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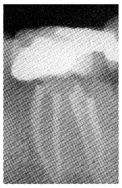

CASE REPORT

An uncommon type of segmental root development after revitalization

X. Jiang & H. Liu
Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology Beijing, China

Abstract

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Aim To describe four cases of an uncommon type of segmental root development after endodontic revitalization procedures. The formation, development and prognosis of this phenomenon are discussed, along with the causes and preventive measures.
Summary This report describes one immature maxillary anterior tooth with an extensive periapical lesion after partial extrusion caused by trauma and three immature mandibular premolars with extensive periapical lesions after fracture of the dens evaginatus. All four teeth underwent revitalization procedures. During follow-up, an uncommon type of segmental root development was observed in each case, where the apical segment appeared to detach from the body of the root and developed separately. In all cases, the detached apical root segments continued to develop with a shape and structure similar to that of a normal root tip. However, further development of the root body did not appear to occur. The follow-up times of the present cases were 11, 60, 41 and 67 months, respectively. All four teeth remains intact and functioned normally without symptoms. Cases 2 and 3 displayed positive reactions to electrical pulp tests during follow-up.

Key learning points

- Trauma and extensive periapical inflammation may result in the detachment of Hertwig's epithelial root sheath (HERS) and apical papilla from the root, thus creating a separate apical root segment.
- Formation of an apical root segment could be regarded as evidence of displacement of the HERS and apical papilla. Once this occurs, there is no chance that the main root of the tooth will develop into a normal-sized root.
- This type of segmental root development is always possible. If the teeth have suffered from severe trauma or have long-term and large periapical lesions before revitalization, the possibility of segmental root development should be considered.
- During the process of revitalization, intracanal bleeding is induced by rotating a precurved K-file 2 mm past the apical foramen. This procedure should be done gently to protect the apical structures and avoid iatrogenic factors that could lead to abnormal root development.

Correspondence: He Liu, Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology, Beijing, China (e-mail： heliu69@126.com).

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Introduction

Revitalization has played an important role in the treatment of immature permanent teeth with necrotic pulp tissue and/or apical periodontitis/abscesses since they were first introduced into clinical practice (Iwaya *et al*. 2001). It is a biologically based treatment aimed at the regeneration of the dentine–pulp complex (European Society of Endodontology 2016). In contrast to traditional apexification or the use of apical barriers, revitalization may result in increased thickening of the canal walls and continued root maturation, which reduces the risk of root fracture as it is strengthened by the deposition of new mineralized tissue in the root canal and continued development of the root (Banchs & Trope 2004, Thibodeau & Trope 2007, Cotti *et al*. 2008, Jung *et al*. 2008, Petrino *et al*. 2010, Geisler 2012, Kim *et al*. 2012, Schmalz & Smith 2014, Miltiadous & Floratos 2015).

The ideal result of revitalization would be complete root development with normal morphology and tooth structure. However, root development, as the most important outcome of revitalization, is not controllable. In animal and human studies, the damaged pulp tissue in the canal space of immature teeth after revitalization is replaced by bone-, cementum- and periodontal ligament-like tissue. Therefore, revitalization is considered a reparative and not a regenerative process histologically (Lin & Rosenberg 2011, Simon *et al*. 2014). Chen *et al*. (2012) described five types of responses of immature permanent teeth following revitalization when assessed radiographically: type 1, increased thickening of the canal walls and continued root maturation; type 2, no significant continuation of root development and the root apex becoming blunt and closed; type 3, continued root development with the apical foramen remaining open; type 4, severe calcification (obliteration) of the canal space; and type 5, a hard tissue barrier formed in the canal space between the coronal mineral trioxide aggregate (MTA) plug and the root apex (Chen *et al*. 2012).

Hertwig's epithelial root sheath (HERS) and apical papilla are responsible for regulating root development (Spouge 1980, Tucker & Sharpe 2004). Root dentine is formed by odontoblasts differentiated from ectomesenchymal cells in the apical papilla after receiving inductive signals from the HERS (Sonoyama *et al*. 2008). In revitalization, the HERS and apical papilla must survive in the apical tissues in order to regulate root development of immature permanent teeth. The viability of the HERS and apical papilla is likely to be dependent on the severity and duration of the apical periodontitis/abscess. Besides, these structures can be separated from the main tooth structure by an external force or iatrogenic factors and, after that, produce a separate root tip (Gibson 1969, Welbury & Walton 1999, Yang *et al*. 1990).

In the field of revitalization, a case was reported in which the root tip had separated from the body of the root after revitalization (Jung *et al*. 2011). The authors believed that severe tooth mobility might have been responsible for this phenomenon, but they failed to observe the formation process of the detached root tip because the separation was apparent from the beginning. The present report describes this uncommon segmental root development in four cases after revitalization in which a separate root tip slowly formed apically and detached from the body of the root. The formation, development, long-term prognosis and possible causes are discussed.

Report

Case 1

An 8-year-old female patient presented to the Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology, for evaluation of tooth 11 in November 2018. Two months before, the patient had fallen off an electric vehicle, and the right maxillary central incisor was extruded by about 5 mm. The patient was admitted to the Emergency Department of Peking University School and Hospital of Stomatology 6 h after the injury and was diagnosed with partial extrusion of tooth 11. The tooth was repositioned and fixed with steel wire and resin (Fig. 1a). The steel wire resin fixation was removed 3 weeks later. However, gingival swelling appeared after 1 week and persisted for 4 weeks.

Clinical examination revealed that the mobility of tooth 11 was +1, and the tooth was mildly sensitive to percussion. A sinus tract was present that traced to the apex of the tooth. A periapical film revealed that the root development of tooth 11 was incomplete and was accompanied by an extensive periapical lesion (Fig. 1b). The tooth was diagnosed with a chronic apical abscess. The patient's medical history was unremarkable. Revitalization was selected for treatment after the risks, complications and alternative treatment options were discussed with the patient and her carers and informed consent obtained. All revitalization procedures were performed in accordance with the 'Position Statement on Revitalization procedures' published by the European Society of Endodontology (2016).

Treatment process

During the initial treatment, chemical disinfection of the root canal was performed after accessing the pulp chamber under isolation with a rubber dam; the pulp was found to be completely necrotic. Copious gentle irrigation was performed twice: first with 1.25% sodium hypochlorite (Department of Pharmacy, Peking University School and Hospital of Stomatology, Beijing, China) (20 mL) for 5 min and then again with saline (20 mL) for 5 min using an irrigator (Suyun Medical Equipment Co. Ltd., Jiangsu, China). The canal was dried with sterilized cotton wool, and calcium hydroxide paste (OCO Präparate GmbH, Dirmstein, Germany) was delivered to the root canal using a lentulo spiral (Kiyohara Industrial Park, Utsunomiya, Tochigi, Japan). The tooth was restored temporarily with glass–ionomer.

The patient returned 2 weeks later with no symptoms. Tooth mobility was normal, but the tooth remained slightly sensitive to percussion. Therefore, the root canal was chemically disinfected during the next two visits (interval of 2 weeks).

At the fourth visit, the patient had no discomfort, and the sinus tract had resolved. After anaesthetizing the tooth with 2% vasoconstrictor-free lidocaine (Tiansheng Pharmaceutical Co. Ltd., Hubei, China) and isolation with a dental dam, the root canal was gently irrigated with 17% ethylenediaminetetraacetic acid (EDTA; Department of Pharmacy, Peking University School and Hospital of Stomatology) (20 mL). The root canal was dried with sterilized cotton wool, after which blood was infused into the canal by rotating a K-file 2 mm past the apical foramen. Blood reached the middle part of the root, and the root canal orifice was filled with iRoot BP Plus (Innovative BioCeramix Inc., Vancouver, Canada). The crown was filled with Filtek Z250 composite resin (3M ESPE, St Paul, MN, USA).

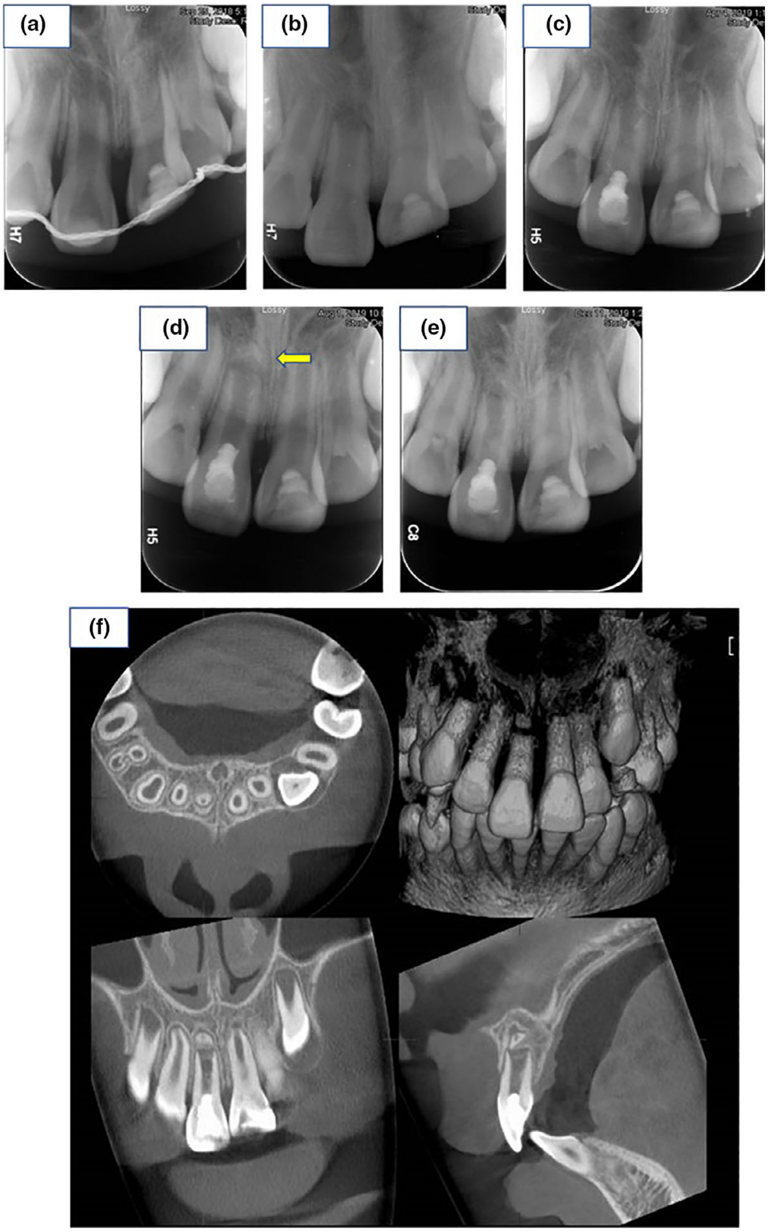

Figure 1 Imaging results over the 11-month follow-up period (a) Periapical film of tooth 11 after repositioning, showing an open root apex. (b) Periapical film of tooth 11 showing an open root apex with an extensive periapical lesion. (c) Three-month follow-up periapical film showing complete resolution of the periapical lesion. The root continued to develop, with root canal wall thickening, but the change in root length was not noticeable. (d) Seven-month follow-up periapical film showing apparent healing of the periapical bone. Radiopaque tissue can be seen apically and detached from the open root end of tooth 11 (arrow). (e) Eleven-month follow-up periapical film showing increased thickness of the root canal wall, but without any apparent change in root length. The newly formed apical segment was still separated from the body of the root. (f) Eleven-month follow-up cone-beam computed tomography (CBCT) scan showing that the apical segment was separated from the body of the root. The morphological structure of the apical segment appeared to be more regular compared to the image shown on the periapical film. Its shape and structure were similar to a normal root tip, with root canal morphology.

Follow-up

The tooth was evaluated regularly with clinical and radiographic examinations. At the 3-month follow-up (i.e. at 3 months after the final restoration), the patient reported no subjective symptoms. Electrical pulp testing was negative. A periapical radiograph revealed complete resolution of the periapical lesion. The root continued to develop, and the root canal wall thickened, but the root did not change in length (Fig. 1c).

At the 7-month follow-up, electrical pulp testing was negative. A periapical radiograph revealed apparent healing of the periapical bone. Interestingly, radiopaque tissue was observed apically, detached from the open root end of tooth 11 (Fig. 1d).

At the 11-month follow-up, the patient remained asymptomatic, and electrical pulp testing was negative. The thickness of the root canal wall had increased, with no noticeable change in root length. The newly formed apical segment was still separated from the body of the root (Fig. 1e). At this appointment, cone-beam computed tomography (CBCT) of tooth 11 was performed to observe the structure of the apical segment three-dimensionally (Fig. 1f). The morphological structure of the apical segment was more regular compared to the image shown on the periapical film. Its shape and structure were similar to a normal root tip, and the root canal was visible.

Case 2

An 11-year-old male patient presented to the Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology, in September 2014. The patient had experienced left mandibular gingival swelling for 3 months. An abscess had been incised and drained in the emergency department 4 days previously. The clinical examination revealed that the swelling was caused by tooth 35, as two-thirds of the tooth had erupted. It was free of caries, but a fractured dens evaginatus (central cusp) was seen on the occlusal surface. The mobility of the tooth was +1, and it was slightly sensitive to percussion. The incision and drainage site of the gingiva had healed, and a sinus could be seen on the labial gingiva. The pulp test was negative. A periapical film revealed that the root development of tooth 35 was incomplete and was accompanied by an extensive periapical lesion (Fig. 2a). The patient was diagnosed with a chronic apical abscess.

Treatment process

Revitalization procedures were performed as in case 1, except that a resorbable collagen matrix (Geistlich Pharma AG, Wolhusen, Switzerland) was placed over the blood clot to prevent the collapse of the coronal restorative material (Jiang *et al.* 2017) and white MTA (Dentsply Tulsa Dental, Johnson City, TN, USA) was used as the capping material.

Follow-up

The tooth was evaluated regularly with clinical and radiographic examinations. At the 3-month follow-up, the patient had no subjective symptoms. The mobility of tooth 35 was normal, and electrical pulp testing yielded a negative result. A periapical radiograph revealed a significant reduction in the size of the apical lesion and continued root development, with increased root canal wall thickness. Hard tissue could be seen in the apical third of the root (Fig. 2b).

The patient remained asymptomatic at the 17-month follow-up, and electrical pulp testing was positive. A periapical film revealed complete resolution of the apical lesion and apparent healing of the periapical bone. Radiopaque tissue was observed apically and detached from the body of the root (Fig. 2c).

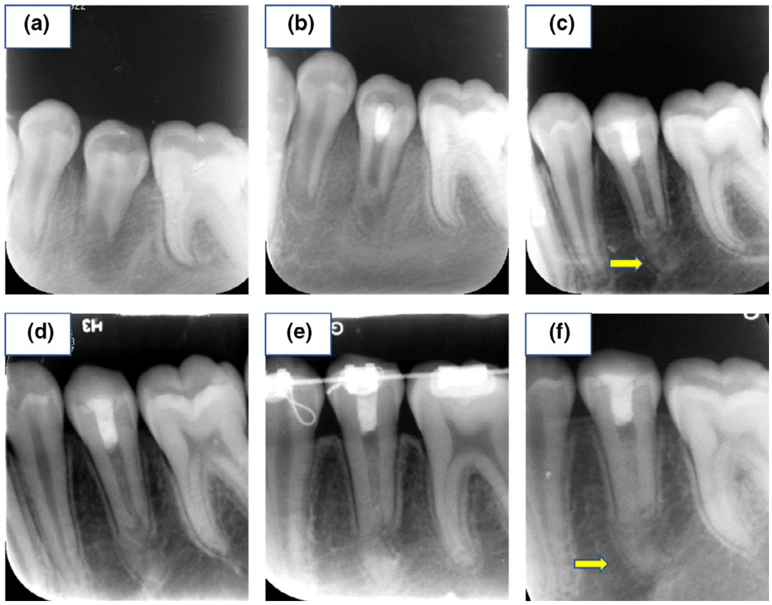

Figure 2 Periapical films over the 60-month follow-up period (a) Preoperative periapical film of tooth 35 showing an incompletely developed root with an extensive periapical lesion. (b) Three-month follow-up radiograph. The size of the apical lesion had decreased significantly. The root canal wall thickened, and hard tissue could be seen in the apical third of the root. (c) Seventeen-month follow-up radiograph showing complete resolution of the apical lesion and apparent healing of the periapical bone. Hard tissue in the apical third of the root body was more evident. Radiopaque tissue could be seen apically and was detached from the body of the root (arrow). (d) Twenty-nine-month follow-up radiograph showing an apparent apical segment detached from the root body, with the hard tissue that had formed between the apical segment and root body being irregular. There was a root canal in the apical segment, but it was not continuous with the body of the root. (e) Forty-four-month follow-up. The patient had undergone orthodontic treatment for 15 months. The morphology of the newly formed apical segment appeared more regular, and its shape and structure were similar to a normal apical segment. Scattered calcification could be seen in the main root. (f) Sixty-month follow-up. The patient had finished orthodontic treatment for 6 months. The newly formed apical segment was still detached from the body of the root (arrow). Scattered calcification could be seen in the body of the root and the apical segment.

At the 29-month follow-up, electrical pulp testing was positive. Radiopaque tissue was detached from the body of the root, and the hard tissue that formed between the apical segment and root body was irregular. It seemed that there was a root canal in the apical segment, but it was not continuous with the root body (Fig. 2d). At this time, the patient decided to undergo orthodontic treatment.

At the 44-month follow-up, electrical pulp testing was positive. The morphology of the newly formed apical segment was more regular, and its shape and structure were similar to a normal root tip. Scattered calcification could be seen in the body of the root (Fig. 2e).

By the 60-month follow-up, the patient had finished orthodontic treatment for 6 months and remained asymptomatic. Electrical pulp testing was positive. The newly formed apical segment was still detached from the body of the root. Scattered calcification could be seen in the body of the root and the apical segment (Fig. 2f).

Case 3

An 11-year-old male patient presented to the Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology, in April 2016. He had experienced night pain, spontaneous pain, occlusive pain and gingival swelling of the left mandibular premolar for 4 weeks. He had been admitted to the Emergency Department of Peking University School and Hospital of Stomatology 4 weeks prior and was diagnosed with acute apical abscess of tooth 35. The pulp chamber was opened, and calcium hydroxide (OCO Präparate GmbH, Dirmstein, Germany) was used as an intracanal medicament. The patient's symptoms were relieved, but he required further treatment in the paediatric dentistry department.

The clinical examination revealed that the mobility of tooth 35 was +1, and the tooth was mildly sensitive to percussion. The tooth had completely erupted and was free of caries, and the pulp chamber had been accessed previously. No obvious abnormality in the gingiva was noted. A periapical film revealed that the root development of tooth 35 was incomplete and was accompanied by an extensive periapical lesion (Fig. 3a). The patient was diagnosed with asymptomatic apical periodontitis.

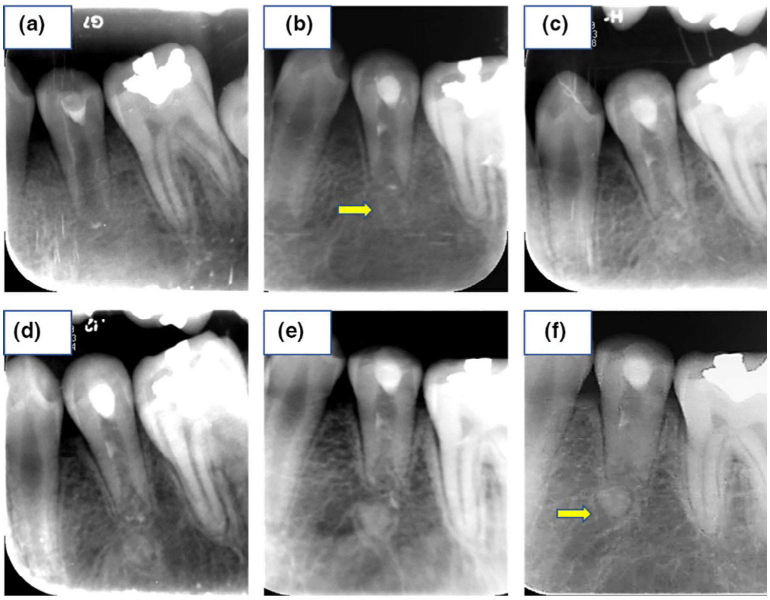

Figure 3 Periapical films over the 41-month follow-up period. (a) Periapical film of tooth 35 showing an open root apex with an extensive periapical lesion. (b) Four-month follow-up radiograph showing complete resolution of the periapical lesion. The root continued to develop, and the root canal wall thickened, but the change in root length was not noticeable. Radiopaque tissue could be seen apically and was detached from the open root end of tooth 35 (arrow). (c) Seven-month radiograph showing apparent healing of the periapical bone. Radiopaque tissue can be seen, detached from the body of the root, and had a root tip-like shape. (d) Ten-month radiograph showing increased thickness of the root canal wall, but without any apparent change in root length. Scattered calcification was seen in the body of the root. The newly formed apical segment was still separated from the main root and showed a slight mesial movement relative to the body of the root. The morphological structure of the apical segment seemed more regular, and its shape and structure were similar to a normal root tip. (e) Twenty-three-month follow-up radiograph. The detached apical segment showed continued development with the closure of the apical apex, whilst there was no obvious development in the root body. (f) Forty-one-month follow-up radiograph. The apical segment (arrow) was still separated from the main root, with a slight upward movement relative to the body of the root. Further calcification could be seen in the body of the root and the separated apical segment.

Treatment process

Revitalization procedures were performed as in case 2.

Follow-up

The tooth was evaluated regularly with clinical and radiographic examinations. At the 4-month follow-up, the patient reported no subjective symptoms. Electrical pulp testing was negative. A periapical radiograph revealed complete resolution of the periapical lesion. The root continued to develop, and the root canal wall thickened, but the root did not change in length. Interestingly, radiopaque tissue was observed apically and was detached from the open root end of tooth 35 (Fig. 3b).

At the 7-month follow-up, electrical pulp testing was negative. A periapical radiograph revealed apparent healing of the periapical bone. Radiopaque tissue was detached from the body of the root and had a root tip-like shape (Fig. 3c).

At the 10-month follow-up, the patient remained asymptomatic, and electrical pulp testing was positive. The thickness of the root canal wall had increased, with no apparent change in root length. Scattered calcification could be seen in the body of the root. The newly formed apical segment was still separate from the body of the root, with slight mesial movement relative to the root body. The morphological structure of the apical segment was more regular in shape, and the structure was similar to a normal root tip (Fig. 3d).

At the 23-month follow-up, electrical pulp testing was positive. No obvious development occurred in the main root, whilst the detached apical segment showed continued development with the closure of the apical foramen (Fig. 3e).

At the 41-month follow-up, the patient remained asymptomatic, and electrical pulp testing was positive. The newly formed apical segment was still separated from the main root, with a slight upward movement relative to the root body. Further calcification could be seen in the root body and separated apical segment (Fig. 3f).

Case 4

A 12-year-old male patient presented to the Department of Pediatric Dentistry, Peking University School and Hospital of Stomatology, in April 2014. The patient had experienced gingival swelling of the right mandibular area and pain on biting for 4 days.

Clinical examination revealed that the swelling was caused by tooth 45. The tooth had completely erupted and was free of caries, but a fractured central cusp was seen on the occlusal surface. The mobility of the tooth was +1, and it was moderately sensitive to percussion. Gingival swelling was noted. The pulp vitality test was negative. A periapical film revealed that the root development of tooth 45 was incomplete and was accompanied by an extensive periapical lesion. The patient was diagnosed with an acute apical abscess.

Treatment process

Revitalization procedures were performed as in case 2, except that a resorbable matrix was not used. However, the blood clot was so fragile that some of the MTA extruded into the apical third of the canal (Fig. 4a).

Follow-up

The tooth was evaluated regularly with clinical and radiographic examinations. At the 4-month follow-up, the patient reported no subjective symptoms. Electrical pulp testing was negative. A periapical radiograph revealed complete resolution of the periapical lesion. Although the presence of extruded MTA was observed, the root continued to

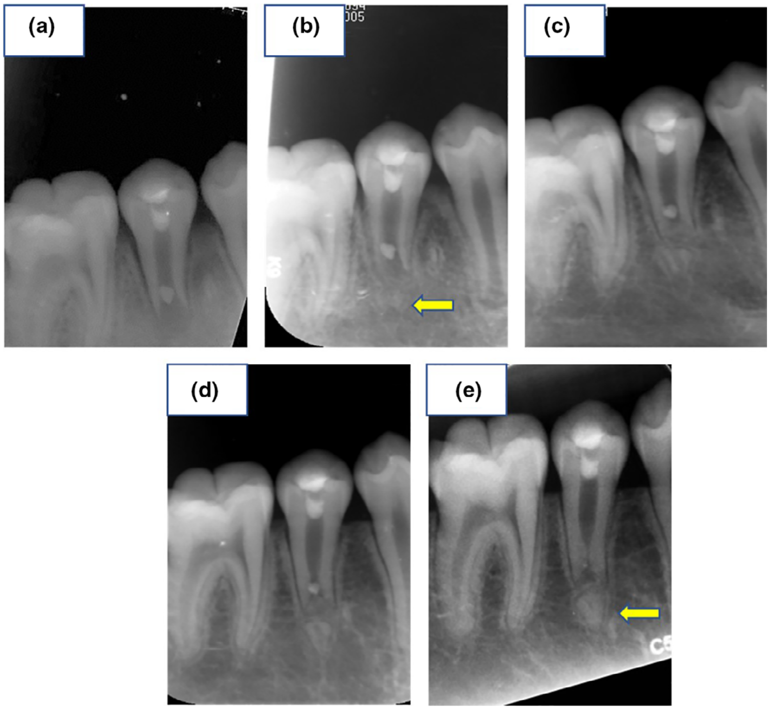

Figure 4 Periapical films over the 67-month follow-up period. (a) Periapical film of tooth 45 showing an open root apex. Radiograph showing the placement of mineral trioxide aggregate (MTA). Note that some of the MTA extruded into the apical third of the canal. (b) Four-month follow-up radiograph showing complete resolution of the periapical lesion. The presence of extruded MTA was observed. The root continued to develop, and the root canal wall thickened, but the change in root length was not noticeable. Radiopaque tissue could be seen apically and was detached from the open root end of tooth 45 (arrow). (c) Eleven-month radiograph showing apparent healing of the periapical bone. Radiopaque tissue was apparent, detached from the body of the root, and had a root tip-like shape. It seemed that there was a root canal in the apical segment, but it was not continuous with the body of the root. (D) Twenty-five-month radiograph showing increased thickness of the root canal wall, but without any apparent change in root length. The morphological structure of the apical segment seemed more regular, and its shape and structure were similar to a normal root tip. (e) Sixty-seven-month follow-up radiograph. The detached apical segment showed continued development with the closure of the apical apex (arrow). Further calcification could be seen in the separated apical segment and apical third of the root body.

develop, and the root canal wall thickened. However, the root did not change in length. Interestingly, radiopaque tissue was observed apically and was detached from the open root end of tooth 45 (Fig. 4b).

At the 11-month follow-up, electrical pulp testing was negative. A periapical radiograph revealed apparent healing of the periapical bone. Radiopaque tissue was detached from the body of the root and had a root tip-like shape (Fig. 4c).

At the 25-month follow-up, electrical pulp testing was negative. The thickness of the root canal wall had increased, with no apparent change in root length. The morphological structure of the newly formed apical segment was more regular in shape, and the structure was similar to a normal root tip (Fig. 4d).

At the 67-month follow-up, the patient remained asymptomatic, and electrical pulp testing was negative. The newly formed apical segment was still separated from the main root. The extruded MTA was no longer evident, and further calcification could be seen in the separated apical segment and apical third of the root body (Fig. 4e).

The demographics, clinical characteristics and procedure details of each case are noted in Table 1. The clinical and radiographic outcomes of each case are summarized in Table 2. All of the revitalization protocols were performed by experienced paediatric dentists.

Discussion

In addition to the five types of root development of immature permanent teeth (Chen *et al*. 2012), an uncommon type of segmental root development in which a separate root tip slowly forms apically and detaches from the body of the root may also occur following revitalization.

This type of segmental root development was reported before revitalization was used in clinical practice. One factor related to this phenomenon is the external force caused by trauma. Due to the weak connection between the HERS, apical papilla and the end of the root in an immature tooth, these tissues can be easily detached from the root end by an external force and lead to segmental root development (Gibson 1969, Barker & Mayne 1975, Burley & Reece 1976, Smith & Thaler 1992, Welbury & Walton 1999). Other reported factors related to this phenomenon are iatrogenic factors. An apexification operation may cause detachment of the HERS and apical papilla from the end of the root and lead to segmental root development (Yang *et al*. 1990). So far, only one related report was found in the field of revitalization. This report discussed a case in which the apical segment had separated from the body of the root after revitalization

Table 1 Demographic, clinical characteristics and procedure details

Variable	Case 1	Case 2	Case 3	Case 4
Age (years)	8	11	11	12
Sex	Female	Male	Male	Male
Tooth number	11	35	35	45
Aetiology	Trauma	BCC	BCC	BCC
Tooth mobility	+1	+1	+1	+1
Periapical lesion	+	+	+	+
Diagnosis	CAA	CAA	AAP	AAA
RCD	3	4	3	3
Resorbable matrix	-	+	+	–
Capping material	iRoot[a]	MTA	MTA	MTA

AAA, acute apical abscess; AAP, asymptomatic apical periodontitis; BCC, broken central cusp; CAA: chronic apical abscess; MTA, mineral trioxide aggregate; RCD, rounds of chemical disinfection
[a]A bioceramic material

Table 2 Clinical and radiographic outcomes

Variable	Case 1	Case 2	Case 3	Case 4
Duration of follow-up (months)	11	60	41	67
Capping material collapse	–	–	–	+
Electrical pulp testing	–	+	+	–
Subjective symptoms	–	–	–	–
Healing of the apical lesion	+	+	+	+
Detached apical root tip	+	+	+	+
Thickening of the root canal wall (main root)	+	+	+	+
Significantly continued development (main root)	–	–	–	–
Thickening of the root canal wall (detached root tip)	+	+	+	+
Significantly continued development (detached root tip)	+	+	+	+

(Jung *et al*. 2011). The authors believed that severe tooth mobility might have been responsible for this phenomenon. Trauma may have caused segmental development of the root in the first case discussed in the current report. However, none of the three premolars had a history of trauma or severe mobility. During revitalization procedures, intracanal bleeding is induced by mechanical irritation of the periapical tissue and rotational movement of an apically pre-bent file. To date, there is no evidence that lacerations beyond the apex can lead to the formation of a separated root. Iatrogenic factors are less likely to be the reason for this phenomenon. The reasons for this type of root development in cases 2–4 are different from those previously reported. All three premolars in cases 2–4 had extensive periapical lesions, which suggests that a long period of extensive periapical inflammation may have caused the separation of the HERS and apical papilla from the main root, leading to segmental development of the root (Fig. 5).

In the present cases, the radiographic features of the apical segment were different from the body of the root. The apical segment had gradually formed and developed, and its shape and structure were similar to a normal root tip, which was evident in the CBCT of Case 1. However, the continued development of the root body was not obvious even though the root canal wall thickened. The HERS and apical papilla may have survived in the presence of chronic periapical inflammation and regulated development of the apical segment. At the same time, the increased root canal wall thickness of the root body revealed only irregular calcification, without the HERS or apical papilla (Jung *et al*. 2011). It has been found that during revitalization procedures, stem cells from the apical papilla could flush into the root canal (Lovelace *et al*. 2011). Stem cells from the apical papilla may survive for a relatively long time during chronic periapical inflammation and retain their regenerative potential (Alongi *et al*. 2010, Galler 2016). This supposition is supported by the present report as all four teeth were accompanied by extensive periapical lesions on the first visit, but two teeth achieved positive reactions to the electrical pulp test during follow-up.

Both anterior teeth and premolars were included in this report, with the formation of a detached root tip in each. This type of segmental root development is not accidental and may occur in both anterior and posterior teeth. If the teeth have undergone severe trauma or have long-term and large-scale periapical lesions before revitalization, the possibility of segmental root development should be considered. All four teeth in this report remained intact and functioned normally in the dentition, without any symptoms. Cases 2 and 4 were observed for at least 5 years, and case 2 completed orthodontic treatment successfully. These results support the long-term survival of this type of teeth. The well-developed separated root tips could not enhance the fracture resistance of the teeth due to their separation from the main root. The long-term prognosis of teeth mainly depends on the root length and root canal wall thickness of the main root.

The follow-up time of the present cases was 11, 60, 41 and 67 months, respectively. Case 4 was the first case to be treated. In case 4, white MTA was used as the capping material over the blood clot; however, the blood clot was so fragile that some of the MTA extruded into the apical third of the canal. Thereafter, in cases 2 and 3, a resorbable collagen matrix was placed over the blood clot to prevent MTA from collapsing into the root canal. In case 1, a bioceramic material was used as the capping material over the blood clot because it has more advantage in aesthetics and was less prone to collapse than MTA.

It has been reported that orthodontic treatment could be considered after revitalization (Chaniotis 2018). Case 2 began orthodontic treatment 29 months after revitalization. During the follow-up period, radiographic images suggested that the orthodontic movement did not exacerbate the root abnormalities, and the pulp maintained vitality during orthodontic treatment. This suggests that orthodontic treatment could be

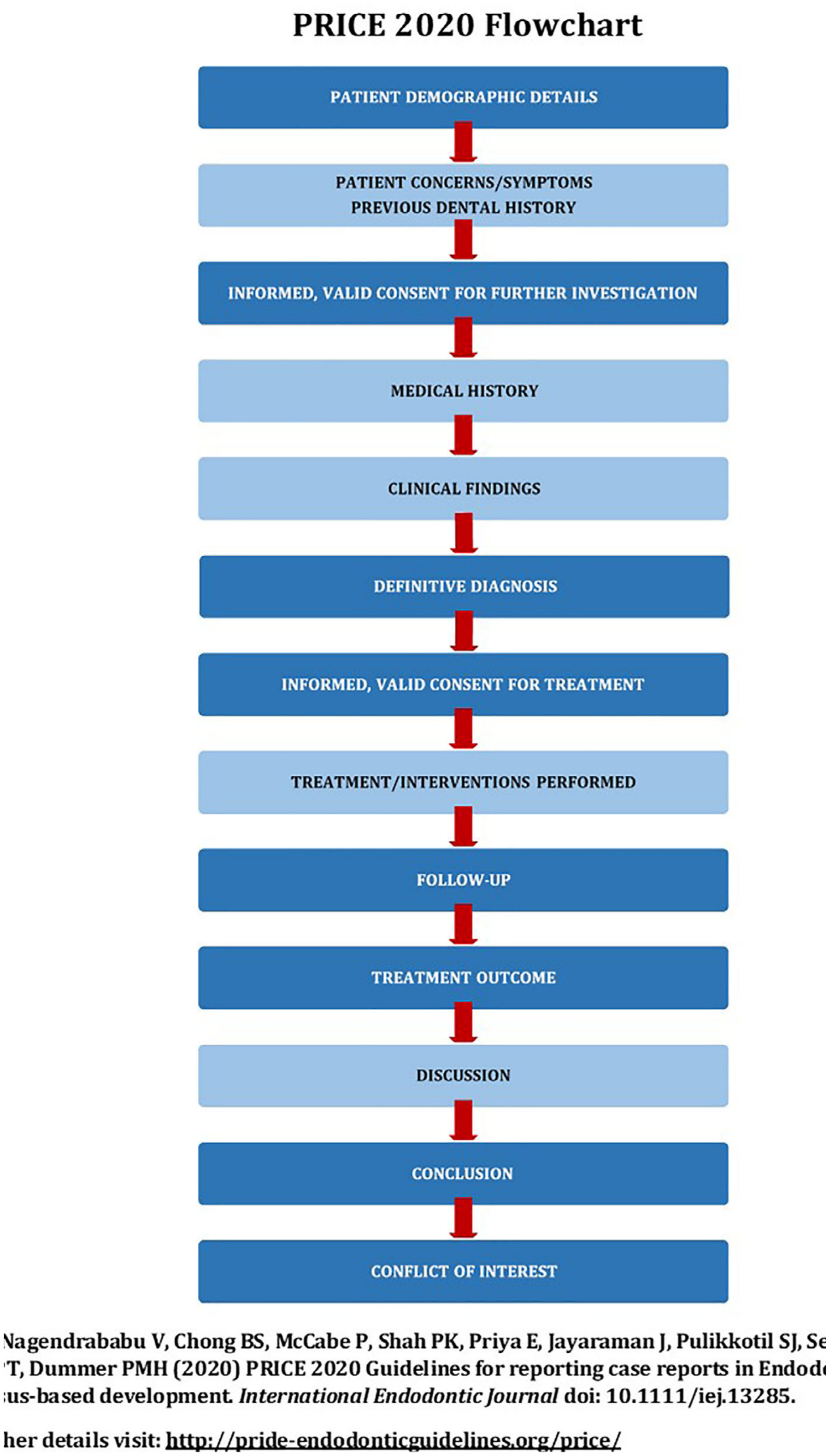

Figure 5 PRICE flowchart.

considered after revitalization, even in teeth with abnormal segmental root development. However, regular follow-up is required in such cases.

Conclusions

Trauma and extensive periapical inflammation may result in detachment of the HERS and apical papilla from the root, thus creating a separate apical segment and leading to segmental root development. This type of root development is not unexpected. If the teeth have undergone severe trauma or have long-term and large periapical lesions before revitalization, this possibility should be considered. Formation of the apical segment could be regarded as evidence of displacement of the HERS and apical papilla. Once this occurs, there is no chance that the main root of the tooth will develop into a normal-sized root. During the process of revitalization, intracanal bleeding is induced by rotating a pre-curved K-file 2 mm past the apical foramen. This operation should be performed gently to protect the apical structures and avoid iatrogenic factors that lead to abnormal root development.

Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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