Dental Traumatology 2005; 21: 80–92

DENTAL TRAUMATOLOGY

Results after replantation of avulsed permanent teeth. I. Endodontic considerations

Pohl Y, Filippi A, Kirschner H. Results after replantation of avulsed permanent teeth. I. Endodontic considerations. Dent Traumatol 2005; 21: 80–92. © Blackwell Munksgaard, 2005.

Abstract – Following avulsion and replantation, teeth are at risk for infection and infection related resorption (IRR). Severe discolorations of tooth crowns and cervical root fractures are common. This study presents data on endodontic related complications of avulsed teeth replanted following an extraoral endodontic treatment. Periodontal aspects will be discussed in the second part of the present publication. Twenty-eight permanent teeth in 24 patients aged seven to 17 years were replanted after avulsion. All teeth could be evaluated. In all teeth extraoral endodontic treatment by retrograde insertion of ceramic or titanium posts was performed. Mean observation period was 31.2 months (median: 24.1 months). Nine teeth healed with a functional peridontal ligament (PDL) (functional healing, FH), 19 teeth exhibited replacement resorption (RR), which was succeeded by IRR in three teeth after observation periods of more than 14 months. Diagnosis was set to tunneling resorption (one case) and to cervical resorption preceded by complete RR (two cases). No early IRR was observed. All six teeth rescued in physiologic conditions (cell culture medium of tooth rescue box) exhibited FH. Discolorations of tooth crowns or other complications (cervical root fractures, fractures of posts) were not observed. No differences in the healing results of immature and mature teeth were observed which is in contrast to previous studies. This finding is explained with the different endodontic treatment protocols. Extraoral endodontic treatment by retrograde insertion of posts prevents early IRR and minimizes the overall incidence of IRR. The method does not negatively influence periodontal healing. As there are further advantages (no discoloration, no root fractures, patient not involved, less radiographs, less time consumption, less costs) the method is recommended in isolated teeth before replantation. Especially immature teeth profit from the prevention of complications.

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Key words: extraoral endodontic treatment; endodontic complications; infection related resorption; crown discoloration; cervical root fractures

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Accepted 13 May, 2004

In replanted teeth severe damage in the periodontal ligament and absence of infection will lead to replacement resorption (RR) and ankylosis. In avulsed teeth the damage in the peridontal ligament (PDL) is predominantly caused by inadequate storage of the isolated teeth. In the second part of this publication this problem and the role of physiologic storage media contained in a tooth rescue box as well as the use of antiresorptive-regenerative therapy (ART) will be discussed in detail (1). Critical is the endodontic condition. The necrotic pulp often will get infected. When the dentinal tubules are opened at the periodontal aspect by resorption as the result of damage in the

PDL the infection in the pulp canal will cause infection related resorption (IRR, formerly named inflammatory resorption) which sets on several days after replantation. Adequate endodontic treatment may stop the progression of this complication. As recommended by most authors and different societies the endodontic treatment should be carried out about 7–10 days after the replantation in teeth in which a revascularization of the pulp after replantation cannot be expected (2–9).

In replanted teeth the technical procedure of conventional root canal treatment is difficult and highly demanding. The root canal filling must not only afford a tight seal at the apex but along the whole root length (10). In a clinical study on 110 avulsed and replanted teeth 39 teeth (35.5%) exhibited IRR. Of these, 31 teeth were removed in total, and 22 teeth were removed within the first year after replantation (11). In a second part of that study, of in total 51 extracted teeth on 22 teeth precise data were given on the endodontic treatment (extraoral, postponed, none) as well as on the healing types and the retention period. With postponed or without endodontic treatment 10 of 11 teeth showed IRR and also 10 of 11 teeth were removed within the first year, and one tooth after 2 years (median: 3 months). With immediate (extraoral) endodontic treatment six of 11 teeth showed IRR and all teeth had a retention rate of at least 24 up to 144 months (median: 45 months). When examined histologically the sites of IRR were correlated to remnants of pulp tissues within the root canal (12). In actual clinical studies on avulsed teeth which were root filled in a conventional way after replantation the incidence of IRR was 30% (13), 27–37% depending on the stage of root development (14), and 25–39.1%, depending on the timing of root canal therapy (15) (Table 1).

In mature teeth a temporary application of calcium hydroxide into the root canal is recommended to treat the endodontic infection. The duration of this treatment is discussed controversely (16). A definite root filling using approved endodontic techniques completes the therapy. Immature teeth may be revasculated following replantation. Depending on the width of the apical foramen and on the length of the pulp the chance of revascularization was about 10–50% in avulsed and replanted teeth (17). In case of pulp necrosis the instillation of calcium hydroxide is used to treat the endodontic infection and to induce the formation of an apical hard tissue barrier (apexification). The time needed for apexification was several months up to 2 years (18, 19). The use of calcium hydroxide in replanted teeth resulted in a higher incidence (20, 21) and progression (22) of RR. A higher incidence of tooth loss and a lower survival expectation was reported when the endodontic treatment was still in a temporary phase compared with teeth with a completed endodontic treatment (23). The incidence of IRR was significantly higher in immature than in mature teeth (14). The use of calcium hydroxide is considered to weaken the resistance against cervical root fractures (24).The rate of this complication was very high in 'luxated' immature teeth. Depending on the root development it occurred in 28–77% of the treated teeth, and mostly within the first year after the onset of treatment (25).

Crown discolorations are common in replanted teeth. Discolorations were observed in 58.3% of avulsed and replanted teeth (26), and 34.9% showed severe discolorations (27). These teeth needed further expensive treatments like internal bleaching, veneers or crowns (26–28). Internal bleaching may provoke cervical root resorptions (29–36), especially in traumatized teeth (30, 32). In long-term observations the success of bleaching was given to be between <50 and 90% (28, 29, 31).

Extraoral endodontic treatment prevented the establishment of IRR in animal experiments (37–41). Nevertheless it is discouraged by most authors and dental societies (2–9, 16). Major concern on extraoral endodontic treatment is additional damage to the periodontal ligament by prolonged extraoral periods, by extraoral root filling procedures as well as by the root filling materials themselves. In two short-term animal experiments there was a slightly higher rate of ankylosis in extracted and replanted teeth with an extraoral but

Table 1. Rates of healing after replantation of avulsed permanent teeth (in %)

	FH	Complic.	RR	IRR	IRR/complic.
Andreasen and Hjörting-Hansen (1966) (11)	24.5	75.5	40.0	35.5	47.0
Andreasen et al. (1995) (14)	28.5	71.5	41.8	29.8	41.6
Boyd et al. (2000) (13)	36.0	64.0	34.0*	30.0	46.9
Pohl et al. (2004) (present study)	32.1	67.9	57.1	10.7	15.8

FH, functional healing; complic.; complication/non-functional healing; RR, replacement resorption; IRR, infection related resorption; IRR/complic., rate of IRR referred to complication.
*Cases without additional IRR.

conventional root filling compared with teeth replanted without endodontic treatment (40, 41). In other studies it was shown that ankylosis is masked by IRR (42) and that 8 weeks are too short for statements on the definite establishment of RR (38). The studies were critically revised elsewhere (43).

Immediate extraoral endodontic treatment by retrograde insertion of posts made of ceramics or titanium (44–46) was shown to prevent the establishment of IRR (43) and to not compromise periodontal healing (1, 43, 47, 48) in long-term clinical studies. In our clinics it is a standard protocol in isolated teeth to be re- or transplanted and in which pulp necrosis is predictable (44–46). Aim of the study was to evaluate the clinical and radiographic results in avulsed teeth replanted after retrograde extraoral insertion of posts with respect to infection related complications, ankylosis, crown discoloration, and fractures of root or post.

Material and methods

The standard treatment protocol concerning the efforts in enhancing periodontal healing of avulsed and replanted teeth will be described in detail in the second part of this publication (1).

Extraoral endodontic treatment

According to the method described by KIRSCHNER (44–46) the avulsed teeth were endodontically treated by an extraoral retrograde insertion of posts made of aluminum-oxide-ceramics (Cerasiv, Plochingen, Germany, no longer available) or titanium (RetroPost®, Brasseler/Komet, Lemgo, Germany). Immature teeth were only subjected to this immediate endodontic treatment when the extraoral dry phase exceeded 15 min and/or the storage in unphysiologic media exceeded 30 min (1). However, recently it was started to also treat physiologically rescued immature teeth by extraoral endodontic treatment.

The isolated tooth was held by forceps exclusively at its crown. Care was taken to not touch the root to avoid mechanical damage to the periodontium. The root tip was resected with discs automatically cooled by sterile isotonic saline (Fig. 1). In mature teeth the resection comprised about 3–5 mm to remove apical ramifications and to allow a complete preparation of the root canal. In immature teeth the resection was adopted to the root length. Then the root canal was prepared with burs from a retrograde direction (Fig. 2), starting with the smallest diameter (1.6 mm). The preparation was widened (consecutive diameters: 2.0, 2.5 and 3.0 mm) until a residual thickness of dentine of about 0.3–0.5 mm resulted

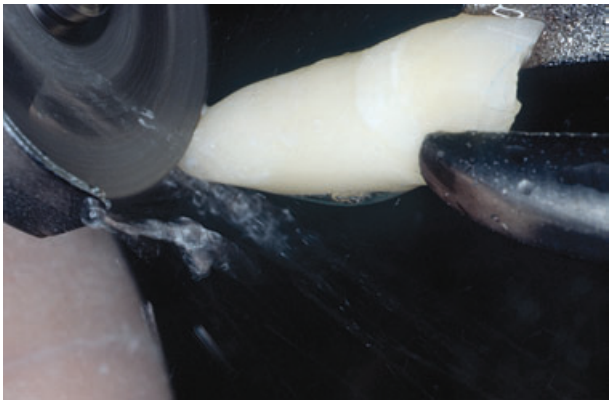

Fig. 1. Resection of the root tip with a cooled disk to remove apical ramifications. The branches of the forceps may not alter the root surface and are placed exclusively at the enamel.

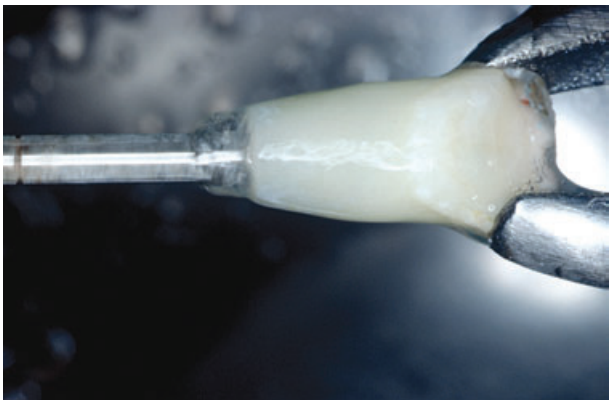

Fig. 2. Preparation of the root canal with intensively cooled burs from a retrograde direction.

at the resection site. The preparation reached beyond the cemento-enamel junction into the crown. During the preparation of the root canal the burs were used in intermittent action: following a loading phase of about 1 s the burs were pulled out of the root canal completely to allow the access of the cooling medium to the tip of the bur. Intensive cooling with sterile isotonic saline (room temperature) was afforded by an automatic pump system attached to the handpiece. Thereby the root surfaces were also rinsed effectively. After preparation the posts were tried in and shortened to the desired length. It was intended that the apical projection of the posts should establish normal root length (Fig. 4). Aggressive irrigants (H_2O_2, NaOCl, Acids) may escape the root canal and damage the PDL, they may never be used in isolated teeth. The prepared root canals were dried with sterilized paper points of different diameters (ISO 80–140). By rotating the paper points pulp tissue remnants in the pulp horns could be removed in some cases (Fig. 3). The posts were cemented in with sealers (Fig. 4). In some cases the fundus of the alveolus was

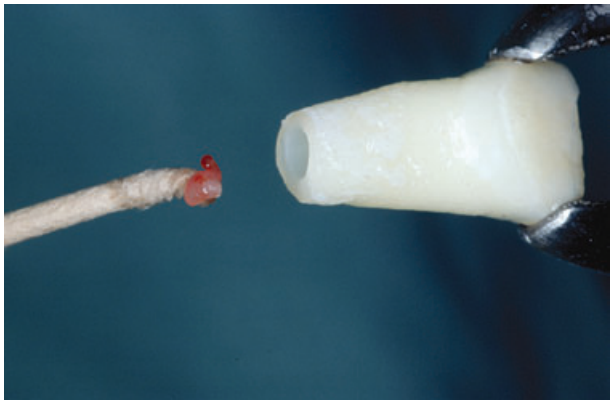

Fig. 3. Pulp tissues from the pulp horn attached to a paper point that was used in rotating movements.

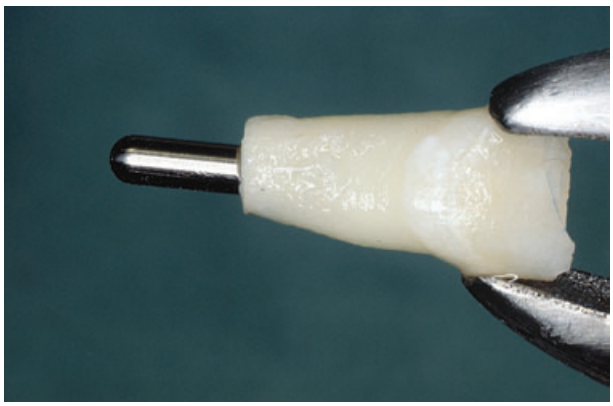

Fig. 4. Titanium post inserted into the root canal. Normal tooth length, eventually a slight overextension of 1–2 mm, is established.

widened with the burs to meet the diameter of the post. Maximum time without active moistening was about 2–3 min during drying of the root canal with sterile paper points, application of sealer, insertion of posts and initial setting of sealer. During the residual periods, i.e. changing of burs or preparation of the alveolus, the teeth were kept moist by interim storage in saline. Since availability (1995) the tissue culture medium of the tooth rescue box (Dentosafe®, Dentosafe GmbH, Iserlohn, Germany) (49–51) was used as a storage medium to apply an assumed reconditioning effect on possibly damaged PDL cells (1). All endodontic treatments were finished within 10–30 min, mainly depending on the number of photographs taken. In no case it was tried to remove possibly left pulp tissue remnants in the pulp chamber through a palatal access intra- or postoperatively. The crown substances were left intact.

Splinting and postoperative follow-up

Following replantation a non-rigid splint was applied for 1–3 weeks. Bracket splints and, since 2000, the titanium trauma splint (TTS®, Medartis, Basel, Switzerland) were used. Immediately after splinting intraoral radiographs were taken. During the regular controls the patients were examined by intraoral radiographs and clinically. Percussion sound, tooth mobility, Periotest® values (Medizintechnik Gulden, Bensheim, Germany), tooth position in relation to the neighbored teeth, reactions to palpation and percussion, pocket probing depths and all pathologic changes (fistulas, pain, swellings) were recorded. Radiographically pathologic changes were assessed.

Classification of postoperative healing

The postoperative healing was classified as replacement resorption (RR)/ankylosis when the tooth showed one or more of the following criteria: high percussion tone, negative vertical Periotest® value, no mobility, progressive infraposition, radiographically loss of periodontal space or osseous replacement of the root substances. The healing was classified as *infection* when clinical signs of infection (swelling, pain, fistula, sensitivity to percussion and palpation) were present and/or the intraoral radiograph showed sites with radiolucency periapically (apical periodontitis) or along the lateral root surfaces (IRR). Subtypes of IRR were classified as early IRR (e-IRR), tunneling IRR (t-IRR) and complete RR succeeded by cervical resorption (cRR-CR). The classification will be explained in the results and the discussion. The healing was classified as functional healing (FH; normal healing, physiologic function) when infection related complications and ankylosis / RR could be excluded by the examination. Criteria were normal percussion tone, positive vertical Periotest® value, no reduced mobility, no infraposition, establishment of a radiolucent space surrounding autologous root and alloplastic post, no clinical and radiographical signs for infection.

Case selection

All patients with avulsed permanent upper front teeth aged up to 18 years and treated by replantation after extraoral endodontic treatment between 1990 and 2000 in the Department of Oral Surgery of the University of Giessen and between 2001 and 2003 in the department of Oral Surgery of the University of Bonn were evaluated. Only teeth were included in the analysis when the observation period exceeded 6 months or teeth exhibited complications or were lost or extracted before that time. No teeth were excluded from the study irrespective of additional injuries (i.e. crown fractures, alveolar fractures).

The data were collected in a Microsoft Access database. For statistical evaluation the computer program SPSS 10.0 (SPSS Inc., Chicago, IL, USA) was used. Cross-tabulations with chi-square tests and a linear regression analysis were performed.

Results

In total 28 avulsed permanent teeth in 24 patients were replanted after extraoral endodontic treatment, and all teeth could be evaluated (Table 2). The mean age of the patients was 10.3 years (±2.6, 7.1–17.3, median: 9.7). For endodontic treatment mainly posts with diameters of 2.5 and 3.0 mm were inserted. Posts made of ceramics (up to 1998) and titanium (since 1996) were used in nine teeth and 19 teeth, respectively. As sealers Diaket® (Espe, Seefeld, Germany), Sealapex® (Kerr, Karlsruhe, Germany) and a mixture of Fixodont® (De Trey Dentsply, Konstanz, Germany) and Jodoform® (Synopharm, Barsbüttel, Germany) were used. Nine different surgeons performed the treatment, the professional experience ranging from 0.21 to 14.76 years. The mean observation period was 31.2 months (±24.1, 5.1–100.2, median: 23.8) (Table 2).

No tooth showed clinical signs of infection (sinus tract, exsudation, swelling, tenderness to percussion). Nine teeth exhibited FH (Figs 5 and 6), including all six teeth that were rescued immediately in a physiologic environment (1). Nineteen teeth were ankylosed and showed RR according to clinical and radiographic examinations (Figs 7 and 8). In three of the ankylosed teeth additionally radiolucencies within the dentin were seen in the radiographs while the bone seemed to be not affected. All three teeth were in a clear infraposition and showed RR without recognizable signs of IRR for at least 14 months. After the diagnosis IRR the teeth were observed for further 1–4 years. In two cases the radiolucencies were located at and coronally of the cemento–enamel junction. The root substances in these cases were resorbed by RR before the occurrence of IRR. The diagnosis was set to complete replacement resorption succeeded by cervical resorption (cRR-CR) (Figs 9–11). In one case

Table 2. Avulsion of permanent incisors in growing patients and replantation following immediate extraoral endodontic treatment (retrograde insertion of posts). Patient-, trauma- and treatment-related factors and healing results

No.	Patient	Age (years)	Gender	Tooth	Maturity	Post	Diameter (mm)	Sealer	Surgeon	Exp. (years)	Healing	Last control without IRR (months)	Diagnosis IRR (months)	Observation (months)	Removal	Reason removal
1	1	13.1	m	11	m	cer			4	1.3	RR			22.0	x	trans
2	2	8.3	f	11	i	TI	3.0	Sealapex	5	11.7	RR			31.7	*in situ*	
3	3	10.0	m	21	m	TI	2.5	Jodoform	2	8.0	func			62.1	*in situ*	
4	4	10.9	m	11	m	cer	3.0	Diaket	3	2.7	RR			100.2	*in situ*	
5	5	9.5	f	11	m	cer	2.5	Diaket	5	7.4	RR			30.9	x	trans
6	5	9.5	f	21	m	cer	2.5	Diaket	5	7.4	RR			30.9	*in situ*	
7	6	8.8	m	21	i	TI	2.5	Jodoform	8	0.9	t-IRR	24.2	28.6	44.6	x	infra
8	7	12.3	m	11	m	TI		Sealapex	1	0.9	RR			22.6	*in situ*	
9	8	7.7	f	11	i	TI	2.5	Diaket	5	11.2	func			17.8	*in situ*	
10	8	7.7	f	21	i	TI	2.5	Diaket	5	11.2	RR			17.8	*in situ*	
11	9	11.2	m	11	m	TI	2.5		6	4.1	RR			24.1	x	trans
12	10	7.9	m	11	i	TI	2.5	Sealapex	9	2.7	func			6.6	*in situ*	
13	11	10.9	m	11	m	TI	2.5	Sealapex	5	11.8	func			21.3	*in situ*	
14	12	9.0	m	21	i	cer		Diaket	3	2.4	RR			89.6	x	infra
15	13	15.1	f	21	m	TI	2.5	Diaket	7	0.2	func			37.1	*in situ*	
16	14	12.6	m	21	m	cer	2.5	Diaket	5	7.7	cRR-CR	17.9	24.7	72.5	*in situ*	
17	15	9.1	m	21	i	cer	3.0	Jodoform	2	5.5	RR			25.2	*in situ*	
18	16	12.2	m	21	m	TI	2.5		5	10.5	func			16.6	*in situ*	
19	17	8.5	m	21	i	cer		Diaket	5	2.6	RR			53.4	x	trans
20	18	9.9	m	11	m	cer	3.0	Jodoform	2	6.0	cRR-CR	14.1	19.3	31.5	x	trans
21	19	8.0	f	11	i	TI	2.5	Sealapex	5	13.2	RR			5.1	x	trans
22	19	8.0	f	21	i	TI	2.5	Sealapex	5	13.2	RR			5.1	x	trans
23	20	17.3	m	21	m	TI	2.5	Diaket	5	13.8	RR			23.4	*in situ*	
24	21	7.6	f	11	i	TI	3.0	Diaket	5	14.5	func			12.4	*in situ*	
25	22	7.1	m	11	i	TI	3.0	SuperEBA	5	14.8	RR			10.3	*in situ*	
26	23	7.9	m	21	i	TI	3.0	Diaket	7	0.3	RR			24.1	x	trauma
27	24	13.3	m	11	m	TI	2.5	Diaket	7	0.7	func			16.9	*in situ*	
28	24	13.3	m	21	m	TI	2.5	Diaket	7	0.7	func			16.9	*in situ*	

No., case number; m, mature (root stages 5 and 6); i, immature; cer, ceramic; TI, titanium; exp., surgical experience; func, functional healing; RR, replacement resorption; t-IRR, tunneling infection related resorption; cRR-CR, complete replacement resorption, followed by infection related cervical resorption; IRR, infection related resorption; X, extraction; trans, consecutive transplantation; infra, infraposition.

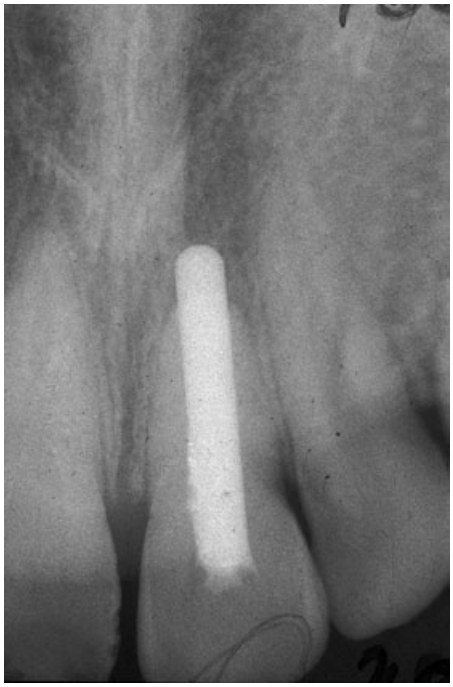

Fig. 5. Avulsion of tooth 21 in a 10-year-old boy. Rescue of avulsed tooth in the tooth rescue box within 3 min and storage for 60 min (and 45 min during treatment). No use of anti-resorptive-regenerative therapy (ART). Situation 62 months after extraoral insertion of titanium post and replantation. Functional healing: absence of infection, absence of replacement resorption. Radiolucent gap surrounding autologous root and alloplastic post.

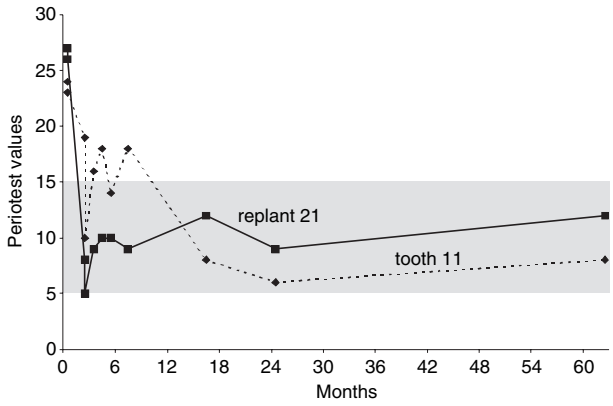

Fig. 6. Same case as in Fig. 5. Horizontal Periotest-values for the replant 21 and the non-injured contralateral tooth 11. Values within normal range (gray field).

the radiolucency was located just apically of the cemento–enamel junction in the cervical third of the root. The root substances were barely resorbed at the periodontal aspect, and the radiolucency spread along the post. The diagnosis was set to tunneling IRR, preceded by (incomplete) replacement resorption (t-IRR) (Fig. 12). One tooth with cRR-CR was removed to allow the transplantation of a premolar

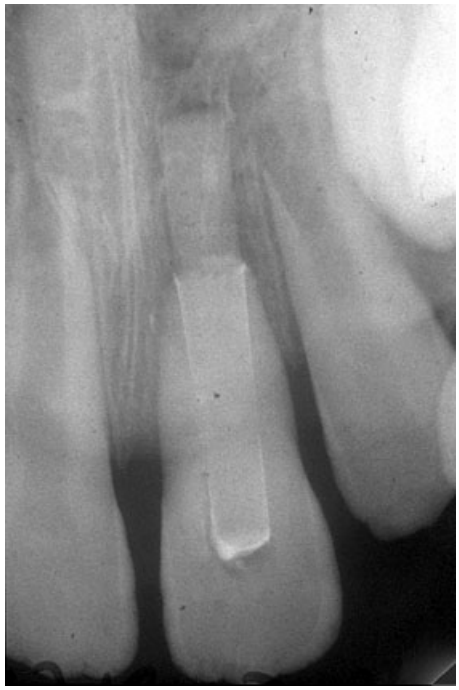

Fig. 7. Avulsion of tooth 21 in an 8-year-old boy. Unphysiologic rescue of tooth 21 (dry storage 30 min, ringer solution 60 min), no use of ART. Situation 2 weeks after extraoral insertion of a ceramic post and replantation.

Fig. 8. Same patient as in Fig. 7, situation 53.4 months after replantation. Incomplete replacement resorption, no infection related complications. Removal of tooth 21 and consecutive transplantation of a premolar.

31.5 months after replantation. The tooth with t-IRR was removed because of progressing infraposition after 44.4 months.

Fig. 9. Intrusion of tooth 11 and avulsion of tooth 21 in a 12-year-old boy. Unphysiologic rescue of tooth 21 (dry storage 150 min, saline 60 min), no use of ART. Situation 17.9 months after extraoral insertion of ceramic posts and replantation. Functional healing of tooth 11, replacement resorption/ankylosis and infraposition of tooth 21.

Fig. 10. Same patient as in Fig. 9, situation 58.2 months after replantation. Functional healing of tooth 11. Complete resorption of the root substances of tooth 21. Radiolucent areas intracoronally, but not concerning the bone. Diagnosis cRR-CR.

Fig. 11. Avulsion of tooth 11 in a 10-year-old boy. Unphysiologic extraoral storage (dry storage 10 min, milk 30 min, saline 45 min), no use of ART. Situation 32 months after extraoral insertion of a ceramic post and replantation. Complete replacement resorption, radiolucencies intracoronally but not in the bone. Diagnosis cRR-CR. The tooth was removed to allow the transplantation of a premolar.

In statistical analysis (chi-square test) no relations could be found between healing and used sealer, diameter of the post, the surgeon or the experience of the surgeons. No influence of the factor maturity was found when immature teeth [root stages 2–4 according to Moorrees (52)] where compared with mature teeth (root stages 5 and 6). The material of the posts (ceramics vs. titanium) was related to healing (FH vs. complication, $P = 0.0122$; FH vs. RR vs. IRR, $P = 0.0319$). There were strong and significant correlations between material of posts and physiologic rescue/use of ART, other factors with influence on the healing results, and in a regression analysis the factor material of post had no impact on healing (1).

Discolorations of the tooth crown were not observed. No treatments like bleaching, veneers, crowns were performed. Crown fractures were reconstructed using composites. No fractures of posts or autologous tooth substances were observed except one crown-root fracture in a severe second trauma. Ten ankylosed teeth were removed primarily to enable the transplantation of primary canines or premolars (1, 53).

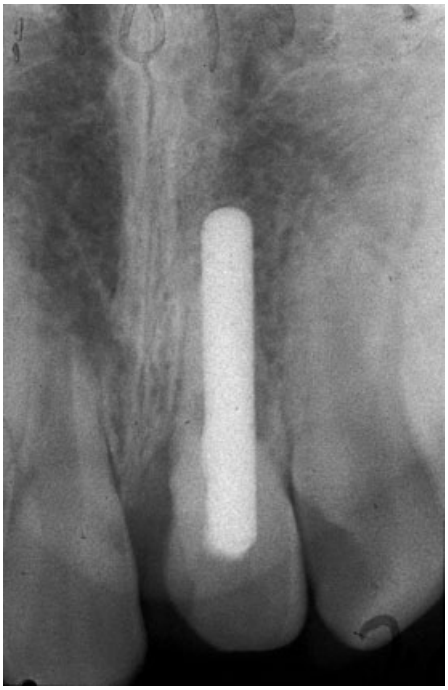

Fig. 12. Avulsion of tooth 21 in a 9-year-old boy. Unphysiologic extraoral storage of tooth 11 (dry storage 15 min, Ringer solution 60 min), no use of ART. Situation 43.7 months after extraoral insertion of a titanium post and replantation. Root substances widely present. Radiolucencies along the post. Diagnosis t-IRR. The tooth was removed 1 month later because of its infraposition.

Discussion

Following replantation of teeth two main complications may occur. Severe damage to the PDL – by the trauma itself, by unphysiologic storage conditions or by inadequate handling – will result in ankylosis and RR when infection does not establish. In all mature replanted teeth and in most teeth with an immature root stage pulp necrosis will occur, get infected and may cause IRR. In these cases root canal treatment is a necessity. Endodontic treatment may be carried out immediately (extraorally) to prevent microorganisms from entering the root canal or may be postponed for several days. In the present study exclusively teeth with extraoral root canal treatment from a retrograde direction using a special system comprising machine driven burs and posts were investigated. As we felt that the advantages of this method for the patient and the dentist were distinct compared with conventional treatment approaches (Table 3) the latter were only followed in our departments when the insertion of posts was not applicable. Especially lower incisors exhibit root anatomies, which prohibit the insertion of round posts. These cases were so rare that a comparative study was not possible.

The method is a very systematic approach with just a few and easy guidelines: prepare the root canal widely, reach the crown, use burs in intermittent action and cool intensively, keep the root surface moist, do not touch the root surface and do not use toxic irrigants. As the burs follow the way that is given by the root canal even inexperienced postgraduates were allowed to perform the treatment. In the statistical analysis no correlation could be found between the healing of the replanted teeth and the surgeon who performed the treatment or the experience of the surgeon.

Infection related resorption

Infection related resorption is defined by showing radiolucent areas within the tooth substances and/

Table 3. Comparison of conventional root canal treatment and extraoral insertion of posts in avulsed teeth to be replanted

	Conventional root canal treatment	Extraoral insertion of posts
Therapy	Prolongated	Immediately, definitive
Additional appointments	Several (70, 71)	None
Duration of treatment	>2 h (70, 71)	15 min
Costs of treatment	Higher	Lower
Social costs (70, 71) (treatment time = 16% of total time)	Higher	Negligible
Microorganisms in pulp	Yes	No
Infection related resorption	Yes, high incidence	Low incidence
Early IRR	Yes, high incidence	No
Radiographs during root canal treatment	Several	None
Compliance of patient	Necessary, important	Patient not involved
Abortion/delay of treatment ⇒ consequences	Possible ⇒ deleterious	Definitive treatment ⇒ none
Coronal leakage	Yes, possible	No
Caries (at palatal access cavity) (72)	Yes	No
Weakening (by palatal access cavity)	Yes	No
Cervical root fractures (25)	High incidence (immature teeth)	No
Crown discoloration	High incidence (26, 27)	No
Reintervention	Possible	Difficult
Applicability	All teeth	Teeth with round or oval-round roots
Instruments	Available	Additional

or the adjacent bone. It can usually be diagnosed few weeks after replantation (54–58). However in the three cases of the present study the IRR was preceded by an infection-free RR for at least 14 months. In two cases the root was completely resorbed before the intracoronal radiolucencies were observed. In one case most of the root substances were kept and the radiolucency spread along the post. In no case a typical early occurrence of IRR was recorded. There are different entities of IRR with different etiologies and/or timings of occurrence: an e-IRR with an early occurrence and the typical bowl-shaped radiolucencies at the lateral aspects of the roots and the adjacent bone. It is caused by microorganisms located in the root canal, which escape via dentinal tubules when these are opened at the periodontal aspect by resorption or damage. The e-IRR is a basic endodontic problem in replanted teeth. The t-IRR spreads along a deficient root filling (11, 58, 59) when an initial RR approaches. Cervical resorption (CR) is a topographical description of resorption. The etiology may be quite different. CR is seen in teeth with a vital pulp and without RR. It is assumed that microorganisms deriving from the dental pocket enter patent dentinal tubules (30, 59). In teeth with pulp necrosis or endodontically treated also irritants located in the pulp chamber or at the entrance of the root canal (microorganisms, bleaching agents, tissue remnants) may induce CR (30, 32, 35, 36, 60). In these cases the root substances need not necessarily be completely resorbed by a preceding RR. However this was the fact in the two cases of the present study. The progressive RR finally approached sites containing irritants, i.e. microorganisms in the dental pocket or tissue remnants or microorganisms in the pulp chamber. Irrespective of the source or kind of the irritants the cervical resorption in these cases can be seen as the endpoint of a complete RR. This conclusion is supported by the data from the 1966-study part II by Andreasen and Hjörting-Hansen (12). Teeth replanted after extraoral endodontic treatment and showing IRR were later extracted than equally treated teeth exhibiting RR. The same was found in the present study. The time-related analysis will be discussed in the third part of the present publication (53). To distinguish the described type of CR from the other types the diagnosis was set to cRR-CR.

In the present study the total incidence of IRR was 10.7% (three of 28 teeth), and the early type (e-IRR) was not observed. In comparison IRR is a common finding when endodontic treatment is not performed immediately (extraorally), and it is usually observed within the first 4 weeks to 6 months (58). In specialized centers this resorption type was recorded in 25–39% of avulsed and replanted teeth (11, 13–15). When teeth are rescued immediately in a physiologic environment the protective cementum may not be destroyed by resorption and IRR may be prevented. Because of different circumstances during rescue and treatment and therefore different rates of FH teeth with this healing type were excluded, and the rate of IRR was related to the total complication rate. In the present study 15.8% of the healing complications were diagnosed as IRR, while in other studies with a delayed endodontic treatment the rate was around 45% (Table 1).

In a clinical study (11) most of the teeth, which exhibited IRR were removed within the first year. In the present study such an early occurrence of IRR was not recorded. The first observation of IRR was 19 months, and the first removal 31.5 months after replantation. This is in close correlation to the data of the second part of the 1966-study by Andreasen and Hjörting-Hansen (12). Teeth with extraoral endodontic treatment showed a lower incidence of IRR and none of the teeth was removed within the first 2 years after replantation. In contrast teeth without extraoral endodontic treatment showed a high incidence of IRR and were removed very early. These observations are also confirmed by short-term animal studies. IRR was prevented in replanted teeth by extraoral endodontic treatment for 8 weeks (39, 41, 42, 61) to 6 months (38) while it was regularly recorded in teeth replanted without endodontic treatment 8 weeks after replantation (39, 41, 42, 61). In accordance with the results from these clinical (12) and animal studies (38, 39, 41, 42, 61) the data of the present study suggest that extraoral endodontic treatment prevents early IRR and reduces the overall incidence of IRR.

In a clinical study with a conventional approach (delayed endodontic treatment) the rate of IRR was significantly higher in immature than in mature teeth (14). No differences were found in the present study when the maturity of roots was tested against healing and especially against IRR despite the fact that all immature teeth except one case were not rescued physiologically (1). It is concluded that the occurrence of IRR is not related directly to the maturity of the tooth roots but to higher difficulties and failures of conventional endodontic treatments in teeth with wide root canals and open apices.

The occurrence of one case of t-IRR in the present material emphasizes the necessity of a wide root canal preparation to not leave pulp tissue remnants within the root canal. This is especially true in teeth with a closed apex but a still wide root canal. A too reserved root resection may exhibit a well-prepared root canal at the resection site. However, because of the conical shape of the root

canal, it may not be completely prepared more coronally. Thus at the resection plane the residual thickness of dentin after root canal preparation should be reduced to about 0.5 mm. In uncertain cases it is better to reduce the root length to enable larger diameters at the resection site for a wider root canal preparation. According to experiences with dilacerated (62) and root fractured (47, 48) teeth treated with the same endodontic method (retrograde insertion of posts), an autologous root length of just 2–3 mm is sufficient for long-term success. The projecting post stabilizes the replant, and normal mobility is achieved.

The original method claimed the removal of pulp tissue remnants in the pulp chamber through a palatal access soon after replantation (44). This increases treatment time and costs, weakens the tooth crown and establishes the risk of coronal leakage as well as that of caries. In favor of non-damaged crowns possible minimal residuals were left *in situ* in all teeth in this study. As mentioned residuals of pulp tissues within the pulp chamber may be one cause for the occurrence of cRR-CR. However the rate was low and cRR-CR occurred after a complete RR of the root. This is the endpoint following a conventional approach at the latest: the crowns fracture during normal function. In the present study there were no consequences of this diagnosis. Following the diagnosis cRR-CR the teeth were retained for additional 1–4 years without any clinical complications. The crowns were firmly attached to the post, and the teeth were in normal daily function. The adjacent bone did not show radiolucencies and there were no clinical signs of infection. Therefore the diagnosis cRR-CR must not induce the immediate removal of the tooth. One tooth was removed not because of acute complications but to solve the problems connected with its infraposition and to enable the transplantation of a premolar (53).

Extraoral endodontic treatment and ankylosis

All teeth that were rescued immediately in a physiologic environment (medium of the tooth rescue box) exhibited FH (1). This is in accordance with the results from a clinical study on intentionally replanted immature teeth with pulp necrosis and/or mid-root fractures in which the same method of extraoral endodontic treatment was used (47). Thus a possible negative effect on periodontal healing by the extraoral insertion of posts can be excluded according to clinical and radiographical parameters. This refutes the current opinions in treatment guidelines (2–9) in which extraoral endodontic treatment is rejected as a treatment option. It was already shown (43) that the two short-term animal studies (40, 41) on which this opinion is based cannot be used for decisions on clinical purposes: 8 weeks are too short for statements on the definite establishment of RR (38) and it was not taken into account that ankylosis was masked by IRR (42) in the control group.

An extended but limited extraoral storage in isotonic solutions was shown to give at least equal or even better healing results compared with immediate plantation (63–66), most probably because of the washing off of bacteria and toxic breakdown products from cell death. It may be speculated that the extraoral insertion of posts might even contribute to prevent ankylosis and RR. The intensive rinsing during root canal preparation should wash off deleterious substrates more intensively than passive soaking. Early completion of endodontic therapy – and extraoral treatment is the earliest endodontic treatment possible – shows lower incidence (20, 21) and less progression (22) of ankylosis and RR and a lower incidence of tooth loss (23) when compared with teeth treated with calcium hydroxide for some time. It is known that calcium hydroxide can have a detrimental effect on vital tissues in the periodontium of replanted teeth by diffusion through dentin when the protective layer of cementum is absent (67).

Projection of posts

The inserted posts primarily serve as an endodontic filling. They may or may not project beyond the resection plane.

Ankylosis of the posts ('osseointegration') would prevent further development of the alveolar bone in growing patients. In these patients such a treatment method would be contraindicated. However, the projecting posts never showed signs of ankylosis, neither in teeth with FH nor in teeth with ankylosed autologous roots. On intraoral radiographs the posts were surrounded by a radiolucent gap representing connective tissue as demonstrated by histology (45, 46). As the planted teeth are splinted in a non-rigid way, and for short periods only, the posts take part in the typical excursions of the articulating teeth. This immediate loading – as is known from implantology (68) – prevents direct bone-to-implant contact.

Cervical root fractures

Despite the extended preparations of the root canals no fractures of the roots were recorded. Even in the cases with complete resorption of the roots the crowns were attached to the posts, stable and allowed normal function. Because of a second trauma fractures of ceramic posts just apically to

the resection plane of teeth treated by retrograde insertion of posts in other indications were described (47, 69) but in no case fractures of the root substances were observed. Only in one case a replanted and ankylosed immature tooth suffered from a crown-root fracture in a second trauma that also caused severe damage to several adjacent teeth. In contrast during and following apexification with calcium hydroxide already minor traumata or even normal function resulted in a very high incidence and a very early occurrence of cervical root fractures in 'luxated' immature teeth (25). Thus it seems reasonable that especially immature teeth would profit from an immediate completion of root canal treatment by insertion of posts. Not only cervical root fractures and IRR can be prevented but also difficult and long-lasting apexification procedures. To prevent any endodontically related complications the immediate extraoral insertion of posts is now used in our clinics also in immature teeth that have been rescued in a physiologic way.

Discolorations

Discolorations of tooth crowns are a common finding in avulsed and replanted teeth when endodontic treatment is not carried out immediately (26, 27). In the present study no discolorations were observed. Obviously the preparation of the root canal soon after avulsion, the intense rinsing during this preparation and the rotating use of paper points removes and washes off most of the blood from the root canal and the pulp chamber when it is still within the tissues and has not reached the dentinal tubules. Furthermore the immediate filling prevents the colonization of the pulp chamber with microorganisms that might cause discolorations. The thickness of dentin and enamel and the opacity of the used sealers are obviously sufficient to cover even the metallic color of the titanium posts. Therefore no additional treatments like bleaching of teeth and prothestic reconstructions (veneers, crowns) had been necessary which themselves may have side-effects like caries or cervical root resorptions.

Patients' comfort and compliance

All patients tolerated the endodontic treatment extremely well – they were simply not involved. No additional treatments except removal of splints and controls and eventually reconstructions with composites of fractured crowns or crowns of teeth in infraposition were performed. The immediate and definite treatment prevents any problems (especially infection related complications) related to an insufficient compliance of the young patients or their parents during the following treatments (rejection, abortion or delay of endodontic treatment). It was reported (25) that after trauma '… most of the patients missed one or several appointments or recalls …'. This is deleterious especially when the conventional endodontic treatment is still in its temporary phase. For these teeth a 10-fold higher risk of tooth loss was calculated compared with teeth with a completed root filling (23). Furthermore multiple radiographs necessary during conventional endodontic treatment can be spared – a relevant factor when the age of the patients is considered.

Conclusion

The analysis of the healing patterns following avulsion and replantation resulted in the differentiation of several entities of IRR: e-IRR, t-IRR and cRR-CR besides further types of CR. There were no differences in the healing results of immature and mature teeth.

Extraoral endodontic treatment by retrograde insertion of posts prevents early IRR and minimizes the overall incidence of IRR in avulsed and replanted teeth. It does not negatively influence periodontal healing and should be used in avulsed or otherwise isolated teeth to be planted and in which pulp necrosis is predictable or has a high incidence. By this method repeated treatments, radiographs and costs are spared, crown discolorations and cervical root fractures are prevented and also patients get a fair chance even when they or their parents are lacking of compliance. Especially immature teeth benefit from the treatment method.

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