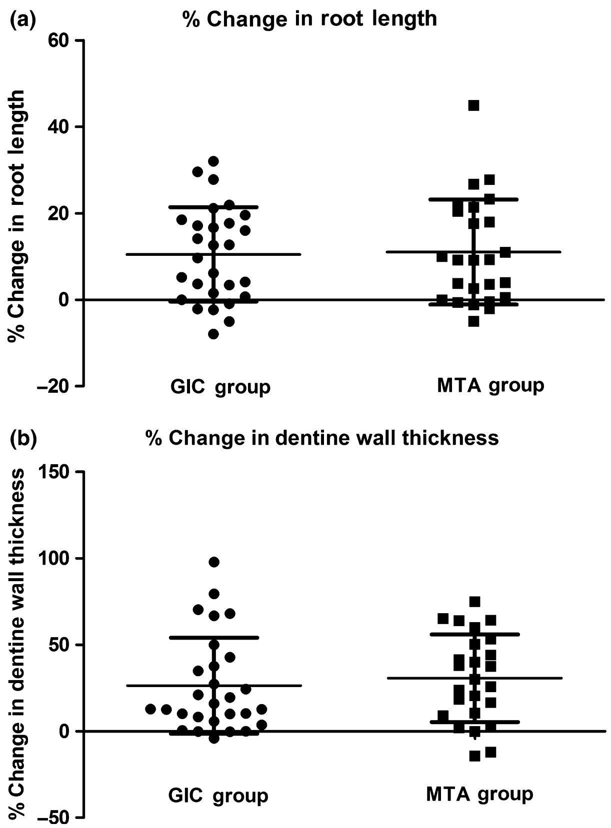

Figure 4. Percentage changes in root length and dentine wall thickness shown with scatterplots. The middle horizontal line represents the mean, and the error bars are standard deviations. (a) Graph showing the percentage change in root length in the GIC and MTA groups. (b) Graph showing the percentage change in dentine wall thickness in the GIC and MTA groups.

Another major reason for treatment failure is residual bacteria surviving in the canal for long period of time. It has been reported that infected dentine tubules could be a reservoir for such bacteria[21,27]. Bacteria can also survive in the lateral canals, apical ramifications, and isthmuses that remain inaccessible despite mechanical preparation and the use of disinfectants[28,29]. The bacterial load in the main canals drops significantly, allowing tissue healing[30]. The resolution of apical lesions could be observed. In a 'traditional' non-surgical root canal-treated tooth, the hermetic sealing of canals via obturation and coronal restoration usually sufficiently suppresses their growth to maintain a low bacterial load, preventing recurrent disease. During a pulp revascularisation procedure, it is even harder to achieve and maintain canal disinfection using irrigation and antibacterial pastes alone because minimal instrumentation is recommended. In the case report by Lin *et al.*, the vascularised, treated tooth remained asymptomatic for 16 months and was extracted because of recurrent pain and local periapical swelling[22]. Radiograph did not show evidence of increased thickening of the canal walls and continued root development. The histological and histobacteriological examinations showed that most bacteria were in the apical portion, not in the coronal portion, of the canal and penetrated into the dentinal tubules. The failure of the revascularised tooth could be due to inadequate root canal disinfection. We speculate that the absence of root dimension change in two teeth in this study may have been the result of the residual bacteria left in the root canals, although the apical lesion did resolve over the long term.

In this study, the root dimensions showed favourable change in most cases. Cases in the MTA group generally showed slightly greater changes in root length and dentine wall thickness than those in the GIC group, although the difference was not statistically significant. A possible reason for this result was that the recurrent apical disease that influenced the root development happened late, up to 33.2 ± 13.0 months of follow-up time. Of the13 failed teeth in GIC group, 11 also showed various levels of root development with apex closure or near closure. Thus, there may have been less influence on the root length and dentine wall thickness.

Pulp canal obliteration was seen in 10 cases in the GIC group and eight in the MTA group. All were clinical successes within the period of our study. We believe that pulp canal obliteration may be a favourable long-term outcome in revascularised root canals.

In this retrospective study, GIC as an inexpensive alternative canal-sealing material for revascularisation procedures was compared with MTA. The overall clinical success rate in the GIC group was significantly lower than that in the MTA group, and most of recurrent apical disease occurred in the GIC group after a long follow-up period; however, the outcomes of the treatment protocol using GIC were still promising; continued root development was observed in most cases during the long-term observation in spite of treatment failure, and fewer crown discoloration cases than MTA group were found during the study. The initial success of GIC in our study suggested that under circumstances where MTA is unavailable, GIC may serve as an interim canal-sealing material during revascularisation, allowing continued root development and even root maturation. The continued root development resulting from this process may significantly improve the long-term prognosis of the tooth and better prepare the tooth for traditional endodontic treatment, even if recurrent disease should occur in the future. We may also consider alternative treatments after root maturation using revascularisation with GIC as a canal-sealing material. Moreover, fewer crown discolouration cases observed in GIC group could be an advantage over MTA when there are aesthetic concerns.

Why this paper is important for paediatric dentists

- The canal-sealing ability of the material in revascularisation is essential for long-term prognosis. MTA is a better choice as canal-sealing material than GIC.
- Under circumstances where MTA is unavailable, GIC may serve as an interim canal-sealing material during revascularisation, allowing continued root development and even root maturation; however, alternative root canal treatment should be considered after root development completed.

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Conflict of interest

The authors deny any conflict of interests related to this study.

Author contributions

Man Qin and Chufang Peng Yuan Yang conceived the ideas; Chufang Peng, Man Qin, Yuan Yang, Dianhong Zhao and He Liu collected the data; Chufang Peng, Man Qin, Yuming Zhao and Zheng Xu analysed the data; Chufang Peng completed the writing. Man Qin, Yuming Zhao and Zheng Xu revised the manuscript.

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