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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

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Abstract – This retrospective study consisted of 400 root-fractured, splinted or non-splinted incisors in young individuals aged 7–17 years (mean = 11.5 ± 2.7 SD) who were treated in the period 1959–1995 at the Department of Pediatric Dentistry, Eastman Dental Institute, Stockholm. Four hundred of these root fractures were diagnosed at the time of injury; and 344 teeth were splinted with either cap-splints, orthodontic appliances, bonded metal wires, proximal bonding with composite resin or bonding with a Kevlar® or glass fiber splint. In 56 teeth, no splinting was carried out for various reasons. In the present study, only pre-injury and injury factors were analyzed. In a second study, treatment variables will be analyzed. The average observation period was 3.1 years ± 2.6 SD. The clinical and radiographic findings showed that 120 teeth out of 400 teeth (30%) had healed by hard tissue fusion of the fragments. Interposition of periodontal ligament (PDL) and bone between fragments was found in 22 teeth (5%), whereas interposition of PDL alone was found in 170 teeth (43%). Finally, non-healing, with pulp necrosis and inflammatory changes between fragments, was seen in 88 teeth (22%). In a univariate and multivariate stratified analysis, a series of clinical factors were analyzed for their relation to the healing outcome with respect to pulp healing vs. pulp necrosis and type of healing (hard tissue vs. interposition of bone and/or PDL or pulp necrosis). Young age, immature root formation and positive pulp sensibility at the time of injury were found to be significantly and positively related to both pulpal healing and hard tissue repair of the fracture. The same applied to concussion or subluxation (i.e. no displacement) of the coronal fragment compared to extrusion or lateral luxation (i.e. displacement). Furthermore, no mobility vs. mobility of the coronal fragment. Healing was progressively worsened with increased millimeter diastasis between fragments. Sex was a significant factor, as girls

Key words: root fractures; pulp healing; periodontal healing; sex; age; stage of root development; fracture type; location of fracture; severity of dislocation

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showed more frequent hard tissue healing than boys. This relationship could possibly be explained by the fact that girls experienced trauma at an earlier age (i.e. with more immature root formation) and their traumas were of a less severe nature. Thus, the pre-injury or injury factors which had the greatest influence upon healing (i.e. whether hard tissue fusion or pulp necrosis) were age, stage of root development (i.e. the size of the pulpal lumen at the fracture site) and mobility of the coronal fragment, dislocation of the coronal fragment and diastasis between fragments (i.e. rupture or stretching of the pulp at the fracture site).

Several epidemiological studies imply that root fractures are a relatively rare trauma entity, with reported frequencies of about 1% of traumatized permanent teeth (1–4). This has naturally resulted in studies based on rather limited patient materials, usually representing 40–100 teeth. Because of the very limited number of cases in each 'cell' when parameters are broken down, this limited material implies low confidence intervals in the statistical analysis of relations between various complications and the parameters, such as age, tooth types, stage of root development. For an example, a reported frequency of complications of 50% will in 40 cases have a 95% confidence limit of ±16%, where 400 cases will have a 95% confidence interval of ±5% (5).

In the clinical study of 208 intra-alveolar root fractures by Cvek et al. (6), factors such as root maturity, severity of injury and adequate repositioning of the dislocated coronal fragments were found to be more closely related to the frequency and type of fracture healing than to splinting as such. However, stages of root development were pooled into only two groups (immature and mature), as was dislocation and repositioning. These simplified classifications were primarily dictated by the limited size of the material studied. It is, therefore, conceivable that by doubling the size of the material, comparisons of various root development stages, extent of dislocation and the introduction of new splinting techniques might yield more information about the biology of root-fracture healing, particularly the event of fusion of the fragments with hard tissue.

The purpose of the present study was, therefore, to study the effect of pre-injury and injury factors, such as sex, age, stage of root development, fracture type, location and severity displacement upon root fracture healing in a larger material. The effect of treatment variables (e.g. treatment delay, repositioning, type of splint, length of splinting period and antibiotics) will be addressed in a later investigation (7).

Material and methods

The original material consisted of 208 root-fractured incisors in patients treated in the period 1959–1973. This material was augmented by 192 root-fractured incisors, which were treated in the period 1977–1995, when adhesive splinting techniques were introduced.

The examination and analysis of the additional material were identical to the previous study (6). However, a few extra parameters were included, such as sex, mobility of the coronal fragment at the time of injury, and three new splinting procedures with varying rigidity. The new splinting techniques were introduced to simplify the fixation procedure and were generally based on adhesive bonding (8). This topic will be further addressed in a following study (7).

In the following, a short description of the variables registered in relation to the trauma treatment and healing will be presented. A more detailed description can be found in the previous study (6).

Records from the time of injury

The material consisted of 400 root-fractured teeth, where a diagnosis and treatment was performed at the time of injury.

The following variables for each case were registered: sex, age ($\bar{x} = 11.5 \pm 2.78$), root development (divided into five stages). The stage of root development was estimated from the length of the root and the width of the apical foramen; the teeth were allotted to five groups: teeth with a wide and divergent apical opening and a root length estimated to be less than one-third (group 1), one-half (group 2) and two-thirds (group 3) of the final root length; teeth with nearly completed root formation and an open apical foramen (group 4); and teeth with completed root development and a narrow apical foramen (group 5) (9). In the statistical analyses, teeth in groups 1–4 were considered immature and those in group 5, mature. Tooth location (maxillary central and lateral incisors and mandibular incisors). Moreover, crown fractures were registered (present or absent). Teeth with pulp exposures are excluded. The type of root fracture was divided into single (usually horizontal), complicated (more than two fragments) and partial (where the mesial or distal part of the root tip has been displaced). Fracture location was described as cervical, middle or apical. Dislocation of the coronal fragment was described as none, slight or marked. Diastasis was registered in tenths of millimeters, according to a pretreatment radiograph. Mobility was described as normal or abnormal. Pulpal sensibility (electric pulp testing, EPT) was described as positive or negative. Repositioning was evaluated from radiographs and described as 'optimal' when a diastasis of ≤0.1 mm was seen. Examination delay was registered in days after injury; the same applied to start of splinting. Details of the above-mentioned variables have been published previously (1, 2).

Splinting

All these have been described in a previous study (6).

Types of splinting

Five different splints were used in this study: orthodontic bands + arch bars, cap splints, resin composite splints, resin composite and arch bars or Kevlar®/glass fiber splints (Du Pont, Wilmington, DE, USA) bonded to the injured and adjacent teeth. Details about these splints will be presented in a following article concerning the effect of various treatment approaches (7).

No splinting

In 56 teeth, no splinting was carried out for the following reasons. In 26 cases, a fracture was not seen in the radiographs at the first examination; and the tooth was only subluxated and registered as subluxated. In 14 cases there was only a partial root fracture of an immature root. In 16 cases, a root fracture was seen in the radiographs at the first examination; but the patient came several days after injury and the tooth showed neither loosening nor other symptoms; and treatment was therefore not initiated.

Follow-up

The follow-up period for healed fractures ranged from 1 to 13 years ($\bar{x} = 3.6$ years $\pm$ 3.0). During the observation period, 30 teeth suffered a new injury; and in these patients registration was terminated with the last radiographs obtained before the second injury.

Healing classification

At the final radiographic control, fracture healing was classified into four groups according to Andreasen and Hjørting-Hansen (10): 1) Healing with hard tissue (fragments are in close contact and the fracture line is not or only slightly visible) (HH_1); 2) Healing with interposition of hard and soft tissue between the fragments (fragments are separated by ingrowth of hard tissue, surrounded by a periodontal-like space); 3) Healing with interposition of only soft tissue (fragments are close, but separated by a distinct radiolucent line and rounding of sharp fracture edges); and 4) No healing (persistent or widened space between the fragments and presence of a radiolucency in the alveolar bone adjacent to the fracture due to pulp necrosis in the coronal fragment) (NEC). For the purpose of clarity, it should be mentioned that in an earlier investigation of the prognosis of root fractures using a multivariate analysis (17), these healing classifications were designated HT (group 1), CT (pooled groups 2 and 3) and GT (group 4).

Groups 2 and 3 were in this study considered to be variations of the same healing pattern and therefore pooled in the statistical analyses and designated PDL.

The results were statistically analyzed using Fisher's exact test, chi-square test, and Mantel–Haenszel analysis (11–13). The level of significance was set at 5%. To control for interaction between the variables registered, a stratified analysis was made, where all variables were tested against each other with respect to healing outcome (6).

When clinical variables were examined against healing the following approaches were used: HH_1 was examined against healing groups 2, 3 and non-healing 4. Note that this is slightly a different classification that used earlier (6). The idea of this analysis was to compare all types of healing or non-healing against alternatives. PDL implies healing groups 2 and 3 against groups 1 and 4. NEC implies healing group 4 against groups 1, 2 and 3. Finally, HEAL implies the whole array of healing, i.e. 1 vs. 2 vs. 3 vs. 4. The idea of this analysis was to compare all type of healing or non-healing events against the alternatives.

Results

General results

In the material as a whole, of the 400 teeth where the fracture *was diagnosed at the time of injury*, 120 teeth (30%) had healed with hard tissue fusion of fragments. Interposition of periodontal ligament (PDL) and bone between fragments were found in 22 teeth (5%), whereas interposition of PDL alone was found in 170 teeth (43%). Finally, non-healing, with pulp necrosis and inflammatory changes between fragments, was seen in 88 teeth (22%) (Table 1).

Table 1. Results and statistical univariate analysis of healing in teeth, distributed according to the relevant clinical variables. Number of teeth in the groups varies due to exclusion of teeth with unknown value of the variable

	Type of healing*, *n* (%)				Significance of type of healing**			
Pre-injury or injury variables	1	2	3	4	Hard tissue healing (HH_1) (1 vs. 2 + 3 + 4)	Periodontal healing (PDL) (2+3 vs. 1+4)	Pulp necrosis (NEC) (1,2,3 vs. 4)	Healing (HEAL) (1 vs. 2 vs. 3 vs. 4)
Sex					0.04	0.12	0.13	0.01
Male	69 (25)	125 (45)	15 (6)	67 (24)				
Female	51 (41)	45 (36)	7 (6)	21 (17)				
Age (years)					0.04	0.08	0.002	0.007
≤10	64 (36)	74 (42)	11 (6)	27 (15)				
11–15	45 (23)	84 (43)	11 (5)	46 (25)				
16–17	11 (30)	12 (31)	0 (0)	15 (39)				
Root development					<0.001	0.02	0.03	<0.001
Immature teeth	34 (59)	16 (27)	2 (4)	6 (10)				
Mature teeth	86 (25)	154 (45)	20 (6)	82 (24)				
Root development (stage)					<0.001	0.04	0.001	<0.001
1	3 (60)	1 (20)	1 (20)	0 (0)				
2	20 (74)	6 (22)	0 (0)	1 (4)				
3	11 (42)	9 (35)	1 (4)	5 (19)				
4	23 (37)	31 (49)	3 (5)	6 (10)				
5	63 (23)	123 (44)	17 (6)	76 (27)				
Tooth type					0.40	0.50	0.95	0.77
Central maxillary incisor	116 (30)	162 (42)	22 (6)	84 (22)				
Lateral maxillary incisor	2 (50)	1 (25)	0 (0)	1 (25)				
Mandibular incisor	2 (17)	7 (58)	0 (0)	3 (25)				
Associated crown fracture					0.20	0.34	0.93	0.25
No	96 (30)	137 (42)	21 (6)	70 (22)				
Yes	15 (42)	14 (39)	0 (0)	7 (19)				
Fracture type					0.12	0.09	0.08	0.04
Simple	106 (30)	151 (42)	18 (5)	82 (23)				
Complicated	6 (19)	17 (52)	3 (9)	6 (19)				
Partial	8 (72)	2 (18)	1 (9)	0 (0)				
Fracture location					0.08	0.003	0.17	0.02
Cervical	12 (30)	22 (55)	2 (5)	4 (10)				
Middle	68 (27)	119 (46)	13 (5)	56 (22)				
Apical	40 (39)	29 (28)	7 (7)	28 (27)				
Type of injury					<0.001	0.04	<0.001	0.002
No dislocation	23 (64)	8 (22)	2 (6)	3 (8)				
Dislocation	45 (26)	66 (39)	15 (9)	44 (25)				
Dislocation					<0.001	0.007	<0.001	<0.001
No	85 (44)	80 (42)	7 (4)	20 (10)				
Slight	27 (18)	74 (50)	10 (7)	37 (25)				
Marked	8 (15)	13 (22)	5 (9)	28 (52)				
Diastases (mm)					<0.001	0.11	<0.001	<0.001
≤0.1	96 (42)	94 (41)	6 (3)	33 (14)				
0.2–0.5	15 (23)	27 (42)	6 (9)	16 (25)				
0.6–1.0	5 (14)	19 (50)	5 (13)	7 (19)				
1.1–2.0	2 (5)	15 (40)	3 (8)	17 (46)				
2.1–7.0	2 (7)	14 (46)	2 (7)	12 (40)				
Mobility of crown fragment					<0.001	<0.001	0.05	<0.001
No	46 (64)	17 (24)	0 (0)	9 (12)				
Yes	68 (23)	133 (46)	20 (7)	69 (23)				
Sensibility test					<0.001	0.51	<0.001	<0.001
Positive	91 (47)	94 (48)	2 (1)	7 (4)				
Negative	19 (11)	57 (34)	19 (11)	72 (43)				
Examination delay					0.33	0.56	0.51	0.61
First day	52 (26)	87 (43)	14 (7)	48 (24)				
Second day	34 (33)	45 (45)	5 (5)	18 (18)				
Third day	14 (34)	14 (34)	2 (4)	11 (27)				
Fourth to 45th day	20 (36)	24 (42)	1 (2)	11 (20)				
Reposition					<0.001	0.53	<0.001	<0.001
Optimal	15 (25)	33 (55)	2 (3)	10 (17)				
Not optimal	4 (4)	40 (39)	13 (17)	45 (44)				
Fixation					<0.001	0.02	0.18	<0.001
No fixation	30 (54)	17 (30)	1 (2)	8 (14)				
Fixation	90 (26)	153 (46)	21 (6)	80 (23)				

Table 1. Continued

Pre-injury or injury variables	Type of healing*, n (%) 1	2	3	4	Significance of type of healing** Hard tissue healing (HH_1) (1 vs. 2 + 3 + 4)	Periodontal healing (PDL) (2+3 vs. 1+4)	Pulp necrosis (NEC) (1,2,3 vs. 4)	Healing (HEAL) (1 vs. 2 vs. 3 vs. 4)
Splint type					0.01	0.54	0.01	0.01
Orthodontic band + arch bar	11 (42)	6 (23)	3 (12)	6 (23)				
Cap splint	58 (25)	108 (46)	16 (7)	54 (23)				
Composite	1 (10)	5 (50)	0 (0)	4 (40)				
Composite + arch bar	3 (11)	12 (43)	1 (4)	12 (43)				
Kevlar®/glass fiber	17 (39)	22 (50)	1 (2)	4 (9)				
Splint mobility					0.07	0.93	0.03	0.03
Flexible	17 (39)	22 (50)	1 (2)	4 (9)				
Rigid	73 (24)	131 (44)	20 (7)	76 (25)				
Fixation start					0.48	0.76	0.47	0.59
<24 h	41 (28)	81 (45)	13 (7)	46 (25)				
1 day	28 (30)	42 (46)	4 (4)	18 (19)				
2 days	9 (29)	10 (32)	3 (10)	9 (29)				
≥3 days	12 (30)	20 (50)	1 (2)	7 (18)				
Fixation length (days)					0.56	0.62	0.86	0.89
≤28	3 (17)	10 (55)	1 (6)	4 (22)				
29–42	5 (20)	14 (56)	2 (8)	4 (16)				
43–56	15 (26)	24 (42)	3 (6)	15 (26)				
57–70	17 (25)	29 (42)	5 (7)	18 (26)				
71–98	32 (33)	43 (43)	3 (3)	20 (20)				
>98	18 (23)	33 (43)	7 (9)	19 (25)				
Antibiotics					0.23	0.03	0.15	0.10
No	94 (30)	138 (44)	19 (6)	63 (20)				
Yes	6 (46)	2 (15)	0 (0)	5 (39)				

*1 = hard tissue repair. 2 = soft tissue. 3 = hard and soft tissue. 4 = no healing (pulp necrosis). ***P*-values obtained by comparing frequencies and types of healing.

Forty-five non-splinted teeth *not diagnosed at the time of injury* and for which the clinical status at the time of injury was not known were excluded from statistical evaluation, 10 cases (22%) had healed with hard tissue fusion, five (11%) with interposition of soft and hard tissue, and 29 (64%) with only soft tissue; while one tooth (2%) had not healed.

Univariate and stratified analysis

Sex

In the unvariase analysis, a significant relation was found to HEAL and HH_1, but not to NEC (Tables 1–3). A further analysis showed that sex was significantly related to age and root development, both factors being strongly related to HH_1. Thus, more girls were injured at an early age (65% vs. 38% boys) and 21% of the girls had teeth with immature root formation at the time of injury (vs. 12% boys). When sex was analyzed against the various groups of root development, the sex difference generally disappeared (Table 4).

Age

When age was related to type of healing, it appears that type of fracture healing (1 and 4) is very age dependent and that fracture healing type 3 (interposition of PDL and bone) is present throughout the age groups, but most prominent from 9 to 15 years of age (Fig. 1).

Being by nature a continuous variable, age was for the purpose of stratified statistics divided into ≤10, 11–15 and 16–17 years, as these ages might reflect stages in root development, with immature stages represented in the first age group. With age divided into three groups, a significant relation was found to HH_1, NEC and HEAL (Table 1).

In order to separate an age factor from root development, age was analyzed as a continuous factor against type of healing (Fig. 1). It appears that a slight but marked decrease in HH_1 and an increase in NEC took place after completed root development.

Root development

A highly significant relation was found between root development and HEAL, HH_1 and NEC (Table 1). This significance was maintained in 14 out of 18 stratified analyses testing for NEC; and in 18 out of 18 tests for HH_1 (Tables 2 and 3). In Fig. 2, the relationship between the various healing groups is shown.

Tooth location

No significant relationship was found for location of tooth involved.

Table 2. *P* values found in a stratified analysis of clinical factors as they relate to HH_1

	Pre-injury factors												Treatment factors						
	Sex	Age	Root development	Tooth location	Crown fracture	Fracture type	Fracture location	Diastasis	Dislocation	Mobility	Dislocation type	Sensibility	Treatment delay	Repositioning	Fixation	Type of splint	Fixation start	Fixation length	Antibiotics
Sex		0.06	<0.001	0.65	0.24	0.11	0.92	<0.001	<0.001	<0.001	0.33	<0.001	0.08	<0.001	<0.001	0.05	0.15	0.36	0.45
Age	0.004		<0.001	0.89	0.17	0.15	0.94	<0.001	<0.001	<0.001	0.30	<0.001	0.06	<0.001	<0.001	0.04	0.12	0.33	0.19
Root development	0.005	0.74		0.77	0.14	0.25	0.43	<0.001	<0.001	<0.001	0.14	<0.001	0.09	<0.001	0.001	0.02	0.14	0.26	0.44
Tooth location	0.001	0.01	<0.001		0.14	0.15	0.89	<0.001	<0.001	<0.001	0.32	<0.001	0.06	<0.001	<0.001	0.04	0.10	0.33	0.19
Crown fracture	0.002	0.05	<0.001	0.28		0.42	0.83	<0.001	<0.001	<0.001	0.71	<0.001	0.08	<0.001	<0.001	0.09	0.17	0.71	0.23
Fracture type	<0.001	0.01	<0.001	0.73	0.13		0.86	<0.001	<0.001	<0.001	0.34	<0.001	0.08	<0.001	<0.001	0.03	0.12	0.37	0.22
Fracture location	0.001	0.01	<0.001	0.64	0.13	0.14		<0.001	<0.001	<0.001	0.23	<0.001	0.07	<0.001	<0.001	0.04	0.12	0.33	0.22
Diastasis	0.001	0.005	<0.001	0.45	0.26	0.40	0.92		0.003	<0.001	0.57	<0.001	0.41	<0.001	0.01	0.02	0.51	0.28	0.15
Dislocation	<0.001	0.003*	<0.001	0.41	0.29	0.41	0.64	<0.001		<0.001	0.57	<0.001	0.33	<0.001	0.03	0.05	0.27*	0.34	0.08
Mobility	0.001	0.007	<0.001	0.84	0.06	0.46	0.79	<0.001	<0.001		0.30	<0.001	0.19	<0.001	0.61	0.26	0.14	0.13	0.30
Dislocation type	0.001	0.004	<0.001	0.83	0.76	0.38	0.10	<0.001	<0.001	0.003		<0.001	0.05	0.002	<0.001	0.29	0.06	0.39	0.90
Sensibility	0.02	0.01	<0.001	0.68	0.29	0.24	0.55	<0.001	0.01	<0.001	0.89		0.07	0.003	0.02	0.11	0.12	0.16*	0.23
Treatment delay	0.001	0.01	<0.001	0.50	0.14	0.17	0.97	<0.001	<0.001	<0.001	0.28	<0.001		<0.001	<0.001	0.01	0.94	0.37	0.19
Repositioning	0.22	0.01	0.001	0.64	0.73	0.40	0.65	NR	0.01	0.02	0.78	0.54	001		NR	0.35	0.01	0.94	0.12
Fixation	0.001	0.05	<0.001	0.79	0.09	0.22	0.95	<0.001	<0.001	<0.001	0.34	<0.001	0.19	<0.001		NR	0.11	NR	0.21
Type of splint	0.001	0.07	<0.001	0.57	0.05	0.29	0.98	<0.001*	<0.001	<0.001	0.43	<0.001	0.03	<0.001	NR		0.04	0.28	0.42
Fixation start	0.001	0.09	<0.001	0.44	0.07	0.46	0.78	<0.001	<0.001*	<0.001	0.38	<0.001	0.95	<0.001	NR	0.01		0.37	0.41
Fixation length	0.001	0.08	<0.001	0.54	0.07	0.45	0.69	<0.001	<0.001	<0.001*	0.40	<0.001*	0.11	<0.001	0.03	0.03	0.12		0.44
Antibiotics	0.002	0.01	<0.001	0.33	0.87	0.67	0.63	<0.001	<0.001	<0.001	0.89	<0.001	0.18	0.005	<0.001	0.01	0.31	0.93	
No. relations	17	12	18	0	1	0	0	18	18	18	0	18	3	18	14	13	1	0	0

*An odds ratio test that suggests that odds ratio differs significantly by stratum. NR, not relevant.

Table 3. *P* values found in a stratified analysis of clinical factors as they relate to pulp necrosis

	Pre-injury factors												Treatment factors						
	Sex	Age	Root development	Tooth location	Crown fracture	Fracture type	Fracture location	Diastasis	Dislocation	Mobility	Dislocation type	Sensibility	Treatment delay	Repositioning	Fixation	Type of splint	Fixation start	Fixation length	Antibiotics
Sex		0.01	0.03	0.76	0.86	0.69	0.06	<0.001	<0.001	0.03	0.19	<0.001	0.38	<0.001	0.13	0.01	0.35	0.89	0.07
Age	0.26		0.17	0.94	0.88	0.16	0.04	<0.001	<0.001	0.03	0.16	<0.001	0.33*	<0.001	0.24	0.01	0.32	0.94	0.11
Root development	0.15	0.04		0.92	0.79	0.53	0.09	<0.001	<0.001	0.04	0.13	<0.001	0.39	<0.001	0.27	0.01	0.34	0.95	0.04
Tooth location	0.10	0.004	0.02		0.77	0.62	0.03	<0.001	<0.001	0.04	0.19	<0.001	0.33	0.003	0.13	0.01	0.29	0.92	0.12
Crown fracture	0.19	0.003	0.01	0.30		0.73	0.29	<0.001	<0.001	0.04	0.29	<0.001	0.42	0.004	0.19	0.10	0.42	0.91	0.11
Fracture type	0.10	0.004	0.01	0.73	0.76		0.05	<0.001	<0.001	0.03	0.17	<0.001	0.34	<0.001	0.12	0.02	0.29	0.96	0.09
Fracture location	0.11	0.003	0.03	0.34	0.82	0.80		<0.001	<0.001	0.06	0.11	<0.001	0.34	<0.001	0.12	0.02*	0.35	0.98	0.13
Diastasis	0.01*	0.002	0.02	0.59	0.95	0.34	0.04		<0.001	0.36	0.25	<0.001	0.89	<0.001	0.69	0.01	0.76	0.97	0.12
Dislocation	0.02*	0.001*	0.01	0.48	0.97	0.37	0.13	0.09		0.98	0.24	<0.001	0.98	0.004	0.50	0.01	0.66	0.90	0.20
Mobility	0.08	0.006	0.05	0.82	0.63	0.75	0.07	0.006	<0.001		0.18	<0.001	0.88	0.003	0.89	0.03	0.66	0.79	0.35
Dislocation type	0.01	0.003	0.03	0.05	0.81	0.32	0.04	0.04	0.08	0.30		<0.001	0.84	0.001	0.14	0.01	0.73	0.66	0.08
Sensibility	0.06	0.02	0.03	0.85	0.90	0.93	0.03	0.95	0.46	0.07	0.42		0.75	0.05	0.33	0.02	0.50	0.86	0.14
Treatment delay	0.10	0.004	0.02	0.67	0.77	0.61	0.05	<0.001	<0.001	0.04	0.18	<0.001		<0.001	0.16	0.009	0.71	0.88	0.21
Repositioning	0.01	0.01	0.65	0.84	0.64	0.14	0.02	<0.001	0.03	0.35	0.09	<0.001	0.66		NR	0.16	0.73	0.17	0.36
Fixation	0.10	0.007	0.03	0.82	0.73	0.57	0.05	<0.001	<0.001	0.07	0.19	<0.001	0.47	<0.001		NR	0.51	0.91	0.10
Type of splint	0.13	0.01	0.14	0.74	0.85	0.53	0.14	<0.001	<0.001	0.16	0.15	<0.001	0.13	0.002	NR		0.12	0.95	0.06
Fixation start	0.12	0.02	0.20	0.89	0.93	0.34	0.08	<0.001	<0.001	0.13	0.009	<0.001	0.89	<0.001	NR	0.009		0.88	0.06
Fixation length	0.11	0.01	0.19	0.75	0.91	0.37	0.08	<0.001	<0.001	0.12	0.18	<0.001	0.34	<0.001	NR	0.02	0.31		0.06
Antibiotics	0.22	0.004	0.006	0.22	0.99	0.45	0.22	<0.001	<0.001	0.01	0.38	<0.001	0.65	0.02	0.27	0.07	0.61	0.71	
No. relations	4	18	14	1	0	0	7	18	18	9	1	18	1	18	0	16	0	0	1

*An odds ratio test that suggest that odds ratio differs significantly by stratum. NR, not relevant.

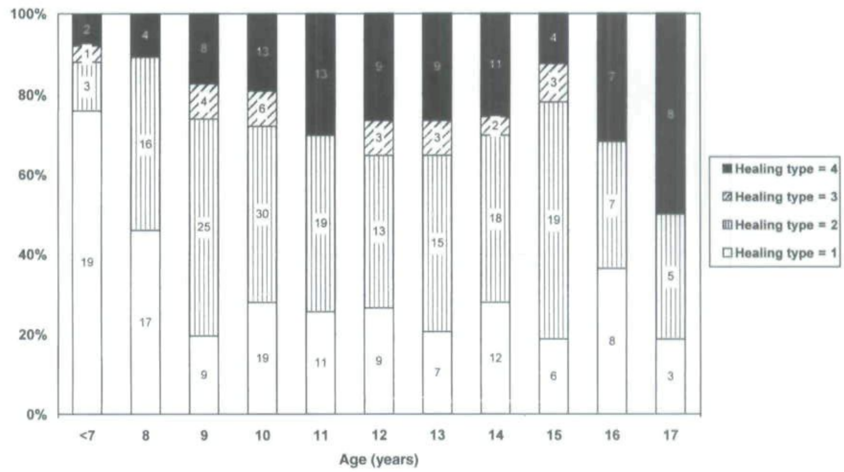

Fig. 1. Relationship between type of root fracture healing and age.

Crown fractures
No significant relation was found to either HH_1, NEC or HEAL.

Fracture type
No significant relation was found between fracture type (single, complicated or partial fractures) and NEC and HH_1; whereas HEAL was just at the level of significance (Table 1).

Fracture location
It appears from Table 1 that fracture location had a significant relation to HEAL but not to NEC or HH_1. The fractures located in the cervical region exhibited the lowest frequency of NEC. A significant relation was upheld in six out of 13 stratified analyses testing for NEC (Table 3).

Dislocation and extent of dislocation
A very significant relation was found to HH_1, NEC and HEAL; and this relationship was upheld in the stratified analysis of NEC and HH_1 (Tables 2 and 3).

Table 4. Relationship between root fracture healing (HH_1), sex and root development

Stage of root development	Healing $-HH_1$	Healing $+HH_1$ (%)	Level of significance
1–2			
Boys	6	12 (66)	$P = 0.69$
Girls	3	11 (78)	
3			
Boys	9	6 (40)	$P = 1.0$
Girls	6	5 (45)	
4			
Boys	26	8 (24)	$P = 0.04$
Girls	14	15 (52)	
5			
Boys	166	43 (21)	$P = 0.22$
Girls	50	20 (29)	

Diastasis
This variable showed that with increasing distance between fragments the chance of pulp necrosis increased; whereas the likelihood of hard tissue healing decreased (Table 1). It appears that the frequency of NEC was relatively stable up to a dislocation of 1 mm; whereas HH_1 showed stable values up to 0.5 mm.

Mobility
Mobility of the coronal fragment appears to have a negative influence on HEAL, NEC and HH_1. This relation was maintained in nine stratified analyses for NEC and in all analyses of HH_1 (Tables 1–3).

Sensibility
A very strongly significant relationship between sensibility was found to HEAL, NEC and HH_1; and this relationship was maintained in the stratified analysis. The strong relationship between sensibility and healing events could possibly be related to the integrity of the neurovascular system at the site of fracture. To examine such a relationship, sensibility was analyzed against the extent of dislocation in mm. It appears from Fig. 3 that sensibility was related to dislocation; and was maintained in only a few cases with dislocations of 1 mm or more.

The strong relationship between pulp sensibility, HH_1 and NEC, as well as a positive sensibility response at the time of injury would imply integrity of the pulp. This had a significant influence not only upon NEC but also HH_1 healing events. In fact only seven cases were found where a positive sensibility response was later followed by NEC.

Discussion

The present study is to date the largest study of root-fractured teeth in the literature. Because of its size, it has been possible to perform a detailed analysis of

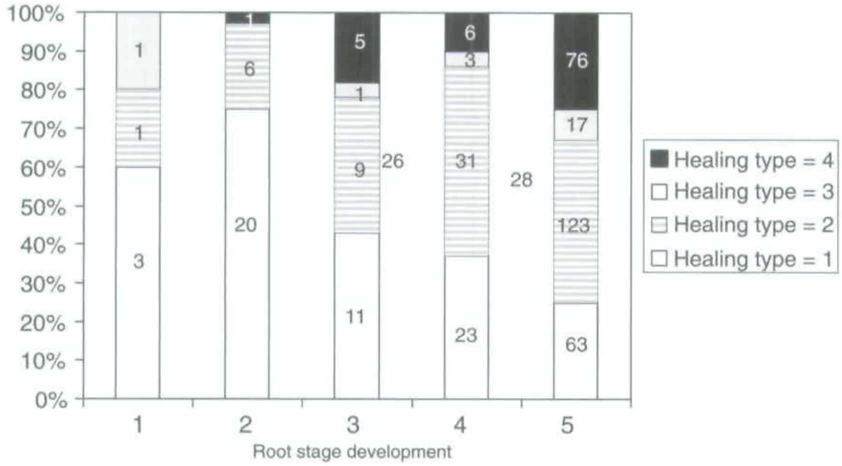

Fig. 2. Relationship between type of root fracture healing and stage of root development.

the different variables. The overall healing rate of 78% and where 22% developed pulp necrosis and 30% hard tissue healing is in agreement with previous results (8, 17) and demonstrates that root fractures have a reasonably good prognosis.

In the present study, pre-injury and injury factors were analyzed and a number of variables were found to have a significant influence upon healing. As many of these factors by nature must be strongly related (e.g. age and root development; dislocation and mobility), a stratified analytical strategy was used to filter out confounding associations.

Root development

The marked influence of root development upon pulpal healing has been shown earlier in root-fracture studies (6, 8, 11, 15–17, 26). This phenomenon has been explained in luxation studies by a combination of immature teeth having widely patent apices and at the same time short pulp length that can facilitate pulpal revascularization (18, 19). In the present study, root-fractured teeth with not more than one-half completed root formation, NEC occurred only in one case (3%) and HH_1 was the predominant healing type. With completed root formation (stage 5), a significantly higher frequency of NEC was seen (27%).

The strong influence of root development is a factor, which like in all other dental trauma entities should be incorporated in prognostic assessment.

Age

It appears from Fig. 1 that increasing age beyond the time of completed root formation seems to negatively influence the chance of optimal healing (HH_1). Furthermore, healing with interposition of bone and PDL occurred in the period from 9 to 15 years of age, a phenomenon, which must be related to the vertical growth of the alveolar process, which may invite interposition of both PDL and bone.

An age relation to wound healing in man is well established for wounds in gingiva and skin (20, 21) and fractures of bone (22); and apparently also operates in the pulp and PDL.

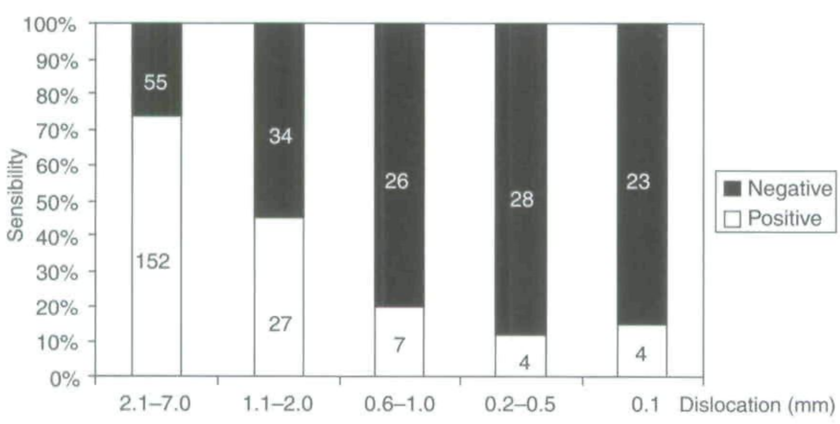

Fig. 3. Pulpal sensibility related to extent of dislocation.

Fracture location

A surprising factor was that cervical fractures had a slightly better chance of healing compared with NEC than fractures located at the middle or apical one-third of the root. This might be explained by the shorter distance needed to be revascularized in the cervical region, or the fact that a certain number of severely displaced teeth with cervical fractures were extracted. The latter explanation cannot be ruled out. The stratified analysis showed that stratification according to displacement did not change the likelihood for better healing with respect to NEC of cervical fractures. In a previous study of 96 teeth, healing was seen in 84%, of which 16% was healing with hard tissue, indicating that location of fracture has no relation of the fracture as such. However, during the further long-term follow-up, 44% of the teeth with transverse and 8% with oblique fractures were lost due to a new luxation injury or an increased mobility of the coronal fragment, indicating that the cervical location of fractures had a negative relationship to the long-term survival of these teeth (23). This finding was supported by a recent study in which the long-term prognosis of fractures located in the apical, middle and cervical thirds, where it was found that the latter fractures had a significantly shorter long-term survival (24). General long-term survival of root-fractured teeth was not analyzed in the present study; but will be the subject of a future investigation. The present finding seems to support the treatment guideline that cervical root fractures have a fair chance of healing and preservation should be attempted (17, 25).

Crown fractures

Crown fractures in this study were not related to healing complications; whereas a negative influence has been reported in a clinical study by Welbury et al. (24). In the present investigation, exposed dentin was always covered with zinc oxide-eugenol, glass–ionomer or resin composite, which could explain the difference.

Dislocation

A very significant relation was found to HEAL, NEC and HH_1; this relationship was upheld in the stratified analysis. In a recent study of the outcome of 84 root-fractured permanent incisors, a different healing classification was used, which described only two events: hard tissue or fibrous/osseous healing (24). Thus, a comparison with the present and all previous studies is very difficult. However, if only these two parameters are considered, it was found that hard tissue healing was significantly more prominent in the non-displaced teeth. The relation found between the presence and extent of luxation in this study is analogous to the relation found for luxated permanent teeth where mature teeth showed NEC with a frequency ranging from 15 to 55% for subluxated and extruded incisors respectively (19).

Mobility

Mobility of the coronal fragment had a negative influence upon healing. This relation could be expected as increased mobility may, apart from disruption of the PDL, also represent a risk that the pulp has been ruptured at the fracture line. This factor can be expected to be strongly related to luxation and displacement.

Sensibility

It appears from Fig. 3 that the nerve supply to the pulp can function even with some displacement of the coronal fragment. This is my agreement with previous findings (17). This must imply that the pulp can be stretched to certain limits. From Table 1, it appears that the limit is usually reached at 1 mm diastasis. With greater separation, the likelihood of the development of pulp necrosis (NEC) is doubled and the chance of HH_1 highly reduced. Altogether, only four teeth out of 67 with more than 1 mm separation showed HH_1, which could imply that a torn pulp most

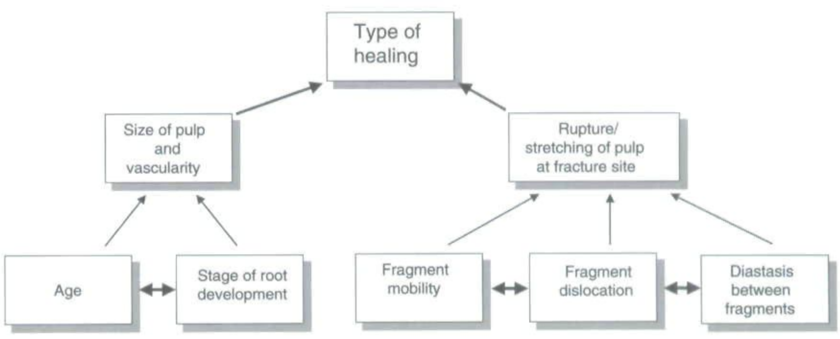

Fig. 4. Synopsis of effect of pre-injury factors on root fracture healing.

likely cannot regenerate and that PDL tissue will invade the coronal part of the pulp.

A unifying concept of the effect of pre-injury and injury factors on root fracture healing could be that the size of the pulpal lumen at the apical foramen and of the level of the fracture with good vascularity and a high number of cells (represented by age and stage of root development) and rupture or stretching of the pulp at the fracture site (represented by mobility, dislocation and diastasis between fragments) appears to be those factors which have a significant influence upon healing (i.e. whether with hard tissue or pulp necrosis) (Fig. 4).

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