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Permanent teeth with horizontal root fractures after dental trauma

A retrospective study

Key words: root fracture, dental trauma, permanent teeth, pulpal necrosis, root resorption

Summary The purpose of the present retrospective study was to evaluate the post-traumatic healing of the pulp and periodontium of 32 permanent teeth with horizontal root fractures. Twenty-nine patients, 8–48 years old, who presented at our department with a root fracture between January 2001 and April 2007, participated in the study. Root-fractured teeth with a loosened or dislocated coronal fragment were repositioned and splinted for 14–49 days (average: 34 days). In cases of severe dislocation of the coronal fragment, prophylactic endodontic treatment was performed. Follow-up examinations were conducted routinely after 1, 2, 3, 6, and 12 months. For this study, follow-up took place for up to 7 years post trauma. Of 32 root-fractured teeth, 29 (91%) survived. 10 teeth (31%) exhibited pulpal healing; 13 teeth (41%) were prophylactically endodontically treated within 2 weeks of injury. At the fracture line, interposition of calcified tissue was evident in 6 teeth (19%), and interposition of granulation tissue was observed in 8 teeth (25%). The prognosis of the root-fractured teeth was good, and one-third of the teeth with root fractures possessed a vital pulp at the final examination.

Introduction

Root fractures result after the impingement of high force upon the root. Frontal forces effect compression zones labially and lingually or palatally, and separate the root into a coronal and an apical fragment. This has detrimental consequences for the cementum, dentin, pulp, and periodontium (Welbury et al. 2002).

Compared to other dental traumas, root fractures are relatively uncommon. The frequency of root fractures in permanent teeth is only 0.5% to 7%, and in deciduous teeth, just 2% to 4% (Andreasen et al. 2007). Root fractures occur mainly in the central (68%) and lateral (27%) maxillary incisors; in contrast, only 5% of root fractures are found in mandibular incisors (Caliskan & Pehlivan 1996).

The classification of horizontal root fractures is based on the location of the fracture line (apical third, middle third, cervical third of the root) and on the degree of dislocation of the coronal fragment. The prognosis of the tooth concerned is also influenced by other factors, such as the patient's age, stage of root growth, mobility of the coronal fragment, and diastasis of the fragments (Andreasen et al. 2007). Communication between the palatal sulcus and the fracture line can additionally negatively influence the prognosis. Fractures in the middle third of the root are the most common (Andreasen et al. 1989).

In a study with 208 root fractures, those located in the cervical third showed the worst prognosis (Cvek et al. 2001). Other studies, however, described no correlation between pulpal necrosis and the level of the fracture line (Andreasen & Hjörting-Hansen 1967). Although the prognosis of root fractures is

generally good, as documented by several studies (Zachrisson & Jacobsen 1975, Andreasen & Hjörting-Hansen 1967, Andreasen et al. 1989), some studies describe complications during the healing process of the pulp and periodontium, which can unfavorably influence the long-term prognosis (Andreasen et al. 2007).

The radiological evaluation of root fractures is normally based on single-tooth radiographs and occlusal images. Since the introduction of cone-beam computed tomography (cone-beam CT), it is possible to examine root fractures three-dimensionally. The orofacial cut provides additional information which may be important for assessing the prognosis of the injured tooth.

The histological reactions at the fracture line are categorized into four types: (I) interposition of calcified tissue (callus formation); (II) interposition of connective tissue, which is characterized by peripheral rounding of the fracture's ends; (III) interposition of bone and connective tissue, radiologically characterized by the clear separation of the two fragments; and (IV) interposition of granulation tissue, caused by an infected or necrotic pulp (Andreasen et al. 2007). Type I is found most commonly in those root-fractured teeth in which the coronal fragment is not or only slightly dislocated. Type II often results after lateral dislocation or extrusion of the coronal fragment. If the trauma occurs before growth of the alveolar process is complete, the coronal fragment continues to erupt, but the apical fragment remains in its pre-trauma position. As a result, bone and connective tissue grow between the two fragments (type III). In type IV, infected or necrotic pulpal tissue causes an inflammatory reaction in the fracture line (Schroeder 1997, Andreasen et al. 2007).

The aim of the present study was to evaluate the clinical and radiological findings after horizontal root fractures in permanent teeth in terms of the pulp, periodontium, and fracture line.

Materials and Methods

Between January 2001 and April 2007, 92 patients with 115 root fractures were examined and treated at the University of Bern's Department of Oral Surgery and Stomatology. Twenty-nine patients with 32 root-fractured teeth were followed-up for 1 to 7 years (average: 2.3 years). The reasons for patient exclusion or drop-out from the study are listed in Table I.

For each patient, a history was taken and clinical examination was performed (inspection, palpation, percussion, probing depths, and sensitivity test using CO_2). In addition, a periapical radiograph and an occlusal radiograph were taken. After local anesthesia, manual repositioning of the coronal fragment was performed, and the fragment was stabilized with a TTS splint (TTS Titanium Trauma Splint, Medartis, Basel, Switzerland), if the coronal fragment showed high mobility (class II–III) or was dislocated. The duration of splinting ranged from 14 to 49 days (average: 34 days). In teeth with a closed apex and a pronounced dislocation of the coronal fragment (extrusion, lateral dislocation), and/or an additional crown fracture with exposed dentin (i.e., teeth with a high probability of pulpal necrosis), prophylactic endodontic treatment was performed within two weeks. Initially Ledermix Paste® (Lederle, Zug, Switzerland) was placed in the coronal fragment. After two to three weeks, the teeth were treated with calcium hydroxide for at least 3 more weeks before performing the root-canal filling with gutta-percha and sealer. The patients also received tetracycline (day 1: 100–200 mg, days 2–10: 50–100 mg, dosage according to body weight) and non-steroid analgesics.

The follow-up examinations were conducted at 1, 2, 3, 6, and 12 months, and up to 7 years after the trauma. The study parameters were pulp sensitivity at the time of injury, fragment diastasis, and dislocation of the coronal fragment. The diastasis between the coronal and apical fragments was classified as either <1 mm or $\geqslant 1$ mm. The dislocation of the coronal fragment was classified according to Andreasen's method by ascending severity: concussion – subluxation – extrusion – lateral dislocation – avulsion (Andreasen & Andreasen 1988). Pulpal healing was classified as follows: (1) prophylactic endodontic treatment within two weeks after trauma; (2) therapeutic endodontic treatment (delayed intervention after pulpal necrosis); (3) pulp canal obliteration; (4) pulpal healing (vital pulp). Periodontal healing was described as either uneventful or external root resorption. The radiographic healing at the fracture line was divided into four types: (I) interposition of calcified tissue (callus formation); (II) interposition of connective tissue; (III) interposition of bone and connective tissue; and (IV) interposition of granulation tissue (Andreasen et al. 2007).

Tab. I Reasons for the exclusion/drop-out of patients from the study

	n patients	n teeth
Number at baseline	92	115
Immediate extraction	24	36
Immediate decoronation	10	12
Patients who did not attend recall	23	27
Patients who were treated elsewhere first, and were referred to us for further treatment	5	7
Avulsion of apical and coronal fragment (apical fragment lost)	1	1
Study material	29	32

Results

The present study included 29 patients (72% male, 28% female) aged 8–48 years (average age: 25.5 years; Table II). Of the 32 examined teeth, 29 were central and 3 were lateral maxillary incisors.

During the follow-up period, three teeth were lost: One had to be extracted due to aggressive root resorption, a second was extracted after a new trauma, and the third tooth was decoronated due to a persisting fistula. The remaining 29 teeth (91%) survived and were examined at the final appointment.

Thirteen (41%) of 32 teeth received early, prophylactic endodontic treatment within two weeks following trauma. Because of pulpal necrosis, 4 teeth underwent endodontic treatment within the first year after trauma. Two teeth exhibited pulp canal obliteration (Fig. 1), and 10 teeth (31%) showed

Tab. II Distribution of patients (n=29) and teeth (n=32) by age group

Age	n patients	n teeth
$\leqslant 7$ years	0	0
8–11 years	2	2
12–19 years	9	10
$\geqslant 20$ years	18	20
Total	29	32

Fig. 1a An 8-year-old patient presented with a fracture in the apical third of tooth 21.

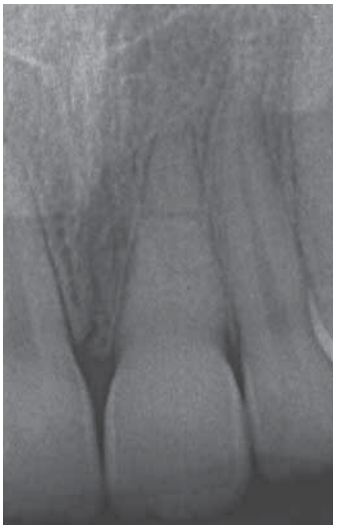

Fig. 1b Five years after trauma, the root-fractured tooth 21 shows pulp canal obliteration in both fragments.

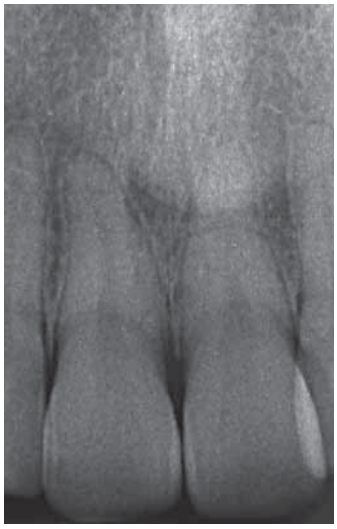

Fig. 2a A 24-year-old patient presented with a root fracture of tooth 21, which exhibited a diastasis of <1 mm and no dislocation of the coronal fragment.

Fig. 2b Two years post-traumatically, tooth 21 shows normal pulpal healing with a vital pulp. The radiograph shows an axially aligned reconsolidation of the root fracture with a distinctly narrowed, still slightly radiolucent fracture line.

Tab. III Pulpal status at the final follow-up examination, by patient age at the time of injury (n=32)

	⩽7 years	8–11 years	12–19 years	⩾20 years	Total teeth
Early prophylactic endodontic treatment	0	1	2	10	13
Therapeutic endodontic treatment after pulpal necrosis	0	1	3	0	4
Pulp canal obliteration	0	1	0	1	2
Pulpal healing (vital pulp)	0	0	1	9	10
Tooth extraction	0	0	2	0	2
Decoronation	0	0	1	0	1

pulpal healing (vital pulp) (Fig. 2). In short, only one-third of the teeth at the final follow-up examination presented a vital pulp, and two-thirds were endodontically treated.

Of 29 patients, 18 (62%) were over 20 years old. The patient's age and the severity of the injury influenced the choice of treatment: The probability of prophylactic endodontic treatment increased with the age of the patient and severity of the injury (Table III). Six of 32 teeth also exhibited injury of the crown substance (3 enamel fractures, 1 uncomplicated crown fracture, and 2 complicated crown fractures, Table IV). A diastasis of >1 mm between the apical and coronal fragments and a dislocation or extrusion of the coronal fragment led to early prophylactic endodontic treatment (Table V).

In the region of the fracture line, 15 of 32 teeth (47%) exhibited an interposition of connective tissue (type II), 8 teeth (25%) had an interposition of granulation tissue (type IV), 6 (19%) demonstrated callus formation (type I), and 3 (9%) showed an interposition of bone and connective tissue (type III). Two of 4 teeth with a concussion exhibited a type I reaction. Eight teeth (25%) with negative pulpal sensitivity at the initial examination, a fragment diastasis of >1 mm, and a lateral dislocation showed type IV healing (Table VI). However, 5 of 15 teeth which demonstrated type II had the same degree of injury as the teeth showing a type IV reaction. Four of 8 teeth with type IV had insufficient root canal fillings: In 3 teeth, both the coronal and the apical fragment had been endodontically

Tab. IV Pulpal status at the final follow-up examination in root-fractured teeth with additional crown fractures (n=6)

	Early prophylactic endodontic treatment	Therapeutic endodontic treatment after pulpal necrosis	Pulp canal obliteration	Pulpal healing (vital pulp)	Total teeth
Enamel fracture	2	0	0	1	3
Uncomplicated crown fracture	1	0	0	0	1
Complicated crown fracture	2	0	0	0	2
Total teeth	5	0	0	1	6

Tab. V Correlation between "injury factors" (pulpal sensitivity at baseline, fragment diastasis and dislocation degree of the coronal fragment) and pulpal status at final follow-up examination (n=32)

	Early prophylactic endodontic treatment	Therapeutic endodontic treatment after pulpal necrosis	Pulp canal obliteration	Pulpal healing (vital pulp)	Tooth extraction	Decoronation
	n=13	n=4	n=2	n=10	n=2	n=1
Pulpal sensitivity at baseline:						
Positive	1	1	1	6	0	0
Negative	12	3	1	4	2	1
Fragment diastasis:						
< 1 mm	3*	1	1	8	0	0
⩾ 1 mm	10	3	1	2	2	1
Dislocation degree of coronal fragment:						
Concussion	1**	0	0	3	0	0
Subluxation	3	0	0	3	0	0
Extrusion	2	0	1	2	1	0
Lateral dislocation	5	4	1	2	1	1
Avulsion	2	0	0	0	0	0

* includes 2 teeth with closed apices, negative sensitivity at baseline and an additional uncomplicated crown fracture
** closed apex, negative sensitivity at baseline and an additional uncomplicated crown fracture

Fig. 3a The root-fractured tooth 21 of a 10-year-old patient shows a diastasis of >1 mm, a lateral dislocation of the coronal fragment, and a crown fracture.

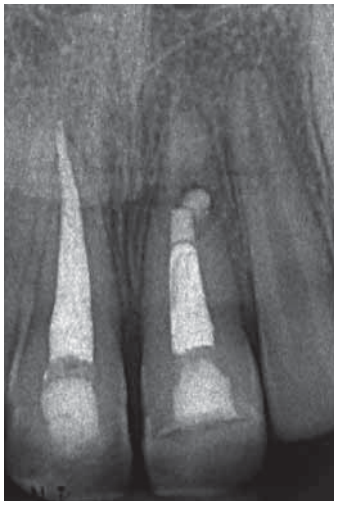

Fig. 3b The single-tooth radiograph of tooth 21 six months post-traumatically shows dislocated, radiopaque root-canal filling material between the apical and the coronal fragment with irregular interfragmentary cementum-dentin resorption.

treated, and in 1 tooth, excess root-canal filling material was found between the fragments (Fig. 3). Two teeth with a radiologically sufficient root canal filling (Fig. 4) showed a large dislocation of 4 mm at the initial examination.

An external infection-related root resorption was diagnosed in 3 teeth (9%). These teeth had an apical foramen of <1 mm and a fragment diastasis of >1 mm; they exhibited a lateral dislocation of the coronal fragment and underwent early, prophylactic endodontic treatment. In spite of this, external root resorption was noted one year post trauma (Fig. 4c).

Discussion

This retrospective study examined the pulpal and periodontal healing of teeth with root fractures, as well as the radiographic reactions at the fracture line. From an initial group with 115 teeth,

Tab. VI Radiographic healing at the fracture line at the final follow-up examination in terms of "injury factors" (A) and treatment of the teeth concerned (B) (n=32)

A	Type I n=6	Type II n=15	Type III n=3	Type IV n=8
Sensitivity at baseline:				
Positive	1	7	0	1
Negative	5	8	3	7
Fragment diastasis:				
< 1	3	9	1	0
$\geqslant 1$	3	6	2	8
Dislocation degree of coronal fragment:				
Concussion	2	2	0	0
Subluxation	1	4	0	1
Extrusion	0	5	0	1
Lateral dislocation	1	4	3	6
Avulsion	2	0	0	0
B	**Type I n=6**	**Type II n=15**	**Type III n=3**	**Type IV n=8**
Early prophylactic endodontic treatment	4	5	1	3
Therapeutic endodontic treatment after pulpal necrosis	0	1	1	2
Pulp canal obliteration	0	1	1	0
Pulpal healing (vital pulp)	2	8	0	0
Tooth extraction	0	0	0	2
Decoronation	0	0	0	1

Fig. 3c The cone-beam CT at the 1-year follow-up depicts the overfilled root-canal filling material between the fragments with tissue reaction type IV.

it was possible to follow-up only 32 of them in an observation period of 1–7 years after trauma (Table I).

Several studies have reported that the average age of patients with root fractures lies between 11 and 20 years (Jacobsen & Zachrisson 1975, Zachrisson & Jacobsen 1975, Caliskan & Pehlivan 1996, Andreasen et al. 2004, Andreasen et al. 2007). In the current study, however, 18 of 29 patients (62%) were older than 20 (average: 25.5 years, Table II). This fact is particularly relevant, because the patient's age at the time of injury is considered one of the most important factors in pulpal healing after root fracture. Andreasen et al. (2004) studied the influence of "pre-injury and injury factors" on the healing of 400 intra-alveolar root fractures. Those authors found that the age of the patients, the stage of root growth, mobility of the coronal fragment, dislocation of the coronal fragment, and fragment diastasis exerted the greatest influence on healing at the fracture line and on the occurrence of pulpal necrosis. The most recent study on root fractures (Cvek et al. 2008) shows that 20% (109 of 534) of teeth with root fractures did not demonstrate healing (pulpal necrosis). Of these 109 teeth, 34 were extracted either before or after inception of endodontic treatment.

The concept of early, prophylactic endodontic treatment practiced here in severe cases differs from the treatment guidelines recently published by the International Association of Dental Traumatology (IADT) (Flores et al. 2007). The guidelines recommend endodontic treatment only after pulpal necrosis, not as a prophylactic intervention. However, considering the large number of patients in this study who were over 20 years old and had a severe root fracture (62%), a different approach was taken in certain cases.

Nevertheless, root-fractured teeth in children and adolescents or root-fractured teeth with a minimum dislocation of the coronal fragment – independent of the patient's age – should not be prophylactically endodontically treated; rather, pulp healing should be carefully observed for a minimum of one year (Flores et al. 2007). If pulpal necrosis develops, endodontic treatment is indicated exclusively of the coronal fragment. However, this cautious and "conservative" method for permanent, root-fractured teeth with severe dislocation and high mobility of the coronal fragment should be re-assessed individually from case to case (von Arx et al. 2007).

Root-fractured teeth often possess a vital apical fragment, even when the coronal fragment is necrotic. For this reason, only the coronal fragment should be endodontically treated (Cvek et al. 2004). In the study by Cvek et al. (2004), overfilled root-canal filling material between the fragments did not lead to healing or lead to interposition of granulation tissue.

Fig. 4a An 18-year-old patient presented with root-fractured teeth 11 and 21, which exhibited a large diastasis and dislocation of the coronal fragments.

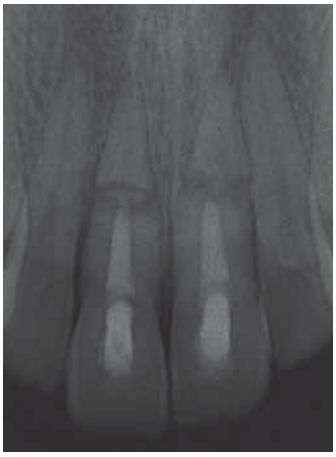

Fig. 4b 30 days after trauma, both root-fractured teeth exhibited pulpal necrosis, and the coronal fragments were consequently endodontically treated.

Fig. 4c One year post trauma, the radiographs of both teeth 11 and 21 showed external root resorption.

The authors assume that contaminated tissue was intruded between the fragments. In the present study, 8 teeth (25%) showed no healing, which agrees with the study by Cvek et al. (2004). Three of these 8 teeth wrongly received endodontic treatment of both fragments, and one tooth had excess filling material between the fragments.

Andreasen et al. (2007) observed that 60% of the teeth with root fractures exhibited external root resorption. In the current study, only three teeth developed external, infection-related root resorption. Because the pulpal and periodontal reaction in root fractures is similar to that of dislocated teeth (Andreasen & Andreasen 1988, Andreasen et al. 1989), a filler of Ledermix Paste® (triamcinolone and dimethylchlortetracycline) was first placed into the root canal (von Arx et al. 2007). Several experimental studies have shown that external root resorption after trauma occurs less frequently when Ledermix Paste® is applied as the first filler in the canal (Thong et al. 2001, Bryson et al. 2002, Wong & Sae-Lim 2002). The steroid component of Ledermix® (triamcinolone) suppresses the initial inflammatory reaction, while the antibiotic component (dimethylchlortetracycline) inhibits the osteoclast-induced root resorption.

Jacobsen and Zachrisson examined 51 root-fractured teeth, focussing on the different tissue reactions at the fracture line (type I–III). They reported that 33 of 51 root-fractured teeth (65%) exhibited a type II reaction (Jacobsen & Zachrisson 1975). These results agree with those of the present study, in which 15 of 32 teeth (47%) healed by means of connective tissue interposition.

The results of the current study on root-fractured permanent teeth differ from the results of previous studies in terms of patient age and the endodontic procedure. This study also shows that endodontically adequately treated teeth with root fractures have a good prognosis. Root resorptions were seldom observed, and the most frequent tissue reaction at the fracture line was interposition of connective tissue (type II). Pulpal necroses and lack of healing at the fracture line (type IV) were the most common complications.

Résumé

Le but de cette étude rétrospective était d'évaluer les guérisons pulpaires et parodontales de 32 dents permanentes atteintes de fractures radiculaires horizontales. Vingt-neuf patients, âgés entre 8 et 48 ans, qui ont consulté notre clinique entre janvier 2001 et avril 2007 à cause d'une fracture radiculaire, ont participé à l'étude. Les dents avec fracture radiculaire qui étaient mobiles et/ou délocalisées ont été repositionnées et immobilisées pendant 14 à 49 jours (moyenne: 34 jours). En cas de déplacement sévère du fragment coronaire, un traitement endodontique à titre préventif a été administré. Des examens de contrôle ont eu lieu après 1, 2, 3, 6 et 12 mois, et ont été prolongés jusqu'à 7 ans. 29 dents (91%) des 32 avec fracture radiculaire ont survécu. 10 dents (31%) des 32 avec fracture présentaient une guérison pulpaire, tandis que 13 dents (41%) ont été traitées endodontiquement durant les deux premières semaines après le traumatisme. La guérison au niveau de la ligne de fracture a été caractérisée soit par l'interposition de tissu calcifié (formation d'un cal) chez 6 dents (19%), soit par l'interposition de tissu de granulation chez 8 dents (25%). Le taux de survie des dents ayant subi une fracture radiculaire était élevé et un tiers des dents fracturées présentait un tissu pulpaire guéri lors de l'examen final.

References

Andreasen J O, Hjörting-Hansen E: Intraalveolar root-fractures: radiographic and histologic study of 50 cases. J Oral Surg 25: 414–426 (1967)

Andreasen F M, Andreasen J O: Resorption and mineralization processes following root-fracture of permanent incisors. Dent Traumatol 4: 202–214 (1988)

Andreasen F M, Andreasen J O, Bayer T: Prognosis of root-fractured permanent incisors – prediction of healing modalities. Endod Dent Traumatol 5: 11–22 (1989)

Andreasen J O, Andreasen F M, Mejàre I, Cvek M: Healing of 400 intra-alveolar root-fractures. 1. Effect of pre-injury and injury factors such as sex, age, stage of root development, fracture type, location of fracture and severity of dislocation. Dent Traumatol 20: 192–202 (2004)

Andreasen F M, Andreasen J O, Cvek M: Root fractures. In: Andreasen J O, Andreasen F M, Andersson L (Ed.): Textbook and color atlas of traumatic injuries to the teeth. Munksgaard, Kopenhagen, 337–371 (2007)

Bryson E C, Levin L L, Banchs F, Abbott P V, Trope M: Effect of immediate intracanal placement of Ledermix Paste® on healing of replanted dog teeth after extended dry times. Dent Traumatol 18: 316–321 (2002)

Caliskan M K, Pehlivan Y: Prognosis of root-fractured permanent incisors. Endod Dent Traumatol 12: 129–136 (1996)

Cvek M, Andreasen J O, Borum M K: Healing of 208 intraalveolar root fractures in patients aged 7–17 years. Dent Traumatol 17: 53–62 (2001)

Cvek M, Mejàre I, Andreasen J O: Conservative endodontic treatment of teeth fractured in the middle or apical part of the root. Dent Traumatol 20: 261–269 (2004)

Cvek M, Tsilingaridis G, Andreasen J O: Survival of 534 incisors after intra-alveolar root fracture in patients aged 7–17 years. Dent Traumatol 24: 379–387 (2008)

Flores M T, Andersson L, Andreasen J O, Bakland L K, Malmgren B et al.: Guidelines for the management of traumatic dental injuries. I. Fractures and luxations of permanent teeth. Dent Traumatol 23: 66–71 (2007)

Jacobsen I, Zachrisson B U: Repair characteristics of root-fractures in permanent anterior teeth. Scand J Dent Res 83: 355–364 (1975)

Schroeder H E: Zahnfrakturen und Zahnluxationen. In: Pathobiologie oraler Strukturen. 3rd edition, Karger Basel, 63–71 (1997)

Thong Y L, Messer H H, Siar C H, Saw L H: Periodontal response to two intracanal medicaments in replanted monkey incisors. Dent Traumatol 17: 254–259 (2001)

von Arx T, Chappuis V, Hänni S: Verletzungen der bleibenden Zähne – Teil 3: Therapie der Wurzelfrakturen. Schweiz Monatsschr Zahnmed 117: 135–144 (2007)

Welbury R R, Kinirons M J, Day P, Humphreys K, Gregg T A: Outcomes for root-fractured permanent incisors: a retrospective study. Pediatr Dent 24: 98–102 (2002)

Wong K S, Sae-Lim V: The effect of intracanal Ledermix on root resorption of delayed-replanted monkey teeth. Dent Traumatol 18: 309–315 (2002)

Zachrisson B U, Jacobsen I: Long-term prognosis of 66 permanent anterior teeth with root-fracture. Scand J Dent Res 83: 345–354 (1975)