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A retrospective study of 889 injured permanent teeth

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Abstract – The aim of this study was to investigate pre-injury factors, causes of dental injuries and healing complications after traumatic injuries to permanent teeth. The analysed sample comprised 889 permanent teeth of 384 patients, who were treated in the Dentistry Department in Faculty Hospital in Pilsen. Enamel-dentin fractures [233 teeth (26.2%)] and lateral luxations [207 teeth (23.3%)] were the most frequent injuries. The age of the patients at the time of injury varied between 7 and 65 years. Predominantly, children were affected [587 injured teeth (66.0%)]. The most frequent causes of injuries in patients older than 11 years were various sport activities, predominantly bicycling. Pulp necrosis was observed in 239 teeth (26.9%). It was the most frequent post-traumatic complication in all types of dental traumas. Teeth with a completed root formation demonstrated a higher prevalence of pulp necrosis than teeth with an incomplete root formation in all types of luxation injuries. External root resorption was observed in 144 teeth. The rate of inflammatory resorption differed between the various types of luxation injuries (extrusive luxation 5.6%, lateral luxation 11.6%, intrusive luxation 33.3%). Following avulsion and replantation, active inflammatory resorptions were diagnosed in 13 (26.5%) of 49 replanted teeth and ankylosis/replacement resorptions were observed in 21 (42.9%) of 49 replanted teeth. After avulsion, primarily, immature teeth were affected by these complications. Within the observation period of 5 years, 39 teeth (4.4%) had to be removed (16 teeth with root fractures, 19 avulsed and replanted teeth, 3 luxated teeth, 1 tooth with crown-root fracture).

Dental injuries confront dental practitioners quite often in their dental offices. The reported incidence of traumatic dental injuries during one year ranges between 1.5% and 2.8% (1, 2). Common aetiological factors are falls, sports and traffic accidents (3–6). Dental injuries occur more frequently in children between 8 and 15 years of age, although lately an increase in the incidence of dental injuries has been reported among patients older than 18 (7, 8). The frequency of injuries to permanent teeth in young adults depends on their lifestyle. Consumption of alcohol, motor biking and various sport activities are important risk factors (5–7). During high-risk sports like inline skating, skateboarding, mountain biking or contact team sports, the probability of suffering orofacial injuries is high in adolescents (4, 8–10). Violence and traffic accidents were also reported as causes for dental injuries (11, 12).

A majority of dental injuries involve anterior teeth. In addition to hard dental tissues, gingiva, periodontal tissues, dental pulp and alveolar bone are often affected (3). Healing depends on factors such as the level of root development, the extent of damage to periodontal tissues and the effect of bacterial contamination from the oral cavity. Complications may occur weeks, months or even several years after the injury and therefore, dental injuries need long-term follow-ups (13–15).

Pulp necrosis is the most common post-traumatic complication. It occurs mostly in teeth with injuries to periodontal tissues. The reported prevalence of pulp necrosis in luxated teeth varies from 17% to 100% (13, 16, 17). Type of injury (13), stage of root development (13) or repeated damage to a tooth influence the outcome of pulp survival (16, 17). Complications following uncomplicated crown fractures are rather uncommon. Again, pulp necrosis is the most frequent complication, the incidence ranging between 2% and 5% (18). A simultaneous luxation injury has been reported to increase the prevalence of pulp necrosis in teeth with crown fractures (14, 15). A late diagnosis of post-traumatic pulp necrosis can result in the manifestations of additional complications, such as apical periodontitis, fistulas or inflammatory root resorption. Root resorption is a serious complication following luxation injuries in permanent teeth. An external root resorption can be classified into three various types such as surface resorption, replacement resorption/ankylosis and inflammatory resorption (19, 20). Surface resorption is considered a favourable type of periodontal healing (20). Replacement resorption/ankylosis appears in injured teeth whose periodontal ligaments have been dried, destroyed or removed from the surface of the root (21, 22). Inflammatory resorption is always associated with necrosis and infection of the pulp. With good and

prompt endodontic therapy, inflammatory resorption can be prevented (23). Once established, the success of the endodontic treatment remains uncertain (24, 25). The prevalence of external root resorption relates to the types of luxation injuries. A higher prevalence of inflammatory resorption and ankylosis has been reported in cases of intrusive luxation or avulsion (22, 26).

In this retrospective study, dental injuries of patients who were treated for trauma to their permanent teeth in Dentistry Department of Faculty Hospital in Pilsen (The Czech Republic) were evaluated.

The aim of this study was to analyse the following factors:

1 The frequency of different types of dental injuries.
2 The age of patients at the time of dental injury.
3 The main aetiological factors of dental injuries in each age group.
4 The occurrence of post-traumatic complications.

Materials and methods

A retrospective study was conducted using the documentations of patients with injuries of permanent teeth. Children and adult patients were included in this study. Patients with repeated dental trauma were excluded. Patients with fractures of jaw bones were included. Totally, 423 patients were treated for dental traumas. Emergency care, definitive treatment and regular controls were performed at Dentistry Department, Faculty Hospital in Pilsen from 1997 to 2002. The examinations for this study were supported by the grant from the Czech Ministry of Health. The patients were invited for follow ups minimally 5 years after the first treatment of their dental injury and 384 of 423 patients (90.8%) responded to the invitation. They were examined at the Dentistry Department of Faculty Hospital in Pilsen, between 2005 and 2007. Totally, 889 injured teeth composed the observed sample. All patients were informed about the study and were asked to sign an agreement.

The following information from the patient documentation (dental records and radiographs from treating dentists) was analysed: type and number of injured teeth, age of the patients at the time of injury, type of dental injury, cause of injury and occurrence of complications. The classification of dental trauma was based on a system adopted by the World Health Organisation in its Application of International Classification of Disease to Dentistry and Stomatology (27).

During the examination of the injured teeth, the following parameters were assessed:

1 The colour of the clinical crown, the mobility and the reaction to percussion of the tooth.
2 Thermal tests made with tetrafluorethan T = −50°C (Cognoscin, AVEFLOR, The Czech Republic).
3 Radiographic examination of all teeth by using periapical bisecting angle exposures.

Diagnosis of pulp necrosis was established in cases of crown grey discolouration, loss of pulpal sensitivity to cold and radiographic periapical radiolucencies. In our study, all three criteria had to be fulfilled for diagnosis of pulp necrosis.

Based on the radiographic examination, other post-traumatic complications were recorded, such as chronic periodontitis, internal and external resorption and obliteration of the root canal.

All types of dental injuries in teeth with closed and open root apices were compared. The influence of a concomitant dislocation injury and the influence of the treatment (pulp capping versus pulpotomy) were analysed in crown-fractured teeth. Non-dislocated luxation injuries, dislocated luxation injuries and avulsions were also compared. For all these statistical evaluations, Fisher's exact test was used. The level of significance was set at 0.05.

Results

Frequency of dental injuries

The observed sample in this study included 889 injured teeth. The maxillary central incisors (in 554 cases) were the teeth most frequently affected.

The most frequent injuries were enamel-dentin crown fractures [233 teeth (26.2%)] and lateral luxations [207 teeth (23.3%)]. Teeth with uncomplicated crown fractures and simultaneously dislocated (lateral, extrusive or intrusive luxations) were found in 21 cases (2.4%). All teeth with complicated crown fractures (exposed pulp) were without dislocation. Concussion or subluxation was observed in 63 cases (7.1%). Crown-root fractures [5 teeth (0.6%)] were the least frequent injuries (Table 1). From a total number of 58 avulsed teeth, 49 (84.5%) teeth were replanted (17 teeth with open root apices and 32 teeth with closed root apices).

In some patients, other injuries were found apart from dental injuries; soft tissue injuries of the oral region in 83 patients, fractures of jaw bones in 21 patients and more serious maxillofacial injuries or polytraumas requiring hospitalization in 19 cases.

Age of patients at injury time

The age of patients at the time of injury varied between 7 and 65 years. Injuries occurred most frequently in patients between 7 and 15 years of age. In children of this age group, totally 587 permanent teeth (66.0%) were registered as injured. In all age groups, males were injured more frequently than females (ratio 2:1) (Table 2).

Table 1. Frequency of dental injuries, stratified for trauma type

Frequency of dental injuries			
Diagnosis of injuries	Number of the teeth	Diagnosis of injuries	Number of the teeth
Enamel fractures	58	Concussion	14
Enamel-dentin fractures	233	Subluxation	58
Crown fractures with exposed pulp	76	Extrusive luxation	89
Crown -root fractures	5	Lateral luxation	207
Root fractures	49	Intrusive luxation	21
Crown fractures and luxation	21	Avulsion	58

Table 2. Age of patients at the time of traumatic tooth injuries

Age of patients at the time of injury				
Age group	Number of males	Number of females	Total number of patients	Number of injured teeth
7–10 years	80	42	122	288
11–15 years	87	49	136	299
16–20 years	32	19	51	132
21–25 years	40	9	49	108
26–30 years	6	3	9	21
Above 30 years	15	2	17	41
Total	260	124	384	889

Causes of dental injuries in the different age groups

In 100 patients, the causes of dental injuries in permanent teeth were various sport activities (26.0%). Bicycling was evaluated as a separate cause and was found to be responsible for dental trauma in 75 patients (19.5%). In children between 7 and 10 years, falls and collisions during their playing were the main aetiological factors (36.1%). Physical violence, alcohol consumption or aggressiveness resulted in dental injuries in 25 patients (6.6%) and most frequently occurred in the age group 21–25 years (11 patients)(Table 3).

Post-traumatic complications

The findings of the clinical and radiographic examinations 5 years after trauma are given in the Tables 4, 5 and 6. Important aspects are reported in detail in the following sections.

Pulp necrosis

Pulp necrosis was the most frequent post-traumatic complication in all types of dental traumas (Table 5). Of the 889 examined teeth, 239 teeth exhibited pulp necrosis (26.9%). In case of luxations, pulp necrosis was most frequently observed in teeth with intrusive luxation (76.2%), more specifically, in 6 of 9 (66.7%) intruded immature teeth and 10 of 12 (83.3%) intruded mature teeth. In laterally luxated teeth, necrosis occurred in 89 of 141 teeth with closed apices (63.1%), and in 9 of 66 teeth with open apices (13.6%), a statistically significant difference ($P < 0.0001$). After replantation of avulsed teeth pulp necrosis occurred in all 32 teeth with closed root apices (100%) and in 13 of 17 teeth with open apices (76.5%) ($P = 0.0112$). Concerning periodontal tissue injuries, no teeth presented with pulp necrosis after concussion injuries while seven mature subluxated teeth (13.2% of all subluxated teeth) had a necrotic pulp. The differences between dislocated luxations and non-dislocated luxations and between dislocated luxations and avulsions were significant ($P = 0.0001$)(Table 7).

Table 3. Causes of traumatic tooth injuries, stratified for age groups

Causes of traumatic tooth injuries								
Causes of injuries	7–10 years	11–15 years	16–20 years	21–25 years	26–30 years	Above 30 years	Total number	*N* = 384
Sports	23	41	21	12	2	1	100	26.0%
Bicycling	16	32	14	9	2	2	75	19.5%
Playing	44	23	0	0	0	0	67	17.4%
School injuries	15	24	4	1	0	0	44	11.5%
Home injuries	16	6	1	6	1	4	34	8.9%
Traffic accidents	6	7	4	9	1	3	30	7.8%
Work accidents	0	0	0	1	3	5	9	2.3%
Violence	2	3	7	11	0	2	25	6.5%

Table 4. Clinical findings within 5 years after trauma, stratified for trauma type

Clinical findings within 5 years after trauma									
Type of injury	No of teeth	Grey discol.	Yellow discol.	Pain to percuss.	Negative reaction to cold	Swelling	Mobility	Spont. pain	Sinus tract
Enamel fractures	58	0	0	0	0	0	0	0	0
Enamel-dentin fractures	233	6	0	2	14	0	0	2	0
Fractures with exposed pulp	76	5	0	3	9	0	0	1	0
Crown-root fractures	5	0	0	0	0	0	0	0	0
Root fractures	49	4	7	12	18	2	16	0	0
Crown fractures and luxation	21	7	2	9	14	1	3	2	0
Concussion	14	0	0	0	0	0	0	0	0
Subluxation	58	3	1	5	7	4	0	4	4
Extrusive luxation	89	19	2	9	31	5	1	8	5
Lateral luxation	207	37	14	29	102	15	5	19	9
Intrusive luxation	21	9	1	2	18	2	0	1	0
Avulsion	49*	6	0	5	13	2	2	2	1

*Nine teeth not replanted.

Table 5. Pulpal healing 5 years after trauma, stratified for trauma type and root development

Pulpal healing 5 years after trauma												
Type of injury	Root develop.	Primary care	Inju-red *n*	Extr. *n* (%)	Control 5 year *n* (%)	Normal 5 year *n* (%)	PN *n* (%)	PN *P* value	AP *n* (%)	AP *P* value	PCO *n* (%)	PCO *P* value	Int R *n* (%)
Enamel fractures	Immature	Restoration	11	0 (0)	11 (100)	11 (0)	0 (0)	–	0 (0)	–	0 (0)	–	0 (0)
	Mature	Restoration	47	0 (0)	47 (100)	47 (0)	0 (0)		0 (0)		0 (0)		0 (0)
Enamel-dentin	Immature	Restoration	67	0 (0)	67 (100)	64 (95.5)	2 (3.0)	1.0000	0 (0)	–	0 (0)	–	1 (1.5)
fratures	Mature	Restoration	166	0 (0)	166 (100)	161 (97.0)	5 (3.0)		0 (0)		0 (0)		0 (0)
Crown fractures	Immature	Pulpcapping	4	0 (0)	4 (100)	3 (75.0)	1 (25.0)	1.0000	1 (25.0)	1.0000	0 (0)	0.2145	0 (0)
with		Pulpotomy	13	0 (0)	13 (100)	10 (76.9)	1 (7.7)		0 (0)		2 (15.4)		0 (0)
exposed pulp	Mature	Pulpcapping	7	0 (0)	7 (100)	2 (28.6)	4 (57.1)		1 (14.3)		1 (14.3)		0 (0)
		Pulpotomy	9	0 (0)	9 (100)	6 (66.7)	2 (22.2)		1 (11.1)		1 (11.1)		0 (0)
		Pulp extirpation	43	0 (0)	43 (100)	0 (0)	NA		1 (2.3)		0 (0)		0 (0)
Crown-root	Immature	Extraction	1	1 (100)	0 (0)	NA	NA	–	NA	–	NA	–	NA
fractures	Mature	Pulp extirpation	4	0 (0)	4 (100)	0 (0)	NA		0 (0)		0 (0)		0 (0)
Root fractures	Immature	Reposition, splinting	5	1 (20)	4 (80)	0 (0)	1 (20)	0.6393	1 (20)	0.2812	3 (60)	0.6392	2 (40)
	Mature	Reposition, splinting	44	15 (34.1)	29 (65.9)	0 (0)	17 (38.6)		2 (4.5)		18 (40.9)		12 (27.3)
Crown fractures	Immature	Restoration, splinting	6	0 (0)	6 (100)	0 (0)	3 (50)	0.3544	0 (0)	0.0186	3 (50)	0.1196	0 (0)
and luxation	Mature	Restoration, splinting	15	0 (0)	15 (100)	1 (6.7)	11 (73.3)		9 (60)		3 (20)		1 (6.7)
Concussion	Immature	No therapy	2	0 (0)	2 (100)	2 (100)	0 (0)	–	0 (0)	–	0 (0)	–	0 (0)
	Mature	No therapy	12	0 (0)	12 (100)	12 (100)	0 (0)		0 (0)		0 (0)		0 (0)
Subluxation	Immature	No therapy	5	0 (0)	5 (100)	4 (80)	0 (0)	1.0000	0 (0)	1.0000	1 (20)	0.3098	0 (0)
	Mature	No therapy	53	0 (0)	53 (100)	42 (79.2)	7 (13.2)		6 (11.3)		3 (5.7)		1 (1.9)
Extrusive luxation	Immature	Reposition, splinting	8	0 (0)	8 (100)	1 (12.5)	2 (25.0)	1.0000	1 (12.5)	1.0000	5 (62.5)	<0.0001	0 (0)
	Mature	Reposition, splinting	81	0 (0)	81 (100)	48 (59.3)	24 (29.6)		14 (17.3)		7 (8.6)		2 (2.5)
Lateral luxation	Immature	Reposition, splinting	66	0 (0)	66 (100)	32 (48.5)	9 (13.6)	<0.0001	3 (4.5)	<0.0001	23 (34.8)	<0.0001	1 (1.5)
	Mature	Reposition, splinting	141	2 (1.4)	139 (98.6)	40 (28.4)	89 (63.1)		38 (27.0)		8 (5.7)		2 (1.4)
Intrusive luxation	Immature	Reposition, splinting	9	0 (0)	9 (100)	1 (11.1)	6 (66.7)	0.6108	0 (0)	0.2286	2 (22.2)	0.1714	0 (0)
	Mature	Reposition, splinting	12	1 (8.3)	11 (91.7)	1 (8.3)	10 (83.3)		3 (25.0)		0 (0)		0 (0)
Avulsion**	Immature	Replantation	17	11 (64.7)	6 (35.3)	4 (23.5)	13 (76.5)	0.0112	3 (17.6)	1.0000	0 (0)	–	0 (0)
	Mature	Replantation, prophyl.endo	32	8 (25.0)	24 (75.0)	0 (0)	32 (100)		5 (15.6)		0 (0)		0 (0)

Extr, extraction; PN, pulp necrosis; AP, apical periodontitis; PCO, pulp canal obliteration; Int.R, internal resorption; NA, not applicable; **, nine teeth not replanted.

Table 6. Periodontal healing 5 years after trauma, stratified for trauma type and root development

	Periodontal healing 5 years after trauma					Periodontium							
Type of injury	Root develop.	Primary care	Inju- red *n*	Extr. *n* (%)	Control 5 year *n* (%)	Normal 5 year *n* (%)	AP *n* (%)	AP Pvalue	SR *n* (%)	RR *n* (%)	RR *P* value	IR *n* (%)	IR Pvalue
Enamel fractures	Immature	Restoration	11	0 (0)	11 (100)	11 (100)	0 (0)	–	0 (0)	0 (0)	–	0 (0)	–
	Mature	Restoration	47	0 (0)	47 (100)	47 (100)	0 (0)		0 (0)	0 (0)		0 (0)	
Enamel-dentin fractures	Immature	Restoration	67	0 (0)	67 (100)	67 (100)	0 (0)	–	0 (0)	0 (0)	–	0 (0)	–
	Mature	Restoration	166	0 (0)	166 (100)	166 (100)	0 (0)		0 (0)	0 (0)		0 (0)	
Crown fractures with exposed pulp	Immature	Pulpcapping	4	0 (0)	4 (100)	4 (100)	1 (25.0)	1.0000	0 (0)	0 (0)	–	0 (0)	–
		Pulpotomy	13	0 (0)	13 (100)	13 (100)	0 (0)		0 (0)	0 (0)		0 (0)	
	Mature	Pulpcapping	7	0 (0)	7 (100)	7 (100)	1 (14.3)		0 (0)	0 (0)		0 (0)	
		Pulpotomy	9	0 (0)	9 (100)	9 (100)	1 (11.1)		0 (0)	0 (0)		0 (0)	
		Pulp extirpation	43	0 (0)	43 (100)	43 (100)	1 (2.3)		0 (0)	0 (0)		0 (0)	
Crown-root fractures	Immature	Extraction	1	1 (100)	0 (0)	NA	NA	–	NA	NA	–	NA	–
	Mature	Pulp extirpation	4	0 (0)	4 (100)	4 (100)	0 (0)		0 (0)	0 (0)		0 (0)	
Root fractures	Immature	Reposition, splinting	5	1 (20)	4 (80)	2 (40)	1 (20)	0.2812	2 (40)	0 (0)	–	1 (20)	0.6393
	Mature	Reposition, splinting	44	15 (34.1)	29 (65.9)	0 (0)	2 (4.5)		2727 (61.4)	0 (0)		17 (38.6)	
Crown fractures and luxation	Immature	Restoration, splinting	6	0 (0)	6 (100)	6 (100)	0 (0)	0.0186	0 (0)	0 (0)		0 (0)	–
	Mature	Restoration, splinting	15	0 (0)	15 (100)	15 (100)	9 (60)		0 (0)	0 (0)		0 (0)	
Concussion	Immature	No therapy	2	0 (0)	2 (100)	2 (100)	0 (0)	–	0 (0)	0 (0)	–	0 (0)	–
	Mature	No therapy	12	0 (0)	12 (100)	12 (100)	0 (0)		0 (0)	0 (0)		0 (0)	
Subluxation	Immature	No therapy	5	0 (0)	5 (100)	5 (100)	0 (0)	1.0000	0 (0)	0 (0)	–	0 (0)	–
	Mature	No therapy	53	0 (0)	53 (100)	52 (98.1)	6 (11.3)		1 (1.9)	0 (0)		0 (0)	
Extrusive luxation	Immature	Reposition, splinting	8	0 (0)	8 (100)	7 (87.5)	1 (12.5)	1.0000	0 (0)	1 (12:5)	0.4415	0 (0)	1.0000
	Mature	Reposition, splinting	81	0 (0)	81 (100)	75 (92:6)	14 (17.3)		1 (1.2)	0 (0)		5 (6.2)	
Lateral luxation	Immature	Reposition, splinting	66	0 (0)	66 (100)	57 (86.4)	3 (4.5)	<0.0001	1 (1.5)	5 (7.6)	0.0133	3 (4.5)	0..0353
	Mature	Reposition, splinting	141	2 (1.4)	139 (98.6)	116 (82.3)	38 (27.0)		1 (0.7)	1 (0.7)		21 (14.9)	
Intrusive luxation	Immature	Reposition, splinting	9	0 (0)	9 (100)	5 (55.5)	0 (0)	0.2286	1 (11.1)	0 (0)	–	3 (33.3)	1.0000
	Mature	Reposition, splinting	12	1 (8.3)	11 (91.7)	8 (66.7)	3 (25.0)		0 (0)	0 (0)		4 (33.3)	
Avulsion**	Immature	Replantation	17	11 (64.7)	6 (35.3)	0 (0)	3 (17.6)	1.0000	0 (0)	9 (53.0)	0.3697	8 (47.0)	0.0383
	Mature	Replantation, prophyl endo	32	8 (25.0)	24 (75.0)	0 (0)	5 (15.6)		15 (46.9)	12 (37.5)		5 (15.6)	

AP, apical periodontitis; SR, surface resorption; RR, replacement resorption; IR, inflammatory resorption; NA, not applicable; **, nine teeth not replanted.

Table 7. Statistical analysis of periodontally injured teeth. Differences between non-dislocated teeth and dislocated teeth and between dislocated teeth and avulsed teeth

Statistical analysis of periodontally injured teeth			
Complication	No of non dislocated teeth (%)	No of dislocated teeth (%)	*P*-value
Pulp necrosis	7 (9.7)	140 (44.2)	0.0001
Chronic apical periodontitis	6 (8.33)	59 (18.6)	0.0358
Pulp canal obliteration	4 (5.5)	45 (14.2)	0.0491
Inflammatory resorption	0 (0.0)	36 (11.4)	0.0001
Replacement resorption	0 (0.0)	12 (3.8)	0.1340
Complication	No of dislocated teeth (%)	No of replanted teeth (%)	*P*-value
Pulp necrosis	140 (44.2)	45 (91.8)	0.0001
Chronic apical periodontitis	59 (18.6)	8 (16.3)	0.8434
Pulp canal obliteration	45 (14.2)	0 (0.0)	0.0017
Inflammatory resorption	36 (11.4)	13 (26.5)	0.0066
Replacement resorption	12 (3.8)	21 (42.9)	0.0001

Non-dislocated teeth, concussion, loosening; dislocated teeth, extrusion, lateral dislocation, intrusion.

In teeth with enamel-dentin fractures, pulp necrosis was observed in 7 of 233 teeth (3%) if the teeth were not simultaneously dislocated. With a concomitant dislocation, the rate of pulp necrosis was 66.6% (14 of 21 teeth). The difference was statistically significant ($P = 0.0001$) (Table 8). No differences were observed in teeth with enamel fractures only. Fractured teeth with exposed pulp had not been simultaneously dislocated.

If crown fractures with exposed pulp were treated by pulp capping, pulp necrosis was observed in 5 of 11 teeth (45.5%). Following pulpotomy, 3 of 22 teeth (13.6%) showed pulp necrosis. The difference was just above the borderline of significance ($P = 0.0532$). When further stratified for maturity, the same difference between the treatment options was observed; however, it was not significant (Table 8).

In children, pulp necrosis was usually diagnosed within 6 months after the injury (91.9% of all injured teeth) and in virtually all teeth within one year. In patients older than 15 years, pulp necrosis was predominantly diagnosed later than 6 months (61.7% of all cases) or even later than 12 months (40%) after the trauma (Table 9).

In 89 teeth, an apical periodontis was observed (Table 5, 6) which was accompanied by a sinus tract in 19 cases (Tables 4). Chronic apical periodontitis was seen in cases of lateral [19.8%; 3 of 66 immature teeth (4.5%) and 38 of 141 mature teeth (27.0%)] or extrusive luxations [16.85%; 1 of 8 immature teeth (12.5%) and 14 of 81 mature teeth (17.3%)]. In cases of lateral luxation, the occurrence of a chronic apical periodontitis was significantly more frequent in teeth with closed apices compared with teeth with open apices (Table 5 and 6).

Pulp canal obliteration

Evaluation of x-ray images revealed a pulp canal obliteration in 80 teeth (9.0%) (Table 5). A statistically significant difference ($P = 0.0001$) was seen between teeth with closed and open root apices after lateral and extrusive luxation. In cases of extrusive luxations, this complication was diagnosed in 5 of 8 teeth with open apices (62.5%) and in 7 of 81 teeth with closed apices (8.6%). In cases of lateral luxation, pulp canal obliteration was seen more frequently in teeth with incomplete root formation [23 of 66 teeth (34.8%)] compared with teeth with complete root development [8 teeth of 141 (5.7%)]. Altogether, 21 of 49 teeth (immature and mature) with root-fractures showed partial or complete obliteration of the pulp in apical fragment.

Table 8 (a) Statistical analysis of crown-fractured teeth with enamel-dentine-fractures. Influence of concomitant periodontal injury (dislocation), stratified for tooth root development. (b) Statistical analysis of crown-fractured teeth with pulp exposures and without periodontal injury. Influence of the treatment (pulp capping versus pulpotomy), stratified for tooth root development

(a)

		Fractures without dislocation		Fractures with dislocation		%	%	
Development of the root	Total No of fractured teeth	No teeth	PN	No teeth	PN	PN in teeth without dislocation	PN in teeth with dislocation	*P*-value
Open apex	73	67	2	6	3	2.99%	50.00%	<0.0001
Closed apex	181	166	5	15	11	3.01%	73.33%	<0.0001

(b)

		Pulp capping		Pulpotomy		%	%	
	No of fractured teeth	No of teeth	PN	No of teeth	PN	PN after pulpcapping	PN after pulpotomy	*P*-value
Total No	33	11	5	22	3	45.45%	13.64%	0.0532
Open apex	17	4	1	13	1	25.00%	7.69%	0.3623
Closed apex	16	7	4	9	2	57.14%	22.22%	0.2215

PN, pulp necrosis.

Table 9. Time of diagnosis of pulp necrosis, stratified fot root maturity and age

Time of diagnosis of pulp necrosis							
		Diagnosis of PN within 6 month		Diagnosis of PN 1 year after injury		Diagnosis of PN more than 1 year after injury	
Group of patients	Total No teeth with PN	PN (%)	Apical healing (%)	PN (%)	Apical healing (%)	PN (%)	Apical healing (%)
Children – open apex	38	35 (92.1)	24 (68.6)	2 (5.3)	2 (100.0)	1 (2.6)	0 (0.0)
Children – closed apex	86	79 (91.9)	71 (89.9)	4 (4.7)	4 (100.0)	3 (3.5)	3 (100)
Patients more than 15 years old	115	44 (38.3)	33 (75.0)	25 (21.7)	21 (84.0)	46 (40.0)	43 (93.5)

Root resorption

Radiographic examinations revealed the occurrence of external resorptions of the root substances in 144 teeth (16.2%) (Table 6). Inflammatory resorptions were observed in seven intruded teeth [33.3%; 3 of 9 immature teeth (33.3%) and 4 of 12 mature teeth (33.3%)], in 24 laterally luxated teeth [11.6%; 3 of 66 immature teeth (4.5%) and 21 of 141 mature teeth (14.9%)] and in 13 avulsed and replanted teeth [26.5%; 8 of 17 immature teeth (47.0%) and 5 of 32 mature teeth (15.6%)]. A statistical difference between teeth with open and closed apices was observed in cases of avulsion ($P = 0.0383$).

The prevalence of replacement resorption was 2.9% in laterally luxated teeth (5 of 66 immature teeth and 1 of 141 mature teeth) and 42.9% of avulsed and replanted teeth (9 of 17 immature teeth and 12 of 32 mature teeth). Inflammatory and replacement resorption occurred more frequently after avulsion than after dislocated luxations ($P = 0.0066$ and $P = 0.0001$, respectively) (Table 7).

Surface resorption (or arrested inflammatory resorption) was observed in 15 replanted teeth (30.6%) in which prophylactic endodontic treatment was provided (Table 5). In teeth with isolated crown fractures, external resorption was not observed.

In teeth with root fractures, inflammatory resorption was diagnosed in 18 teeth [36.7%; 1 of 5 immature teeth (20%) and 17 of 44 mature teeth (38.6%)]. Internal resorptions were diagnosed predominantly in root fractured teeth [2 of 5 immature teeth (40%) and 12 of 44 mature teeth (27.3%)](Table 5).

Loss of the injured teeth

Thirty- nine teeth were extracted within the observation period of 5 years (Table 5). Of 49 teeth with root fractures 16 teeth (32.6%) were extracted due to the formation of granulation tissue between the fragments and due to active inflammatory resorptions of the apical and coronal fragments.

Eight teeth with open root apices and 11 teeth with closed root apices from a total number of 49 avulsed and replanted teeth were extracted during the observation period of 5 years. An inflammatory resorption was the cause of extraction in 13 replanted teeth (26.5%) and 6 replanted teeth (12.2%) were extracted due to replacement resorption with advanced infraocclusion of the affected tooth. Eight avulsed teeth had not been replanted. Tooth loss was a rare observation in the other trauma types (Table 5).

Discussion

Some basic observations in the present study are in accordance with the data in the literature. Males are involved in accidental injuries more often than females, the maxillary central incisors are the most affected teeth and crown fractures are the most common dental injuries (1, 3, 4).

The causes of dental injuries seem to vary in different countries. Behavioural and cultural diversity may explain the differences. Physical leisure activities, violent incidents and traffic accidents appear to be the relevant aetiological factors in adolescents in Europe (5, 6, 28–32). In our retrospective study, accidents, sports or physical leisure activities were the most frequent causes of dental injuries in permanent teeth in patients older than 11 years. In children between 7 and 10 years, falls and collisions during their playing were the main aetiological factors. Traffic accidents represent quite frequent causes of injuries in oral and maxillofacial region (6, 33). They were reported in our study to be the cause of dental injuries in 30 patients (7.8%) and of these, 19 had to be hospitalized either because of polytrauma or due to jaw fractures. Violence and aggressiveness were found to be among the main causes of traumatic dental injuries in patients belonging to the age group between 21 and 25 years.

Enamel-dentine fractures without a concomitant dislocation of the tooth were the most frequent injuries in our sample, comprising more than one quarter of all injuries. Complications following crown fractures are rather uncommon. The incidence of pulp necrosis was about 3% in our study which corroborates previous studies in which the incidence of this consequence ranged between 2% and 5% (2, 18). Concomitant luxation injuries have been reported to increase the incidence of pulp necrosis (14, 15). This was confirmed by the analysis of our data, which revealed a significantly higher rate of pulp necrosis in teeth with enamel-dentine-fractures and concomitant dislocation injuries.

Crown fractures which reach the dentine open the dentinal tubules that are wide enough for microorganisms. If the pulp is healthy, the flow of the dentin liquor is one shelter against intruding microorganisms, and as another protection, the pulp has the ability to produce dentine. In case of dislocation injuries, not only the periodontal ligament (PDL) is damaged but also the pulp tissues may be torn or ruptured at the apical foramen. The distally located tissues may then be ischaemic or will even become necrotic. If so, the protective shields are

weakened or lost, and microorganisms can easily enter the pulp chamber via the dentinal tubules and invade the damaged tissues. Fractures restricted to the enamel do not open these pathways for microorganisms, and if a pulp was somehow damaged by a dislocation, its healing is not impaired by an infection. This hypothesis is supported by the observation that a concomitant dislocation was of no influence on pulp survival in teeth with enamel fractures in the present study.

Complicated crown fractures result in the exposure of the pulp to the oral environment. The key factor in determining prognosis after complicated crown fractures is to minimize the bacterial invasion of the pulp. Despite a treatment within the first 24 h is not an absolute necessity and thus can be postponed to daytime appointments (34, 35), the removal of infected pulpal tissues and a bacterial tight filling should be performed as soon as possible. The prognosis of pulp survival in complicated crown fractures given in the literature varies from 63% to 94% (35–37). Much worse results were found in our study. Only in 32% of cases with these fractures, pulp survival was found in the observation period of 5 years. The reason for this discrepancy is most probably the fact that pulp extirpation had been the most frequently provided treatment in primary care in fractured teeth with closed apex at that time.

If adequately treated, a long-term maintenance of pulp vitality (75.8%) was observed in teeth with complicated crown fractures. The treatment method was of significant influence. Pulp capping resulted in an about threefold higher rate of pulp necrosis (45.5%) than partial pulpotomy (13.6%). The explanation for the different results could be that in pulp capping treatments, the pulp capping materials like calcium hydroxide may occupy and contaminate some parts of dentine and perhaps even enamel, thus reducing the chance of the necessary bacteria-tight seal of the adhesive filling. In pulpotomy treatments, these pulp capping materials can by ''submerged'' thus reducing the risk of contamination and therefore the risk of bacterial penetration. Another explanation is that potentially infected pulp tissues are not removed in case of direct pulp capping. Irrespective of the reason, pulpotomy has high success rates, regardless of the size of the pulp exposure or the time elapsed from the injury (35).

Root fractures are relatively uncommon injuries and, in the present study, were found in 5.5% of the injured teeth. In the previous studies, pulp survival was reported from 60% to 80% of cases of root fractures (38–41). In this study, pulp survival was found in 63.3% of cases. Of 49 teeth, 16 teeth (32.6%) demonstrated granulation tissues at the fracture line and resorptions at the coronal and apical fragments. At that time, a less conservative treatment was followed and primarily the teeth were extracted, thus resulting in a comparatively high loss rate.

Only a few pulpal and periodontal healing complications were observed in teeth that sustained concussion or subluxation, but they increased in extrusions and lateral luxations and reached highest levels in intrusions thus indicating a more pronounced damage to the tissues in the latter trauma types. The prevalences in our study and in that of Andreasen are similar (13). In our sample, teeth with a completed root formation developed pulp necrosis more frequently than teeth with an incomplete root formation in all types of luxation injuries. This corresponds to the findings of other researchers (13, 16, 17). However, this difference was significant in the present study only in lateral luxations. We assume that the missing differences in extrusive and intrusive luxations may be due to the small sample.

Diagnosis of pulp necrosis is quite difficult in first weeks after injury. Immediately after trauma, approximately half of teeth with luxation injuries do not respond to sensibility tests (13). At later follow-up examinations, a negative reaction can turn into a positive one. Therefore, the protocol of follow-up controls is very important. The finding of periapical rarefaction on X-ray images almost always represents pulpal infection (20). Complications like apical periodontitis or sinus tracts were observed more frequently in mature teeth than in immature teeth. We assume that it was the later diagnosis of pulp necrosis in elder patients which was a decisive factor for that observation. However, the difference was significant in lateral luxations only. As lateral luxations were the luxation type with the highest prevalence, we assume that the missing significance in the other luxation types is related to too low case numbers.

The development of pulp canal obliteration was also related to the stage of the root development and the extent of injuries. It was observed more often in dislocated luxations with a lower damage potential which is reasonable, as pulp canal obliteration is a kind of healing. Thus, it was also observed more frequently in immature teeth which have a higher healing potential compared with mature teeth. This finding corresponds to the findings reported by Andreasen (42). The development of pulp necrosis secondary to pulp canal obliteration is a late complication that may occur, (43) but was not observed in our sample.

Post-traumatic resorption of the root hard tissues is a very serious complication of luxation injuries (44–46). The development of an external inflammatory root resorption is directly related to the damage of the periodontium at the time of trauma, and to the presence of bacteria within the root canal and dentinal tubules (44, 45). In the present study, the prevalence of an external inflammatory root resorption following luxation injuries varied between 5.6% (extrusive luxation) and 33.3% (intrusive luxation). The difference can be explained by a higher damage to the PDL and the pulp coming along with intrusions compared with lateral luxations or extrusions. Significantly worse results were observed in avulsed teeth when compared with the teeth with dislocated luxations. The direct trauma to the tissues in avulsion injuries is comparable to an extrusion, the high complication rates are a result of an additional damage due to inadequate storage during the extraoral phase (25, 47, 48). Previous studies have reported that the prevalence of root resorption is between 57% and 80% in avulsed and replanted teeth (24, 25, 47). In the present study, replacement root resorption (21 of 49 teeth: 42.9%) and inflammatory root resorption (13 of 49 teeth: 26.5%) were observed in comparable rates. Despite teeth with an incomplete root formation having

a thicker PDL which dries off more slowly and thus having better chances for healing, they demonstrated a higher prevalence of external root resorptions than teeth with a complete root formation. This was especially true for inflammatory resorptions, where the difference was on a significant level. At first glance, this observation seems to be contradictory but this contradiction may be explained by the deleterious effect of an endodontic infection which may establish while revascularisation is awaited and therefore the endodontic treatment is postponed in immature teeth, whereas in mature teeth, a strict protocol ensured the start of an endodontic treatment about 7–10 days after the trauma. It has been shown that a prophylactic endodontic treatment minimizes the overall rate of inflammatory resorptions and allows equal results for mature and immature teeth (23). Nineteen replanted teeth (38.8%) were extracted due to an external root resorption within the observation period of 5 years. If the nine teeth that had not been replanted are taken into account, then the ''tooth retention rate'' 5 years after avulsion is 48.3%. Thus, avulsion is the injury with the by far lowest chance of tooth survival in the present study, and again primarily immature teeth are affected. Previous studies have reported that the prognosis of avulsed teeth is predominantly determined by the extraoral storage condition. It is therefore of utmost importance to focus on informing and educating the public about how to prevent dental traumas and how to provide first aid in these cases.

Conclusion

The rate of pulp necrosis is high following traumatic tooth injuries. Teeth with dislocation injuries additionally sustain a considerable risk for periodontal healing complications. Thus, regular controls are necessary for an early detection of complications. Avulsion has by far the lowest healing rate and highest loss rate. Early replantation, adequate transport medium and early extirpation of necrotic pulps are of high importance for the healing results in this type of injury.

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